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by

José Carlos B. Dubeux, Jr.
To my wife, Georgia, and my sons, Victor and Arthur.
ACKNOWLEDGMENTS

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MANAGEMENT STRATEGIES TO IMPROVE NUTRIENT CYCLING IN GRAZED PENSACOLA BAHIA GRASS PASTURES

By

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August, 2005

Chair: Lynn E. Sollenberger
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Efficient nutrient cycling plays a major role in pasture sustainability in low-input systems and in preservation of the environment in high-input systems. In this work, we studied the effect of a range of management practices on aspects of nutrient return to pastures via animal excreta and plant litter. There were two grazing experiments. In Experiment 1, bahia grass pastures were continuously stocked and the treatments were three management intensities: Low (40 kg N ha\(^{-1}\) and 1.4 AU [animal units] ha\(^{-1}\)), Moderate (120 kg N ha\(^{-1}\) and 2.8 AU ha\(^{-1}\)), and High (360 kg N ha\(^{-1}\) and 4.2 AU ha\(^{-1}\)). Patterns of excreta deposition, changes in soil nutrient concentration, and herbage responses were measured. Litter production and decomposition rates were also assessed. In Experiment 2, rotational and continuous stocking methods were compared in terms of their effect on animal grazing behavior, uniformity of excreta distribution in the pasture, changes in soil nutrient concentration, and herbage responses. Finally, the effect of management intensity and grazing method on soil organic matter (SOM) was determined.
Based on the herbage responses to N fertilizer it is concluded that under continuous
stocking the use of more than 120 kg N ha\(^{-1}\) yr\(^{-1}\) is not justified for Pensacola bahiagrass
in North Central Florida. In terms of stocking methods, rotational stocking promoted
greater herbage accumulation (70 kg DM ha\(^{-1}\) d\(^{-1}\)) than continuous stocking (40 kg DM
ha\(^{-1}\) d\(^{-1}\)). Soil nutrient concentration was greater closer to shade and water, but rotational
stocking with short grazing periods promoted a more uniform excreta distribution across
the pasture. The litter results showed that the above-ground plant litter pool does not
supply a large amount of nutrients for plant and microbial growth, but it does act as a
buffering pool reducing potential N losses to the environment, particularly in more
intensive systems. Finally, the SOM results demonstrated that increasing management
intensity increased C and N accumulation in grazed pastures. These data aid in assessing
potential environmental impacts and nutrient-use efficiency of various grazing
management practices as well as providing data needed for modeling nutrient cycling in
forage-livestock systems.
CHAPTER 1
INTRODUCTION

Native grasslands and planted pastures are important ecosystems worldwide, occupying vast land areas. They provide animal products for humankind, habitat for wildlife, and serve as ground water recharge areas and as a carbon sink to reduce atmospheric CO$_2$. Grasslands also cover large land areas in the southeastern USA and in Florida (Chambliss, 2000) and are one of the most important agroecosystems in this region.

The constant increase in human population necessitates greater food production efficiency in agricultural systems. The availability of nutrients and their cycling in agricultural systems play a major role in determining production efficiency. In some areas of the world, decreasing soil fertility and the high cost of fertilizers have provided a challenge to agricultural researchers seeking to maintain food production, food security, and the sustainability of rural populations, while keeping inputs low. In contrast, the excessive use of fertilizers or livestock manures in some developed countries has led to environmental concerns such as pollution of ground water and eutrophication of lakes. The improvement of nutrient use efficiency is critical in both nutrient-limiting and nutrient-abundant systems, and the ultimate goal is to increase food production per unit of nutrient used with less environmental pollution.

Approaches that may increase nutrient use efficiency in pasture ecosystems include adapted plant and animal germplasm and more effective management of stocking rate, stocking method, supplementation, and soil nutrient management. Introduction of forages
that grow in low soil fertility environments may enhance livestock production in developing countries. On the other hand, forages with higher nutrient uptake, higher quality, and rapid growth may be desired in a high soil fertility environment. Animals adapted to the environment and with a higher efficiency of nutrient use, i.e., more animal product produced per unit of nutrient ingested, should also be selected. Grazing management is another important tool and the choice of stocking rate is one of the most important decisions. Besides its effect on animal performance and pasture persistence, stocking rate influences crucial aspects of nutrient cycling like the amount and forms of nutrients returned to the pasture, changes in the vegetation, and soil exposure to erosion.

Stocking method may also play a role in nutrient use efficiency by affecting the uniformity of excreta distribution, which affects nutrient losses. Supplementation of animal diets with minerals and concentrate feeds may provide another mechanism to improve nutrient use efficiency. Synchrony in availability of energy- and protein-supplying compounds in the rumen enhances ruminal microbial growth reducing N excretion. In this way, nutrient use efficiency may be improved by feeding a readily available source of energy for cows having a high level of soluble N in the diet.

Fertilization management completes the list of the most important tools affecting nutrient use efficiency. Examples include fertilizer source, level, and timing of application within the season.

Plant litter (above and below ground) and animal excreta are the two major pathways through which the nutrients return to pasture soils. The availability of nutrients and their distribution across the soil surface differ for these two nutrient sources. Plant litter is more evenly distributed but the nutrients are not as readily available as the ones
present in the animal excreta. The litter acts not only as a pool which is continuously
degradng and providing nutrients to the plants and soil organisms, but also as a buffering
mechanism that prevents nutrient losses in higher soil fertility environments. Depending
upon pasture management, the amount of nutrients returned through these two pathways
may vary. The understanding of these pathways in terms of amount and fluxes of
nutrients for particular pasture management practices is important in order to provide a
better understanding of nutrient cycling in the system.

Animal behavior is another variable affecting nutrient use efficiency. Animals
adapted to high temperatures and relative humidity may spend less time under shade and
around watering areas, leading to a reduction in sod degradation, less concentration of
nutrients from dung and urine, and fewer nutrient losses from those areas. Lounging
areas, where animals tend to rest, are other locations where nutrients tend to be
concentrated. Stocking method may play a role in reducing both problems; however, few
studies have been done in tropical and sub-tropical areas to confirm this hypothesis.

Bahiagrass is the most widely planted perennial pasture grass in Florida, occupying
more than one million ha (Chambliss, 2000) and serving as the basis for the beef cattle
production system. Research related to yield, animal performance, and nutritive value of
bahiagrass is abundant in the literature (Stanley, 1994; Cuomo et al., 1996; Burton et al.,
1997; Sollenberger et al., 1988); however, there is little information regarding the effect
of pasture management on nutrient cycling in bahiagrass pastures. Florida also has
environmental conditions that require additional concern for nutrient fate. The
combination of sandy soils, high rainfall, and high water table may lead to contamination
of ground water if proper nutrient management practices are not adopted.
In summary, bahiagrass is the most important species in the environmentally sensitive agroecosystems of Florida, yet little is understood about nutrient dynamics in these systems. Research is needed to guide producer pasture management practices and to aid regulators in making informed decisions. Thus, the objectives of this study were i) to determine the effect of management intensity and stocking method on herbage responses in bahiagrass pastures (Chapter 3); ii) to evaluate excreta distribution and soil nutrient redistribution as affected by animal behavior under a range of management intensities and stocking methods (Chapters 4 and 5); iii) to quantify litter production and decomposition in grazed Pensacola bahiagrass pastures managed at different intensities (Chapter 6); iv) to evaluate litter disappearance and litter nutrient dynamics in grazed Pensacola bahiagrass pastures (Chapter 7); and v) to describe the physical and chemical characteristics of soil organic matter from Pensacola bahiagrass pastures grazed for 4 yr at different management intensities (Chapter 8).

In order to accomplish these objectives, a 4-yr grazing experiment was conducted from 2001 through 2004. Herbage and soil fertility data were collected from 2001 through 2003, litter measurements and animal behavior data were obtained in 2002 and 2003, and the soil organic matter was characterized in the middle of the fourth grazing season (2004).
CHAPTER 2
LITERATURE REVIEW

Pasture Management as a Tool to Improve Nutrient Cycling

General

Pasture management involves a series of decisions by the farmer, and the ultimate goals are to obtain the most profitable result, maintain pasture persistence, and adherence to environmental regulations. Choice of stocking rate, stocking method, fertilization, irrigation, supplementation, shade and water distribution across the pasture, animal type (sire, sex, age), and use of fire are the most important decisions that will determine if these goals are achieved (Sollenberger et al., 2002). The following section discusses a subset of these management decisions and how they are related to nutrient cycling in a pasture ecosystem.

Stocking Rate

Stocking rate (SR) is defined as “the relationship between the number of animals and the grazing management unit utilized over a specified time period” (Forage and Grazing Terminology Committee - FGTC, 1991; p.15). It may also be expressed as animal units or forage intake units over a described time period per unit of land area (FGTC, 1991).

The relationship between SR and animal performance is well-described by a model developed by Mott (1960). According to that model, increasing SR increases animal gain per area up to a point after which gain starts to decrease. The gain per animal, however, is greatest at low SR, and decreases as the SR increases. Equilibrium between herbage mass
and SR must be obtained in order to achieve desirable economic results and also to maintain pasture persistence. If fertilization and other management tools are used to increase forage growth, SR must be adjusted in order to utilize the extra forage. Cowan et al. (1995) reported an increase in the above-ground plant litter pool when N fertilization increased from 150 kg N ha\(^{-1}\) to 600 kg N ha\(^{-1}\), respectively. The authors suggested that part of this accumulation was due to maintaining SR at two cows per hectare.

The amount and form of nutrients returned to the pasture are also affected by SR. Increasing SR will increase the proportion of herbage consumed by the grazing animals, which will increase the amount of nutrients returned through dung and urine as opposed to plant litter. On the other hand, a system characterized by low utilization of the available forage (< 40%) has a higher proportion of nutrients returned through litter rather than through excreta (Thomas, 1992). Nutrients recycled through excreta, especially those from urine, are more readily available to the plants. However, this high availability and the tendency for excreta to be deposited in high concentrations in small areas of the pasture lead to greater nutrient losses and risk of environmental pollution when compared to the losses originating from litter decomposition. The rate of flow of nutrients among nutrient pools increases with greater SR because the nutrients in dung and urine are more readily available than in litter; however, the return of nutrients across the pasture surface is more uniform from plant litter than excreta (International Center for Tropical Agriculture - CIAT, 1990; Haynes and Williams, 1993; Cantarutti and Boddey, 1997; Braz et al., 2003).

**Stocking Method**

Stocking method, also known as grazing method, is a defined technique of grazing management to achieve specific objectives (FGTC, 1991). Stocking methods can be
separated into two main categories: rotational and continuous stocking. Experiments date back to the 1930s comparing rotational vs. continuous methods (Hodgson et al., 1934), but in many cases the differences between them are not clear. The purpose of rotational stocking is to allow a period for forage regrowth without animal interference. In this way, the forage has time to reestablish carbohydrate levels and leaf area needed for the plant to reach the steeper part of the growth curve, resulting in faster regrowth. Grazing pressure (i.e., the relationship between the number of animal units and the weight of forage dry matter per unit area at any one point in time; or the inverse, forage allowance), however, may be even more important than stocking method in determining plant growth rate. As long as the available forage and the stocking rate are in equilibrium, a natural grazing rotation from feeding station to feeding station occurs even with continuous stocking.

Reasons cited for use of rotational stocking include superior plant persistence (Mathews et al., 1994a) and increased animal production (Blaser, 1986) over continuous stocking. There are many effects of stocking method on the forage-livestock system; however, the focus in this review will be its effect on nutrient cycling.

Stocking method may affect nutrient cycling in the pasture through its impact on uniformity of excreta distribution. Peterson and Gerrish (1996) suggested that short grazing periods and high stocking rates promote a more uniform excreta distribution on the pasture than do other grazing methods. The rationale is that the higher stocking density, the relationship between the number of animals and the specific unit of land being grazed at any one point in time (FGTC, 1991), obtained by the subdivision of the pasture when using rotational stocking, leads to greater competition for forage among the
animals, reducing their time spent under the shade or close to watering areas (Mathews et al., 1999).

Climate and stocking method may interact. In temperate areas, short grazing periods and high stocking rate may improve nutrient distribution; however, in warmer climates the results do not always corroborate this idea (Mathews et al., 1994b; Mathews et al., 1999). In warm-climate areas, the animals tend to congregate under the shade and closer to water points during the warmer period of the day, regardless of the stocking rate (Mathews et al., 1994b; Mathews et al., 1999; White et al., 2001), reducing the effect of the stocking method. Moving shades and watering points is an alternative to overcome this situation (Russelle, 1997), but it may not be practical for more extensive systems. Mathews et al. (1994a) found that nutrient distribution and concentration did not differ among continuous and two rotational stocking methods when shade and water were moved regularly for all treatments, but N, P, and K accumulated in the third of the pastures closest to lounging areas. Likewise, Mathews et al. (1999) did not find any differences between two rotational stocking methods (short vs. long grazing periods) in uniformity of excretal return. Sollenberger et al. (2002) suggested that if there are advantages in nutrient distribution of rotational stocking or having more paddocks in a rotational system in warm climates, these may accrue due to animals being forced to utilize a greater number of lounging points (one in each paddock) as opposed to achieving greater uniformity of excreta deposition within each paddock.

Fertilization

Fertilization is another management tool that influences nutrient cycling in pastures. Fertilization increases the amount of nutrients cycling within the soil-plant-animal continuum, acting as a catalyst in the main recycling processes, particularly in
low-soil-fertility environments. Fertilization increases the total plant biomass produced (below- and above-ground) which leads to an increase in i) stocking rate and excreta deposition; ii) litter production and its respective decomposition rate; iii) soil organic matter (SOM) mineralization rate. Phosphorus fertilization not only promotes the above- and below-ground plant growth (Novais and Smyth, 1999), but also accelerates plant residue decomposition, increasing the availability of nutrients in those residues (Cadisch et al., 1994; Gijsman et al., 1997a).

In a low-soil-fertility environment and in the absence of fertilization, recycling becomes an even more important nutrient source for pasture growth, but it is often insufficient to maintain productive pastures (Sollenberger et al., 2002). Planted grasslands are considered a nutrient-conserving ecosystem; however, losses still occur. Therefore, if soil fertility is not replenished, pasture productivity decreases with time. Fisher et al. (1997) recommended fertilizer applications once every 2 yr at half the rates used for establishment. These applications compensate for the loss of nutrients that occur through the net nutrient removal by grazing animals. In the case of tropical grass swards, N fertilization is likely needed to minimize pasture degradation associated with production of low quality litter and subsequent N immobilization by microbes (Sollenberger et al., 2002).

Excreta distribution from grazing animals is usually described by a negative binomial function which is characterized by clustered and overlapped areas of excreta in some areas of the pasture (Braz et al., 2003). This distribution creates higher soil fertility close to shade, water, and lounging areas. The knowledge of this uneven distribution of nutrients in grazed pastures is useful in guiding fertilization practice (Mathews et al.,
1996; Franzluebbers et al., 2000). These authors suggested that lounging areas should be avoided in plant and soil sampling for routine fertilizer recommendations and when applying maintenance fertilizer.

**Supplementation**

Energy supplementation for animals grazing high-N forages may reduce N losses through excreta, lowering N emissions to the environment and increasing N use efficiency by the animal (Vuuren et al., 1993). Energy availability and synchrony with N release are considered two of the most important factors affecting microbial synthesis in the rumen (Valadares Filho and Cabral, 2002). Thus, to maximize efficiency of N utilization, animals grazing forages with high levels of N in the soluble fraction (Fraction A) should be supplemented with a readily available source of energy such as molasses or citrus pulp. Valk and Hobbelink (1992) reported an increase in N-use efficiency and a 50% reduction in N excreted through urine when cows had a balanced diet in terms of energy and protein. Tropical forages fertilized with N may reach crude protein (CP) concentrations between 100 and 150 g kg\(^{-1}\) and in vitro digestible organic matter (IVDOM) concentrations around 600 g kg\(^{-1}\) (Brâncio et al., 2003). Balsalobre et al. (2003), however, pointed out that 70% of the total N found in ‘Tanzânia’ guineagrass (*Panicum maximum* Jacq) is in the A (200 g kg\(^{-1}\)), B3 (400 g kg\(^{-1}\)), and C (100 g kg\(^{-1}\)) fractions, which might present problems for the utilization by ruminants because of rapid degradability (Fraction A), slow degradability (Fraction B3), or even non-degradability in the rumen (Fraction C). Therefore, besides the reduction in N availability for the rumen microorganisms which leads to the protein deficiency for the animal (Balsalobre et al., 2003), the N excretion to the environment will also increase, reducing the N-use efficiency. Supplements that contain highly ruminal degradable carbohydrates have
potential to decrease the non-protein N losses (A fraction). Molasses and citrus pulp, depending upon cost and availability, are possible alternatives (Larson, 2003).

Irrigation

Irrigation is a management tool that may enhance pasture productivity (Müller et al., 2002; Marcelino et al., 2003) and may also affect nutrient cycling in the pasture. Soil moisture is one of the abiotic variables affecting microorganism activity (Brady and Weil, 2002); therefore, residue and SOM decomposition are also affected by irrigation. Pakrou and Dillon (2000) reported a 50% increase in annual N mineralization in irrigated vs. non-irrigated pastures. They attributed this to higher excreta deposition (higher stocking rate due to irrigation), residues with faster decomposition rates, and higher water availability during the summer season. Irrigation has also been linked, however, to degradation of soil physical characteristics. Increasing compaction is often reported in soils from irrigated pastures. The compaction intensity is greater in soils with higher soil moisture and pastures with higher SR (Warren et al., 1986; Silva et al., 2003). Soil compaction alters nutrient availability due to changes in SOM mineralization, residue decomposition, and nutrient movement in the soil, potentially leading to pasture degradation (Cantarutti et al., 2001).

Animal Behavior and Nutrient Redistribution: How Are They Linked?

Grazing animals congregate close to the shade and watering areas during the warmer periods of the day (Mathews et al., 1994a; Mathews et al., 1999). Because there is a correlation between time spent in a particular area and the number of excretions (White et al., 2001), this behavior leads to an increase in the concentration of soil nutrients close to shade and water. Russelle (1997) suggested the use of mobile shade and water troughs for intensive systems, but this would not be practical for more extensive
systems. Animal characteristics also interact with the environment. In Florida, Holstein cows with predominantly black coats spent 20 additional minutes per day under the shade than did those with predominantly white coats (Macoon, 1999). Blackshaw and Blackshaw (1994) reported that Zebu cattle spent less time under the shade when compared to non-Zebu cattle. Tanner et al. (1984) evaluated the behavior of Zebu-European cross-bred cattle in South Florida. They observed that shade was not a requisite for resting sites, even during the warmest days, and excretion activities were more closely associated with grazing than resting. Therefore, the sire and even the coat color within a sire may interact with the environment and alter the time spent under shade or close to water, altering the nutrient redistribution in the pasture.

Grazing management includes important decisions like SR and stocking method which play a role in the animal behavior and ultimately in the pasture nutrient distribution. Some of the influences of SR and stocking method on animal behavior were already discussed.

Grazing time is affected by herbage mass, with cattle spending more time grazing when herbage mass is low (Sollenberger and Burns, 2001). Cattle may compensate for the lower forage availability by increasing grazing time up to a limit, beyond which further compensation cannot occur and intake is reduced. Because herbage mass is affected by SR (i.e., increasing SR without an increase in forage growth rate will decrease herbage mass) grazing time will also be affected as an ultimate result. Chacon et al. (1978) reported increasing grazing time with greater stocking rate and lesser herbage mass on setaria (Setaria anceps Stapf cv. Nandi) and ‘Pangola’ digitgrass (Digitaria eriantha Steudel) pastures. The increase in grazing time as a proportion of time spent on
the pasture may improve the uniformity of excreta distribution. White et al. (2001) observed that with a greater proportion of time on a pasture spent grazing, excreta deposition was more uniform. Because most nutrients ingested by cattle return to the pasture in excreta (Peterson and Gerrish, 1996), the uniformity of excreta distribution is crucial for the maintenance of soil fertility.

Lounging areas are greatly affected in terms of soil nutrient concentration. Nutrient transfer from grazed areas to lounging areas is likely to occur, enhancing the soil fertility at the lounging sites at the expense of that on the main grazing areas. Haynes and Williams (1999) found an accumulation of soil organic C, organic and inorganic P and S, and soluble salts in the lounging areas due to the transfer of nutrients and organic matter to those areas via dung and urine. Soil pH also tended to be higher in lounging areas.

**Nutrient Pools in a Grazed Ecosystem**

Essential nutrients are allocated to different pasture pools, e.g., soil, vegetation, animals, and atmosphere (Stevenson and Cole, 1999). The potential nutrient supply for plant growth in a pasture ecosystem may be estimated by measuring the amount of nutrients present in each one of the pools with their respective rates of flow among pools. These estimations, however, are highly variable and may be affected by abiotic and biotic factors.

**Carbon**

Photosynthesis is the mechanism of C input to pastures, but the major pool of C in the pasture ecosystem is SOM. Thomas and Asakawa (1993) and Stevenson and Cole (1999) reported that the amount of C contained in the OM of terrestrial soils (30 to 50 x 10^{14} kg) is three to four times the C contained in the atmosphere (7 x 10^{14} kg) and five to six times that in the land biomass (plants and animals; 4.8 x 10^{14} kg). Although
vegetation and grazing animal pools store less C than the SOM, they play an important role in the cycling of C within the pasture ecosystem through surface litter deposition and decomposition as well as excreta return. Castilla (1992) estimated a fecal C return of 3.9 t ha\(^{-1}\) yr\(^{-1}\) in a creeping signalgrass \([Brachiaria humidicola\) (Rendle) Schweick.]/desmodium \([Desmodium heterocarpon\) (L.) DC. subsp. ovalifolium\) (Prain) Ohashi] pasture, and, compared to leaf litter, it was the main source of above-ground C. As noted earlier in the review, the extent of pasture utilization (C consumption) by herbivores determines whether litter or excreta is the main source of above-ground C.

The potential of the soil as a CO\(_2\) sink has led many scientists to characterize the C cycle in pasture ecosystems and the conditions in which the soil works as a C source or sink (Fisher et al., 1994; Lal et al., 1995; Rao, 1998; Silva et al., 2000). Fisher et al. (1994) suggested that introduced deep-rooted tropical grasses like gambagrass \((Andropogon gayanus\) Kunth.) and creeping signalgrass could store greater amounts of C in the soil profile than the native savanna grasses; legume-grass associations enhanced C storage even more. Tropical grasses cause storage of large quantities of C mainly by producing large amounts of very poor quality below-ground litter (Gijsman et al., 1997a; Rao, 1998; Urquiaga et al., 1998). Estimates of C storage must be interpreted cautiously, however, because the low inputs of fertilizer and high stocking rates used in the South America savanna region have left many pastures in a process of degradation, likely decreasing their ability to act as a sink of atmospheric CO\(_2\) (Fisher et al., 1994; Silva et al., 2000).

Understanding the C cycle has additional importance because the availability of N, P, and S, nutrients associated with organic compounds and microbial activity is
dependent on the processes of mineralization and immobilization (Robertson et al., 1993a; Robertson et al., 1993b; Fisher et al., 1994; Cantarutti, 1996; Silva et al., 2000). These processes often are related to indexes of C concentration and “quality” of the organic matter, e.g., C:N, C:P, C:S, C:N:P:S, lignin:N and (lignin+polyphenols):N ratios (Thomas and Asakawa, 1993; Fisher et al., 1997).

Nitrogen

The major N pools in a pasture ecosystem are the soil, vegetation, grazing animals, and atmosphere. The fluxes between them are very complex and are a function of multiple interactions that take place among weather conditions, soil microbiota, forage species, and herbivores (Myers et al., 1986).

The atmospheric-N pool is the largest; however, it is available to plants only through highly endergonic processes. Biological N fixation, mediated by free-living or plant-associated bacteria, requires about 960 kJ or 25 to 30 moles of ATP per mole of N₂ fixed (Marschner, 1995). This is the major reason why N is considered the most limiting nutrient in many agricultural ecosystems (Wedin, 1996).

Considering all terrestrial ecosystems, the soil-N pool is about 16,000 times smaller than the atmospheric-N pool (Russelle, 1996). In tropical pasture ecosystems, however, the soil is the second largest N reservoir. Total N in a soil profile is primarily a function of its SOM content, soil microbial biomass, fixed NH₄⁺, and to a lesser extent the plant-available inorganic N concentration (NO₃⁻-N; NH₄⁺-N). The below-ground soil mesofauna, e.g., nematodes, termites, and earthworms, is also an important component of the soil-N pool. The soil profile to the bottom of the rooting zone may contain from 4500 to 24 000 kg N ha⁻¹ (Henzell and Ross, 1973). These amounts are greater than those typically reported in live herbage of tropical forages (usually between 20 and 400 kg N
ha$^{-1}$). In pastures of signalgrass (*Brachiaria decumbens* Stapf.), palisadegrass [*B. brizantha* (A.Rich.) Stapf.], gambagrass, and ‘Tanzânia’ and ‘Tobiatâ’ guineagrass, roots accounted for 53 to 76% of total plant biomass but had low N concentration (Kanno et al., 1999); thus the sum of live herbage and below-ground, total-plant N is still much lower than that for soil.

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 (Dubeux Jr. et al., 2004). Excluding soil N, Robertson et al. (1993a) estimated that in green panic (*Panicum maximum* Jacq.) pastures, 30 to 50% of all N in the ecosystem was in plant litter and senesced tissues, i.e., unavailable for plant uptake.

**Phosphorus**

Highly weathered tropical soils (Oxisols, Ultisols), often utilized for pastures, are characterized by low total and available P concentration and often by a very high P sorption capacity. The P cycle is even more complex than the N cycle, because availability of P depends not only on biologically mediated turnover processes of organic P, but also on the chemistry of inorganic P (Novais and Smyth, 1999; Oberson et al., 1999).

Much lower P than N concentrations in both plant and animal tissues and the high soil P sorption capacity result in the soil profile being the largest and most important P pool in pasture ecosystems (Haynes and Williams, 1993). Some *Latossolos* of the Brazilian Cerrado region can sorb more than 2 mg P cm$^{-3}$, which is equivalent to 4000 kg P ha$^{-1}$ within the 0- to 20-cm soil layer (Novais and Smyth, 1999). Efficient cycling of inorganic P is not expected because competition between the soil and the plant for
orthophosphate in solution rendering most of the inorganic P unavailable to plants (Novais and Smyth, 1999).

Like the mineral forms, organic P compounds in the soil differ in their availability to plants and in their turnover rates. For tropical soils receiving little or no P fertilizer, organic compounds are considered to be the most important sources of P to plants and the primary P pool controlling the efficiency of P recycling (Beck and Sánchez, 1994; Guerra et al., 1995; Friesen et al., 1997; Novais and Smyth, 1999; Oberson et al., 1999). In recent years, more attention has been given to the development of management strategies that minimize the flux of P out of the production cycle (inorganic P sorption) and maximize the flux of P through more dynamic organic P pools that can be accessed by the plant roots and/or mycorrhizae (Guerra et al., 1995; Friesen et al., 1997; Gijsman et al., 1997b; Oberson et al., 1999).

**Potassium**

The biogeochemistry of the K cycle in pastures is simpler and faster than the N and P cycles, mainly because K is not part of any organic compound and the chemistry of K in tropical soils is almost solely based on cation exchange reactions. The soil is again the greatest reservoir of K in tropical pasture ecosystems. Most of it is in nonexchangeable forms, e.g., residues of 2:1 minerals in the silt and clay fractions (mainly muscovite), Al-interlayered 2:1 minerals, and 1:1 minerals (kaolinite) (Ayarza, 1988; Melo, 1998). Exchangeable K is very mobile in the soil and is prone to leaching; however, Ayarza (1988) found losses of K in tropical pastures only at high application rates (300 kg K ha⁻¹), even under high rainfall conditions. He suggested that the main K-retention mechanisms are adsorption by Al-interlayered 2:1 minerals, retention in high-yielding
forages, and luxury consumption of K. Ayarza (1988) also reported that plant residues enhanced recycling.

Animals do not comprise one of the largest K pools, but they have a very important role in recycling because of the large amount of K ingested and excreted. In New Zealand, Williams et al. (1990) estimated that animals were directly or indirectly responsible for 74 to 92% of all K losses in pastures grazed by dairy cows over a 30-yr period. In creeping signalgrass-desmodium pastures in the Amazon region, animals were said to disrupt rather than enhance K cycling, and losses were 30 to 95 kg K ha⁻¹ yr⁻¹, whereas without animals K losses were negligible (Castilla et al., 1995). The direct losses through animal products are much lower (0.12 - 0.18 kg K per 100 kg of animal product) than the indirect losses associated with the spatial transfer and concentration of K that occur due to the pattern of urine and dung deposition (Wilkinson et al., 1989; Williams et al., 1990; Mathews et al., 1994b).

**Other Nutrients**

Other essential nutrients like Ca, Mg, S, and the micronutrients are also distributed in below- and above-ground pools, and like the other nutrients play important roles in plant and animal nutrition. Calcium, Mg, and micronutrients are returned to the pasture mainly in feces, whereas S has a similar pattern of return as N (Haynes and Williams, 1993). Calcium and Mg are commonly added to tropical pastures through liming and S is a component of some commonly used fertilizers including ammonium sulfate and superphosphate. Awareness of the need for micronutrients is increasing, and in well-managed pastures, micronutrient fertilizers are being used. Mineral supplements are another source of these nutrients and in most cases are more economical than pasture fertilization for overcoming mineral deficiencies in grazing animals (Joost, 1996).
Animal Excreta and Nutrient Cycling

Grazing animals affect nutrient cycling by consumption of mineral nutrients in pasture plants and returning them to the soil via excretion. The retention of ingested nutrients in body tissue and their exportation in animal products are quite low, and most mineral nutrients consumed are excreted in feces and urine.

Cattle defecate and urinate, on average, 11 to 16 and 8 to 12 times per day, respectively, but these numbers can vary considerably, being greatly influenced by grazing conditions and environmental factors. Each urination event for cattle and sheep has a mean volume of 1.6 to 2.2 L and 0.10 to 0.18 L, respectively. The mean fresh weight per defecation is 1.5 to 2.7 kg for cattle and 0.03 to 0.17 kg for sheep (Haynes and Williams, 1993). The area covered by each cattle defecation ranges from 0.05 to 0.14 m², whereas the area for an urination ranges from 0.14 to 0.39 m² (Peterson and Gerrish, 1996). Dung and urine deposition areas are about 2 to 4 m² per mature cow per day but at least twice this area is affected because of changes in animal selectivity, redistribution of feces by invertebrate soil fauna, and lateral movement of soluble nutrients (Mathews et al., 1996). Phosphorus, Ca, Mg, and micronutrient metals (Fe, Cu, Mn, and Zn) are excreted primarily in the feces, while K and to a lesser extent Na are excreted primarily in the urine. Nitrogen and S are excreted both in feces and urine (Mathews et al., 1996), with the relative proportion dependent on amounts in the diet.

Since grazing animals often excrete minerals at sites other than where the minerals were ingested, nutrient redistribution occurs. Urination and defecation happen throughout the pasture, but there generally is a concentration of excreta near lounging areas where animals feed, rest, seek shade, or drink water. Several studies across a range of environments and grazing methods have documented that nutrient accumulation is greater
near shade than near water (Gerrish et al., 1993; Mathews et al., 1997). In lounging areas, P and K accumulation is likely to occur (Mathews et al., 1994a; Castilla et al., 1995; Mathews et al., 1999). There is also an accumulation of C and N in the 0- to 150-mm soil layer (Carran and Theobald, 2000). Haynes and Williams (1993) reported that although excretal patches may cover only 30 to 40% of the pasture surface annually, the associated high nutrient input stimulates herbage growth such that these areas may be responsible for 70% of the annual pasture production. Non-uniformity of excreta return is greater for sheep than cattle. According to Peterson and Gerrish (1996), at equal grazing pressure, cattle defecate and urinate less frequently than sheep in a given area because there are fewer animals and also because sheep have a greater tendency to repeatedly camp at the same location than do cattle.

Excretion sites on the pasture surface are also known as “hot spots” due to the high concentration of nutrients, and they become an important pathway through which nutrient losses may occur (Schölefield and Oenema, 1997). A single urination from cattle is equivalent to 5 mm of rain on the 0.4 m² of ground that it covers, and it may provide the equivalent of more than 400 kg N ha⁻¹ yr⁻¹ (Jarvis et al., 1995). It also represents an addition of approximately 637 mg of K (Castilla et al., 1995). This hot spot of N is likely to exceed the current demands of the sward for N, and losses by volatilization and leaching will most likely take place. Leaching losses of SO₄⁻² are also likely to occur (Haynes and Williams, 1993; Jarvis et al., 1995). Ammonia loss from urine spots is typically significant, resulting from the high pH and ammonia concentration. Urea is the source of nearly all of the ammonia lost by volatilization, and volatilization is greatest the first 2 d after urine deposition (Russelle, 1996). Depending on weather conditions, a 4 to
66% loss of N has been observed for urine- and dung-affected areas of pasture while losses of 20 to 120 kg N ha\(^{-1}\) yr\(^{-1}\) have been reported for grazed swards (Ryden, 1986). Gaseous losses predominate in dry conditions, whereas NO\(_3^-\) leaching losses predominate under high rainfall conditions (Russelle, 1992).

Jarvis et al. (1995) reported that denitrification in soils is thought to be the largest source of atmospheric N\(_2\)O, which is increasing at a rate of 0.2 to 0.5% per year. Molecular nitrogen (N\(_2\)) is the other major product of this process, and the combined efflux of these gases represents a serious economic loss of N to the farmer. Dung beetles and earthworms reduce NH\(_3\) volatilization and denitrification losses by incorporating feces into the soil and by elimination of anaerobic zones within dung piles (Mathews et al., 1996). The role of stocking method in the excreta return to the pasture was discussed previously.

**Litter: Its Importance for the Pasture Ecosystem**

In pasture ecosystems, the deposition and decomposition of below- and above-ground plant residues (plant litter) during the growing season exert a continuous influence on nutrient supply to plants. This contrasts with the influence of litter on crop systems that occurs primarily as periodic pulses. The influence of litter depends primarily on the net balance between mineralization and immobilization processes. This is especially important for N, P, and S, nutrients whose availability is controlled in part by biological processes (Myers et al., 1994). Thus, both the quantity and quality of plant residues returned to the soil play a role in regulating nutrient cycling in pastures. In the case of N, Wedin (1996) emphasized that it is simply not valid to consider soil N availability as a “soil” property in isolation from the characteristics of present and past vegetation. Key characteristics of litter quality include its physical properties, and
especially its chemical composition, particularly the concentrations and ratios of concentrations of N, P, C, lignin, and polyphenols (Thomas and Asakawa, 1993; Myers et al., 1994).

Mathematical models have been developed, most often using litter-bag techniques, for litter decomposition patterns and for estimating rates of OM disappearance. The most frequently used models for this purpose are the single and double exponential models. They are assumed to best describe the loss of mass over time with an element of biological realism (Weider and Lang, 1982). Gijsman et al. (1997b) emphasized, however, that in the single exponential model the relative decomposition rate (RDR) is assumed to be constant over time, and in the double exponential model the litter is assumed to consist of two unique organic fractions. Both assumptions are biologically unrealistic. In order to overcome that problem, Gijsman et al. (1997b) recommended the Ezcurra and Becerra (1987) model. In this model the RDR decreases nonlinearly as a function of the litter fraction remaining. Gijsman et al. (1997b) also considered that this model allows the RDR of various litter types to be compared under different conditions at each stage of decay, providing a useful tool for analyzing litter decomposition. All those considerations are deemed necessary because the RDR is an important parameter for estimating nutrient cycling rate and availability (Myers et al., 1994).

Pasture degradation is usually related to decreasing soil N availability caused by an accumulation of low quality plant litter and, consequently, by an increase in net N immobilization due to greater numbers and activity of soil microorganisms (Robbins et al., 1989; Robertson et al., 1993a; Robertson et al., 1993b; Cantarutti, 1996). In green
panic pastures in Australia, net N mineralization did not occur until 50 to 100 d after litter deposition (Robbins et al., 1989). Even after a year, only 20 to 30% of all litter N was released in the soil, primarily due to microbial immobilization (Robbins et al., 1989; Robertson et al., 1993a; Robertson et al., 1993b). In southern Bahia state, Brazil, Cantarutti (1996) determined that incubation of soil samples with litter of creeping signalgrass, desmodium, and combinations of the two led to significant net N immobilization. During the first week of incubation, 60 to 80% of all soil mineral N was immobilized in the microbial biomass, and 30 to 50% stayed immobilized after 150 d. At the same time, the author verified an increase of N in the microbial biomass of 12 to 36%. This reinforced the hypothesis that a large proportion of soil-mineral N was effectively immobilized and that competition existed between plants and microorganisms for the available N.

The recommendation for establishing grass-legume mixtures in tropical pastures is partially based on the assumption that legumes increase soil fertility and pasture sustainability through the deposition of better quality litter. Cantarutti (1996) determined that litter production was similar between creeping signalgrass and creeping signalgrass-desmodium pastures (15 to 18 tons of dry matter ha\(^{-1}\) yr\(^{-1}\)); however, the legume increased litter N concentration and, consequently, the amount of N recycled. In the creeping signalgrass pasture the rates of net mineralization and nitrification and the inorganic N concentration were always lower than in the grass-legume pasture.

Recently, more attention has been given to litter dynamics related to P recycling. The P mineralization and immobilization processes are especially important to understand because organic P is the soil P pool for which management has the greatest
potential to increase the efficiency of P recycling in tropical pastures (Beck and Sánchez, 1994; Guerra et al., 1995; Friesen et al., 1997; Novais and Smyth, 1999; Oberson et al., 1999). When P fertilizer is applied to a crop or pasture system a considerable amount of that P accumulates in plant biomass and is “re-applied” in an organic form through litter deposition and animal excreta (McLaughlin and Alston, 1986; Haynes and Williams, 1993). The concentration of 2 g P kg\(^{-1}\) in plant residues is often considered the threshold for maintaining a balance between the mineralization and immobilization processes. Below that concentration, immobilization predominates. When considering C:P ratio, values below 200:1 result in mineralization predominating, whereas above 300:1 immobilization is greatest (Dalal, 1979; McLaughlin and Alston, 1986; Novais and Smyth, 1999). Considering that the P concentration in tropical grasses is usually lower than 1.5 g kg\(^{-1}\) (CIAT, 1982), high rates of net P immobilization from forage grass litter are to be expected. Nevertheless the influences of other factors such as lignin and polyphenol concentrations play a role in P mineralization rates as well.

**Soil Organic Matter: Importance and Management**

Soil fertility and agricultural systems sustainability depend upon the SOM, particularly in tropical regions because of the highly weathered soils and low fertilizer inputs. Benefits of SOM include improvement of soil physical properties (soil structure, macro- and microaggregates, water holding capacity), soil chemical properties (increased CEC, reduced Al toxicity, higher nutrient supply), and soil biological properties (soil microorganism biodiversity). Because of that, Greenland (1994) suggested that SOM would be one reliable indicator of agro-ecosystem sustainability. Thus, land sustainable management should include practices that elevate, or at least maintain, the appropriate SOM level for a given soil (Greenland, 1994; Hassink, 1997). In this aspect, well-
managed pastures might be considered sustainable production systems because an increase in SOM has been observed in these ecosystems. Additionally, because the C input in highly productive pastures is expected to be greater when compared to low-input systems, it should also be expected that SOM increases more in intensive pasture systems (Barrow, 1969; Malhi et al., 1997; Bernoux et al., 1999; Pulleman et al., 2000; Batjes, 2004).

**Soil Organic Matter Dynamics**

Native vegetation is the major source of residues contributing to SOM in natural ecosystems. Agroecosystems, however, have at least two major sources of residues: the reminiscent native vegetation and the residues originated from the new planted crops (Bernoux et al., 1999). Johnson (1995) proposed a conceptual model of SOM dynamics. According to that model, when an ecosystem is in equilibrium, i.e., the litter deposition is equal to the litter degradation; the SOM is also in equilibrium. Whenever a change occurs in the vegetation or in the soil tillage system, the SOM will likely change due to modifications in the residue deposition/decomposition ratio. The higher SOM decomposition rate occurs due to its higher exposure to microbial attack when the soil structure is broken down by soil tillage. According to Johnson (1995), after an initial reduction in the SOM levels (disturbance phase), a new equilibrium is established between litter production and decomposition rates. This equilibrium, depending upon the new soil management, will determine if the SOM will stabilize at lower, the same, or higher levels than the original one. Before a new equilibrium is reached, SOM accumulation must occur, and the basic premise for that is that residue deposition must be higher than residue decomposition (Batjes and Sombroek, 1997). For example, Bernoux et al. (1999) reported an increase of 0.33 and 0.89 kg soil C m^{-2} (0 – 30 cm depth) in
planted pastures, respectively, 4 and 15 yr after clearing the native vegetation (rain forest). The same authors concluded that 10 yr after pasture establishment the SOM reached the same level found in the soil under native vegetation. Thus, the increase in pasture productivity may lead to the increase in SOM levels, mainly due to an increase in above- and below-ground litter deposition.

**Mechanisms Regulating Soil Organic Matter**

The SOM increases up to a maximum and reaches an equilibrium phase. This maximum is regulated by three primary mechanisms: i) physical stabilization or protection against decomposition by forming soil microaggregates; ii) complexing of SOM with silt and clay particles; and iii) biochemical stabilization by forming recalcitrant compounds (Feller and Beare, 1997; Hassink, 1997; Hassink et al., 1997; Six et al., 2002).

The first mechanism is physical protection by forming soil microaggregates. In order for soil aggregation to occur, flocculation must also occur. The newly formed floccules also need a biological “cement” (e.g., polysaccharides found in fungi hyphae) to build up macrofloccules (Hartel, 1999; Hillel, 1998). Soil aggregates are hierarchically organized, starting from micro clay structures, microaggregates ($\Phi < 250 \mu m$), and macroaggregates ($\Phi > 250 \mu m$) (Cambardella and Elliott, 1993; Oades, 1993; Six et al., 2002).

The soil structure originated from aggregate formation protects the SOM due to i) compartmentalization between substrate and microbial biomass, i.e., higher OM concentration in the inner part of the aggregate and higher microbial density on the outer part; ii) reduction in oxygen diffusion towards the inner part of the aggregates,
particularly the microaggregates; and iii) compartmentalization of microbial biomass and microbial predators (Six et al., 2002). Therefore, the soil aggregate formation promotes the increase or maintenance of SOM levels due to physical protection (Cambardella and Elliott, 1993; Six et al., 2002). The opposite of this process is associated with excessive soil tillage that breaks down the soil structure reducing the physical protection and leaving the SOM exposed to microbial attack.

The second mechanism of SOM stabilization is the complexing between SOM and silt/clay particles (Feller and Beare, 1997; Six et al., 2002). Hassink (1997) observed a relationship between soil particles < 20 µm and the amount of C and N found in that fraction. The author considered that the potential of the soil to protect C and N increases with association of these elements with the silt/clay fractions. Therefore, it is expected that silty and clayey soils have higher potential to protect SOM when compared to sandy soils. In tropical soils, due to high Fe and Al oxides presence, this clay/silt mechanism is reduced. The Fe and Al oxides act in two contrasting ways: i) reducing surface area of clay particles due to clay flocculation, the SOM protection is reduced; ii) flocculating the SOM itself, the SOM protection is increased (Shang and Tiessen, 1997; Shang and Tiessen, 1998; Tiessen et al., 1998). These two mechanisms produce a net effect that requires further investigation (Six et al., 2002).

Biochemical stabilization by forming recalcitrant compounds is the third major mechanism of SOM protection (Six et al., 2002; Rovira and Valejjo, 2003). Recalcitrant compounds are hard-to-decompose substances and are originated either by compounds found in plants (e.g., tannins, lignin, polyphenols), or are formed during the decomposition process (Six et al., 2002). Lignin, C, N, P, and polyphenols and their
ratios are often used as indicators of litter quality (Thomas and Asakawa, 1993). As a general rule, legumes have better quality residue than grasses, and above-ground residues have better quality than roots and rhizomes, however, large variability among species occurs. Thus, the utilization of plants with low quality residues and higher allocation of biomass to the root system could be proposed as an alternative to increase SOM. Fisher et al. (1994) suggested that tropical grasses (gambagrass and *Brachiaria* spp.) are able to increase C storage in the soil not only due to their large root system, but also due to the low quality residue originating from this root system. It is important to keep in mind, though, that the large C:N and C:P ratios may lead to net immobilization of nutrients that could be available for the plants. Fertilization and mixed grass-legume pastures would reduce this effect.

**Soil Organic Matter Characterization**

Traditionally SOM has been characterized by chemical fractionation (fulvic acid, humic acid, humin), however, the applicability of this fractionation for agroecologic systems is limited. Humic and fulvic acid have minimal influence on short-term soil processes (e.g., nutrient availability, CO₂ evolution) due to low turnover rate of these compounds. Because of that, it is difficult to establish relationships between those fractions and crucial processes in the soil like SOM mineralization and aggregate formation (Feller and Beare, 1997).

Physical fractionation of SOM, by size or density, with subsequent analysis of the OM associated with each fraction, has become a more useful method to characterize SOM quality (Feller and Beare, 1997; Tiessen et al., 2001). Usually the sampled fractions represent the clay (< 2 µm), silt (> 2 µm and < 50 µm), sand (> 50 µm and < 2000 µm),
and macro-organic matter (> 150 µm) (Hassink, 1995; Meijboom et al., 1995; Feller and Beare, 1997).

Meijboom et al. (1995) proposed a SOM physical fractionation method where three fractions were obtained: the light fraction, composed mainly of plant residues at different decomposition levels; the intermediate fraction, formed by partially humified material; and the heavy fraction, composed of amorphous organic material. The importance of this fractionation is that the SOM mineralization rates decrease from the light to the heavy fractions, i.e., C and N mineralization rates are positively correlated with the amount of C and N in the light fraction and in the microbial biomass. Besides that, the light fraction is more sensitive to changes in management which alters the residue deposition when compared to the total SOM. Therefore, early detection of SOM changes is possible by the physical fractionation method (Hassink, 1995; Six et al., 2002).

Summarizing, the gradual increase of SOM levels by increasing the primary productivity of the pasture with consequent increase in the residue deposition is possible, but the SOM physical protection (aggregate formation and complexation with silt and clay) is limited by the silt and clay content of the soil. The OM deposited beyond this limit may still undergo biochemical protection by forming recalcitrant compounds, however, this limit is not well established (Six et al., 2002). Finally, the unprotected OM, with higher turnover rates (light fraction) will also increase, ultimately increasing the supply of nutrients to the pasture ecosystem.

**Summary**

Nutrient cycling in pasture ecosystems is a major issue impacting pasture productivity, nutrient use efficiency, and nutrient losses to the environment.
Understanding nutrient cycling requires a multidisciplinary approach including soil and water scientists, agronomists, and animal scientists, and this is probably one of the reasons that it has not been extensively studied. Grazing animal, soil, and plant responses need to be linked with management practices in order to provide a better understanding of the processes involved.

Critical questions are yet to be answered regarding the effect of stocking methods, stocking rates, and N fertilization on animal, plant, and soil responses when optimization of nutrient use efficiency is pursued. A series of studies was conducted to address these questions. Over-arching objectives included the effect of different stocking methods, stocking rates, and N fertilization on herbage responses, soil nutrient distribution, and animal behavior in different pasture zones defined by their distance from shade and water. Additionally, stocking rate and N fertilization effects on litter production, litter decomposition, and SOM dynamics on continuously stocked Pensacola bahiagrass pastures were studied.
CHAPTER 3
SPATIAL EVALUATION OF HERBAGE RESPONSE TO GRAZING MANAGEMENT STRATEGIES IN PENSACOLA BAHIAGRASS PASTURES

Introduction

Pasture management has a major impact on nutrient cycling in grazing systems (Sollenberger et al., 2002; Dubeux Jr. et al., 2004). Nitrogen fertilization and grazing management (stocking method and stocking rate) are examples of practices that play an important role in nutrient dynamics in grazed pastures.

Fertilization increases the amount of nutrients cycling within the soil-plant-animal continuum, acting as a catalyst in the main recycling processes, particularly in low soil-fertility environments. Fertilization increases the total plant biomass produced (below- and above-ground) which favors an increase in i) possible stocking rate and excreta deposition, ii) litter production and decomposition rate, and iii) soil organic matter mineralization rate (Dubeux Jr. et al., 2004). Increasing stocking rate increases the proportion of herbage consumed by livestock, increases the importance of excreta relative to litter in nutrient return to the soil, and, because of the greater availability to plants of nutrients in dung and urine relative to litter, increases the rates of nutrient flows among pools (Haynes and Williams, 1993; Castilla et al., 1995). Stocking method may also play a role altering distribution of excreta return across the pasture surface (Peterson and Gerrish, 1996).

Soil nutrient concentrations in areas closer to animal lounging sites (e.g., shade and water sources) tend to be greater than in the rest of the pasture because of higher density
of excreta deposition, particularly in warm environments (Mathews et al., 1996; Mathews et al., 2004). Management practices that improve nutrient distribution would be desirable not only because overall pasture productivity may improve, but also because of improved nutrient retention and utilization by the pasture system. There are few studies that have evaluated the effect of management practices on spatial patterns of plant growth and nutrient concentration in pastures. Thus, the objectives of this study were to evaluate different management practices including N fertilization, stocking rate, and stocking method on herbage responses (herbage mass and accumulation, plant N, P, and in vitro digestible organic matter concentration) in different pasture zones as defined by their distance from shade and water.

**Materials and Methods**

**Experimental Site**

Two grazing experiments were performed at the Beef Research Unit, northeast of Gainesville, FL, at 29°43’ N lat on ‘Pensacola’ bahiagrass (*Paspalum notatum* Flügge) pastures. Soils were classified as Spodosols (sandy siliceous, hyperthermic Ultic Alaquods from the Pomona series or sandy siliceous, hyperthermic Aeric Alaquods from the Smyrna series) with average pH of 5.9. Mehlich-I extractable soil P, K, Ca, and Mg average concentrations at the beginning of the experiment were 5.3, 28, 553, and 98 mg kg⁻¹, respectively. The methods for each experiment are provided in the following sections, with the statistical analyses described in a common section at the end of the materials and methods.
Experiment 1

Treatments and design

This experiment tested the effect of three management intensities of continuously stocked bahiagrass pastures on herbage responses in different zones defined according to their distance from shade and watering locations. Treatments were combinations of stocking rate and N fertilization rate, and in this dissertation they are termed management intensities.

The three management intensities tested were Low (40 kg N ha\(^{-1}\) yr\(^{-1}\) and 1.2 animal units [AU, one AU = 500 kg live weight] ha\(^{-1}\) target stocking rate), Moderate (120 kg N ha\(^{-1}\) yr\(^{-1}\) and 2.4 AU ha\(^{-1}\) target stocking rate), and High (360 kg N ha\(^{-1}\) yr\(^{-1}\) and 3.6 AU ha\(^{-1}\) target stocking rate). These treatments were chosen because Low approximates current bahiagrass management practice in Florida cow-calf systems, Moderate represents the upper range of current producer practice, and High is well above what is currently in use. Stocking rate and N-rate combinations for Moderate and High were chosen based on studies of bahiagrass yield response to N fertilizer conducted by Burton et al. (1997) and Twidwell et al. (1998). A strip-split plot arrangement in a completely randomized block design was used and each treatment was replicated twice. Zones within pastures were the strip-plot feature and will be described in more detail below. The bahiagrass pastures were continuously stocked and the experiment was performed during the grazing seasons of 2001 (26 June – 16 Oct.; 112 d), 2002 (8 May – 23 Oct.; 168 d), and 2003 (12 May – 27 Oct.; 168 d).

Two crossbred (Angus x Brahman) yearling heifers were assigned to each experimental unit. Stocking rate was fixed and calculated based on the estimated average daily gain throughout the grazing season. The targeted initial animal live weight was 270
to 275 kg. Projecting a heifer live weight gain of 0.35 kg d⁻¹ (Sollenberger et al., 1989) during 160 d of grazing would lead to a total weight gain of 56 kg animal⁻¹ and a final weight of approximately 325 to 330 kg. As an example, on the Low treatment this weight gain would result in an average stocking rate across the grazing season of 600 kg (i.e., two animals of 300 kg average weight) live weight ha⁻¹ or 1.2 AU ha⁻¹. Initial heifer weights were greater than anticipated at the beginning of the grazing seasons resulting in SR being greater than the target SR in each year. The actual average stocking rates for the 3 yr are shown in Table 3.1.

Table 3.1. Actual stocking rates (SR) of continuously stocked bahiagrass pastures.

<table>
<thead>
<tr>
<th>Target SR AU ha⁻¹</th>
<th>2001</th>
<th>2002</th>
<th>2003</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.2</td>
<td>1.5</td>
<td>1.4</td>
<td>1.3</td>
</tr>
<tr>
<td>2.4</td>
<td>3.0</td>
<td>2.8</td>
<td>2.6</td>
</tr>
<tr>
<td>3.6</td>
<td>4.4</td>
<td>4.1</td>
<td>4.0</td>
</tr>
</tbody>
</table>

Pasture area varied according to treatment, and area decreased as the management intensity increased. Pasture area was 1, 0.5, and 0.33 ha for Low, Moderate, and High treatment experimental units, respectively. Artificial shade (3.1 m x 3.1 m) was provided at a fixed location on each experimental unit, and cattle had free-choice access to water and a mineral mixture. The water troughs were always located under the artificial shade, and each time they were filled, the mineral mix trough was placed at a new, randomly selected location in the pasture.

Nitrogen fertilization dates are shown in Table 3.2. The Low treatment received all N (40 kg N ha⁻¹) in one application at the beginning of each grazing season; the Moderate treatment received three applications of 40 kg N ha⁻¹ in the beginning, mid- and late-grazing season; the High treatment received four applications of 90 kg N ha⁻¹ each
grazing season. Because drought delayed the start of the grazing season in 2001, only 270 kg N ha\textsuperscript{-1} was applied that year on the High treatment. Phosphorus (17 kg ha\textsuperscript{-1} yr\textsuperscript{-1}) and potassium (66 kg ha\textsuperscript{-1} yr\textsuperscript{-1}) were applied to all treatments prior to N application in 2001 (17 April), and with the initial N application in 2002 (30 April) and 2003 (23 April). There was a second application of the same amount of P (17 kg P ha\textsuperscript{-1} yr\textsuperscript{-1}) and K (66 kg K ha\textsuperscript{-1} yr\textsuperscript{-1}) for Moderate and High treatments only in 2002 (15 July). Micronutrients were applied on 23 Apr. 2003 at a rate of 400 kg ha\textsuperscript{-1} of the following formula: [B (0.9 g kg\textsuperscript{-1}), Fe (6.8 g kg\textsuperscript{-1}), Mn (9.1 g kg\textsuperscript{-1}) and Zn (3.6 g kg\textsuperscript{-1})]. Sulphur was also applied on 30 Apr. 2002 at a rate of 30 kg S ha\textsuperscript{-1} (Mitchel and Blue, 1989). Application rates and frequency of S and micronutrients reflect recommended practice in the region.

### Table 3.2. Nitrogen application dates on continuously stocked bahiagrass pastures.

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Grazing season</th>
<th>2001</th>
<th>2002</th>
<th>2003</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>13 June (40)</td>
<td>30 Apr (40)</td>
<td>23 Apr (40)</td>
</tr>
<tr>
<td>Moderate</td>
<td></td>
<td>13 June (40)</td>
<td>30 Apr (40)</td>
<td>23 Apr (40)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>20 July (40)</td>
<td>15 July (40)</td>
<td>16 July (40)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>24 Aug (40)</td>
<td>20 Aug (40)</td>
<td>14 Aug (40)</td>
</tr>
<tr>
<td>High</td>
<td></td>
<td>13 June (90)</td>
<td>30 Apr (90)</td>
<td>23 Apr (90)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>20 July (90)</td>
<td>12 June (90)</td>
<td>12 June (90)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>24 Aug (90)</td>
<td>15 July (90)</td>
<td>16 July (90)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>20 Aug (90)</td>
<td>14 Aug (90)</td>
</tr>
</tbody>
</table>

### Response variables

Forage sampling was performed in three zones of each experimental unit. Zones were defined based on their distance from shade and water. Zone 1 consisted of a semi-circle with an 8-m radius and included the shade structure and water trough. Zone 2 was
the area located between an 8- to 16-m radius away from the shade and water, and Zone 3 was the remaining area of the pasture (Figure 3.1).

Figure 3.1. Diagram showing the three pasture zones. Zone 1 is an 8-m radius semi-circle where the shade and water are included. Zone 2 is the area between an 8- to 16-m radius, and Zone 3 is the remaining area of the pasture. Figure is not drawn to the scale.

Forage response variables measured include herbage mass and accumulation, herbage N and P concentration, and in vitro digestible organic matter (IVDOM). Forage sampling started just prior to grazing initiation and occurred every 14 d thereafter until the end of the grazing season.

To determine herbage mass, 10 disk meter readings (0.25-m² aluminum disk) were taken per zone of each experimental unit at each evaluation date. The disk meter was calibrated every 28 d by measuring the disk settling height and cutting the herbage to soil level at 18, 0.25-m² sites (three per pasture). These sites were chosen across the six experimental units in order to represent the range of herbage mass in those pastures. Regression equations were obtained to estimate herbage mass. This method of correlating
the indirect measurement (disk settling height) with the direct measurement (herbage
mass cut at ground level) is defined as double sampling (Sollenberger and Cherney,
1995). Double sampling dates with their respective regression equations and r² for the 3
yr are shown in Table 3.3. Because animals were present on the pasture during the entire
grazing season, a cage technique was used to quantify herbage accumulation
(Sollenberger and Cherney, 1995). Two 1-m² cages were placed in each zone of each
pasture at initiation of grazing. Disk settling height was taken prior to placing each cage,
and sites were chosen that represented the average disk settling height of that particular
zone. Fourteen days after a cage was placed, the cage was removed and disk settling
height measured inside the cage. Herbage accumulation was calculated as change in
herbage mass between the initial measurement and that taken 14 d later. Cages were then
moved to new locations that represented the average herbage mass of each zone, and the
procedure was repeated. Frequent sampling and movement of cages is required if the
measured accumulation rate is to be representative of the surrounding grazed pasture
(Sollenberger and Cherney, 1995).

Herbage N, P, and IVDOM concentrations were measured biweekly to describe
forage chemical composition. Hand-plucked samples were collected from each zone in
each pasture. This technique attempts to simulate the forage actually being grazed by the
animals by removing the top 5 cm of herbage at approximately 10 locations per zone per
pasture. The herbage was dried at 60°C and ground to pass a 1-mm screen. Analyses
were conducted at the Forage Evaluation Support Laboratory using the micro-Kjeldahl
technique for N and P (Gallaher et al., 1975) and the two-stage technique for IVDOM
(Moore and Mott, 1974).
Table 3.3. Regression equations and $R^2$ for the double sampling technique used to estimate herbage mass and herbage accumulation.

<table>
<thead>
<tr>
<th>Date</th>
<th>Equation</th>
<th>$R^2$</th>
</tr>
</thead>
<tbody>
<tr>
<td>11 July</td>
<td>$y = -97 + 220x$</td>
<td>0.82</td>
</tr>
<tr>
<td>8 Aug.</td>
<td>$y = -250 + 251x$</td>
<td>0.84</td>
</tr>
<tr>
<td>4 Sept.</td>
<td>$y = -401 + 337x$</td>
<td>0.85</td>
</tr>
<tr>
<td>2 Oct.</td>
<td>$y = 359 + 279x$</td>
<td>0.80</td>
</tr>
<tr>
<td>22 May</td>
<td>$y = -313 + 235x$</td>
<td>0.86</td>
</tr>
<tr>
<td>19 June</td>
<td>$y = -331 + 260x$</td>
<td>0.75</td>
</tr>
<tr>
<td>14 July</td>
<td>$y = -724 + 336x$</td>
<td>0.78</td>
</tr>
<tr>
<td>14 Aug.</td>
<td>$y = -648 + 328x$</td>
<td>0.83</td>
</tr>
<tr>
<td>11 Sept.</td>
<td>$y = -277 + 299x$</td>
<td>0.81</td>
</tr>
<tr>
<td>9 Oct.</td>
<td>$y = -447 + 357x$</td>
<td>0.82</td>
</tr>
<tr>
<td>27 May</td>
<td>$y = -1329 + 431x$</td>
<td>0.89</td>
</tr>
<tr>
<td>24 June</td>
<td>$y = 89 + 286x$</td>
<td>0.85</td>
</tr>
<tr>
<td>22 July</td>
<td>$y = -481 + 296x$</td>
<td>0.89</td>
</tr>
<tr>
<td>19 Aug.</td>
<td>$y = -461 + 415x$</td>
<td>0.87</td>
</tr>
<tr>
<td>16 Sept.</td>
<td>$y = -775 + 519x$</td>
<td>0.94</td>
</tr>
<tr>
<td>14 Oct.</td>
<td>$y = -259 + 581x$</td>
<td>0.86</td>
</tr>
</tbody>
</table>

**Experiment 2**

**Treatments and design**

This experiment tested the effect of four rotational stocking strategies on Pensacola bahiagrass herbage responses in different pasture zones defined according to their distances from shade and water locations. Treatments were imposed in 2001, 2002, and 2003 and consisted of four grazing periods (1, 3, 7, and 21 d) with the same resting period of 21 d. Treatments were replicated twice using a strip-split plot arrangement in a completely randomized block design. Zones within pastures were the strip-plot feature. Stocking rate and N fertilization were the same as the High management intensity from Experiment 1, i.e., 4.2 AU ha$^{-1}$ and 360 kg N ha$^{-1}$ yr$^{-1}$, respectively. In Experiment 2, an
experimental unit for the rotational treatments consisted of only one paddock from the entire rotational system. Experimental units were 454, 1250, 2500, and 5000 m² for 1-, 3-, 7-, and 21-d grazing period treatments, respectively. These sizes were calculated based on a pasture size of 1 ha which would in practice be subdivided into 22, 8, 4, and 2 paddocks of the sizes indicated for the 1, 3, 7, and 21-d treatments, respectively. The area for the continuously stocked High treatment was 3333 m².

At the beginning of each grazing season, crossbred (Angus x Brahman) yearling heifers were arranged in groups of five or six animals, and total initial live weight (1809 kg) was approximately the same (± 10 kg) across groups. The total average live weight of each group across the grazing season was to be 1800 kg, corresponding to 3.6 AU, but because heifers were heavier than anticipated at the start of the experiment, actual stocking rates on the four treatments exceeded the target rates and were the same as those reported earlier for High. A group was assigned to each rotational treatment for the designated length of grazing period. When not grazing experimental pastures, animals were assigned to other similarly managed bahiagrass swards.

Nitrogen fertilization followed the same schedule as shown for the HIGH management intensity described in Experiment 1. Water, shade, and minerals were available for each experimental unit in the same manner as in Experiment 1.

**Response variables**

Herbage hand-plucked samples, disk height measurements, and double sampling procedures were used following the same zonal approach described for Experiment 1. Because rotational stocking was used in this experiment, no cages were needed to estimate herbage accumulation. Instead, 10 disk settling heights were taken per zone from
each experimental unit at the initiation and at the end of each grazing period. Herbage mass in each zone at the initiation (Pre-herbage mass) and at the end (Post-herbage mass) of the grazing period was calculated using the average disk settling height for the 10 observations per zone and the regression equations obtained from double sampling. Daily herbage accumulation was calculated by subtracting the post-herbage mass of cycle$_{n-1}$ from pre-herbage mass of cycle$_{n}$ and dividing the result by the number of days between measurements. Herbage hand-plucked sampling and chemical analysis followed the same protocol described for Experiment 1.

**Experiments 1 and 2**

Statistical analyses were performed using Proc Mixed of SAS (SAS Inst. Inc., 1996), and the LSMEANS procedure was used to compare treatment means. Data averaged across evaluations within each grazing season were used for analysis. Management intensity was considered the main plot and the zones the strip-split plot. In Experiment 2, treatment comparisons included the High management intensity from Experiment 1 because it had the same stocking rate and N fertilization, and the experimental units were arranged following the same blocking criteria as the rotational treatments.

**Results and Discussion**

**Experiment 1**

**Herbage accumulation and mass**

Herbage accumulation was affected by a treatment by year interaction (Table 3.4). In the first year, herbage accumulation was similar among treatments, but in 2002 and 2003, increased management intensity increased herbage accumulation rates. Rates for High were approximately three times those for Low in Years 2 and 3 (Table 3.4), but
Moderate and High were not different in any year. In 2001, the High treatment pastures received less fertilizer N than in 2002 and 2003 and that likely affected the herbage response. Also, April, May, and August 2001 rainfall were much lower than average and were lower than in 2002 or 2003 (Figure 3.2). The lower August rainfall had a major effect on response to N because it happened in the middle of the growing season when greater plant growth rates are expected. Also, at this time of the year temperature and evapotranspiration rates are high, creating a negative water balance if soil moisture is reduced, particularly in sandy soils which have low soil water holding capacity (Brady and Weil, 2002). Another possible explanation for the increase in the herbage accumulation for Moderate and High after 1 yr of treatment applications is the residual effects of previous N fertilization and high stocking rate on soil fertility (Chapters 4 and 7). These effects are most likely through excreta and plant litter, not residual N fertilizer. Increasing bahiagrass yield in response to N fertilization is reported by several authors (Blue, 1972; Burton et al., 1997; Gates and Burton, 1998), but the responses varied. Stanley and Rhoads Jr. (2000) found that bahiagrass response to N in the range of 0 to 168 kg N ha\(^{-1}\) was 26 kg of dry matter (DM) kg\(^{-1}\) of N but the response to N between 168 and 336 kg ha\(^{-1}\) was marginal. Burton et al. (1997) reported that rates of 56, 112, 224, and 448 kg N ha\(^{-1}\) produced average annual DM yields of 6010, 8240, 11 900, and 15 200 kg ha\(^{-1}\). Rhoads et al. (1997) suggested that even the highest rate of N (336 kg ha\(^{-1}\)) tested in their research was economical, however, Overman and Stanley (1998) stated that maximal incremental OM response to applied N on bahiagrass occurred at 140 kg N ha\(^{-1}\). In the current study it was probably not economically viable to use the higher N fertilization, i.e., 360 kg N ha\(^{-1}\) yr\(^{-1}\), on bahiagrass pastures because the herbage
accumulation from Moderate to High management intensity did not change significantly (Table 3.4).

Table 3.4. Herbage accumulation rates on continuously stocked bahiagrass pastures at different management intensities during 2001-2003.

<table>
<thead>
<tr>
<th>Year</th>
<th>Treatment</th>
<th>2001 (kg DM ha$^{-1}$ d$^{-1}$)</th>
<th>2002</th>
<th>2003</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Low</td>
<td>22 a A†</td>
<td>14 b A</td>
<td>17 b A</td>
</tr>
<tr>
<td></td>
<td>Moderate</td>
<td>20 a B</td>
<td>41 a A</td>
<td>42 a A</td>
</tr>
<tr>
<td></td>
<td>High</td>
<td>26 a B</td>
<td>41 a A</td>
<td>53 a A</td>
</tr>
<tr>
<td></td>
<td>SE</td>
<td>6</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

† Means followed by the same letter, lower-case letters within the same column and upper-case letters in the same row, do not differ statistically by the LSMEANS test (P > 0.05).

Figure 3.2. Monthly rainfall data at the experimental site; average of 30-yr, 2001, 2002, and 2003. Cumulative annual rainfall for the 30-yr average, 2001, 2002, and 2003 were 1341, 1008, 1237, and 1345 mm, respectively.
Herbage accumulation rate differed among pasture zones and was greater in Zone 1 (lounging area) than Zone 3 (Figure 3.3). Because animals congregate in lounging areas (e.g., shade and watering locations), soil fertility tends to be higher in those sites due to greater excreta return per unit area (Mathews et al., 1996; Mathews et al., 2004). This pattern of increasing soil nutrient concentration was observed in the present study (Chapter 4), therefore, herbage accumulation was greater in Zone 1 due at least in part to higher soil fertility.

For grass species with a decumbent growth habit like bahiagrass, the protection of basal leaf meristems from defoliation allows a rapid refoliation of the defoliated plants and the restoration of a positive C balance within a few days (Lemaire, 2001). Consequently, as long as overgrazing does not occur, more frequent grazing in zones closer to lounging areas (Table 3.5) is not likely to have a negative effect on bahiagrass regrowth, but it can play an important role in enhancing soil fertility. Bahiagrass stores C and N in roots and rhizomes, especially under higher soil fertility conditions (Impithuksa and Blue, 1978), therefore, it is likely that C and N reserves from roots and rhizomes also contributed to faster bahiagrass regrowth in Zone 1.

Herbage mass did not differ (P > 0.05) among management intensities, but there was a year x zone interaction (Table 3.5). There was no management intensity effect on herbage mass because the additional forage growth of High and Moderate treatments was compensated for by higher stocking rate. Interaction occurred because herbage mass was least in Zone 1 in 2001 and 2003, but there were no zone effects in 2002. This response was likely due to proportionally greater grazing time in Zone 1 (Chapter 4).
Figure 3.3. Herbage accumulation rates in different pasture zones on continuously stocked bahiagrass pastures during 2001 through 2003. Zones are defined based on their distance from shade and water (Zone 1: 0 – 8 m; Zone 2: 8-16 m; Zone 3: > 16 m). Means followed by the same letter do not differ statistically by the LSMEANS (P > 0.05) procedure. SE = 3 kg DM ha\(^{-1}\) d\(^{-1}\).

Table 3.5. Herbage mass of continuously stocked Pensacola bahiagrass in pasture zones defined by their distance from shade and water.

<table>
<thead>
<tr>
<th>Year</th>
<th>Zone 1</th>
<th>Zone 2</th>
<th>Zone 3</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>kg DM ha(^{-1}) d(^{-1})</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2001</td>
<td>2260 b B†</td>
<td>2780 b A</td>
<td>2810 b A</td>
</tr>
<tr>
<td>2002</td>
<td>2290 b A</td>
<td>2290 c A</td>
<td>2430 b A</td>
</tr>
<tr>
<td>2003</td>
<td>2690 a B</td>
<td>3630 a A</td>
<td>3860 a A</td>
</tr>
<tr>
<td>SE</td>
<td></td>
<td>330</td>
<td></td>
</tr>
</tbody>
</table>

†Means followed by the same letter, lower-case letters within the same column and upper-case letters in the same row, do not differ statistically by the LSMEANS test (P > 0.05).
Herbage nutritive value

**Plant nitrogen concentration**

There was a treatment by year interaction for plant N concentration in hand-plucked samples (Table 3.6). Interaction occurred because there was no difference between Low and Moderate intensities in 2002, but Moderate was greater than Low in the other 2 yr. Herbage CP for High was greater than Moderate in all 3 yr. Increased management intensity generally increased plant N concentration due to higher N fertilization. Increasing stocking rate may also have played a role by increasing the proportion of the nutrients cycling through excreta as opposed as plant litter (Thomas, 1992). Therefore, a higher amount and availability of soil N probably resulted in higher plant N concentration. Grass responses to N fertilization and simultaneous increases in forage N concentration have been observed with numerous species throughout the world (Mathews et al., 2004) and with bahiagrass in Florida (Impithuksa et al., 1984; Blue, 1988). Nitrogen concentration observed in this research was well above 11.2 g N kg\(^{-1}\) (70 g kg\(^{-1}\) of crude protein), the level at which animal intake is likely to be limited by a protein deficiency (Coleman et al., 2004). An increase in crude protein above this level usually does not result in further improvement in intake (Minson, 1990). Although not measured in this experiment, bahiagrass also accumulates N in the roots and rhizomes (Impithuksa and Blue, 1978; Impithuksa et al., 1984) and these likely were important N sinks in the High pastures.
Table 3.6. Nitrogen concentration in hand-plucked samples from continuously stocked bahiagrass pastures during 2001-2003.

<table>
<thead>
<tr>
<th>Year</th>
<th>2001</th>
<th>2002</th>
<th>2003</th>
</tr>
</thead>
<tbody>
<tr>
<td>Treatment</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Low</td>
<td>14.0 c C†</td>
<td>17.0 b A</td>
<td>15.7 c B</td>
</tr>
<tr>
<td>Moderate</td>
<td>17.2 b A</td>
<td>17.9 b A</td>
<td>17.8 b A</td>
</tr>
<tr>
<td>High</td>
<td>20.0 a B</td>
<td>22.5 a A</td>
<td>23.5 a A</td>
</tr>
<tr>
<td>SE</td>
<td>0.9</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

†Means followed by the same letter, lower case letters within the same column and upper case letters in the same row, do not differ statistically by the LSMEANS test (P > 0.05).

There also was a treatment by zone interaction for plant N concentration (Table 3.7). Differences among zones occurred only for the Low management intensity treatment, where overall N was most limiting. In this treatment, herbage N concentration was greater in Zone 1, as opposed to other zones. Zone 1 is where animals lounged, returning a greater proportion of excreta per unit area (Chapter 4). In the Moderate and High treatments, more N fertilizer was used. As a result, Zones 2 and 3 in these pastures were likely less soil-N limited than in the Low treatment, and herbage N concentration was the same as in Zone 1.

Table 3.7. Nitrogen concentration in hand-plucked samples from different pasture zones of continuously stocked bahiagrass pastures during 2001 through 2003.

<table>
<thead>
<tr>
<th>Zone</th>
<th>1</th>
<th>2</th>
<th>3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Treatment</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Low</td>
<td>16.6 b A†</td>
<td>15.3 c AB</td>
<td>14.7 c B</td>
</tr>
<tr>
<td>Moderate</td>
<td>17.8 b A</td>
<td>17.7 b A</td>
<td>17.5 b A</td>
</tr>
<tr>
<td>High</td>
<td>21.5 a A</td>
<td>22.1 a A</td>
<td>22.4 a A</td>
</tr>
<tr>
<td>SE</td>
<td>0.9</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

†Means followed by the same letter, lower case letters within the same column and upper-case letters in the same row, do not differ statistically by the LSMEANS test (P > 0.05).
Plant phosphorus concentration

Plant P concentration was affected by an interaction of treatment x year, with values generally increasing each year (Table 3.8). Pastures managed at higher intensities presented higher plant P concentration in yr 2 and 3. Although P fertilization was greater for Moderate and High only in 2002, the stocking rate was approximately three times greater in the High than in the Low treatment. Increasing stocking rate increased the amount of excreta returned per unit area and P is more available in excreta than in plant litter (Thomas, 1992; Braz et al., 2002). As a result, increasing soil P availability due to higher excreta return likely resulted in higher forage P concentration in the High treatment. Highly fertilized pastures tend to allocate proportionally more biomass to above-ground tissue when compared to nutrient-limited pasture, which needs to invest more in the root system to explore more soil volume to obtain the same amount of nutrients (Tinker and Nye, 2000; Brady and Weil, 2002). At the same time, roots in tropical grasses present low P concentrations resulting in large C:P ratios and P immobilization (Thomas and Asakawa, 1993; Schunke, 1998). Phosphorus net mineralization in plant residues is generally positive when C:P ratios are ≤ 200:1 to 300:1 (Mullen, 1999; Novais and Smyth, 1999), which is not the case for most tropical grasses (Thomas and Asakawa, 1993; Schunke, 1998), particularly in the root tissue. Gijsman et al. (1997), for example, reported C:P ratios up to 1540:1 in roots of creeping signalgrass [Brachiaria humidicola (Rendle) Schweick.] grown on Colombian Oxisols. Therefore, pastures managed at the Low intensity probably had proportionally more roots with large C:P ratios contributing to P immobilization in the soil, and, ultimately showing lesser P concentration in the forage.
Table 3.8. Phosphorus concentration in hand-plucked samples from continuously stocked bahiagrass pastures during 2001 through 2003.

<table>
<thead>
<tr>
<th>Year</th>
<th>Treatment</th>
<th>2001</th>
<th>2002</th>
<th>2003</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>g kg⁻¹</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2001</td>
<td>Low</td>
<td>1.53 a</td>
<td>1.61 b</td>
<td>2.02 c</td>
</tr>
<tr>
<td></td>
<td>Moderate</td>
<td>1.58 a</td>
<td>1.71 ab</td>
<td>2.13 b</td>
</tr>
<tr>
<td></td>
<td>High</td>
<td>1.48 a</td>
<td>1.77 a</td>
<td>2.37 a</td>
</tr>
<tr>
<td></td>
<td>SE</td>
<td>0.04</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

†Means followed by the same letter, lower-case letters within the same column and upper-case letters in the same row, do not differ statistically by the LSMEANS test (P > 0.05).

Plant P concentration also was affected by the interaction of treatment with pasture zones (Table 3.9). The same trend that occurred with plant N concentration also occurred with plant P concentration, i.e., increasing plant P concentration in the zones closer to shade and water for the Low treatment, but not for the High. Phosphorus availability, as already discussed previously, was likely less in Low pastures due to lower stocking rate and less excreta deposition per unit area. Because Zone 1 was P enriched due to higher density of dung deposition (Chapter 4), differences in plant P concentration were accentuated in the Low treatment (Table 3.9).

Table 3.9. Phosphorus concentration in hand-plucked samples from different pasture zones in continuously stocked bahiagrass pastures during 2001-2003.

<table>
<thead>
<tr>
<th>Zone</th>
<th>Treatment</th>
<th>1</th>
<th>2</th>
<th>3</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>g kg⁻¹</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>Low</td>
<td>1.77 b</td>
<td>1.71 b</td>
<td>1.68 b</td>
</tr>
<tr>
<td></td>
<td>Moderate</td>
<td>1.85 ab</td>
<td>1.74 b</td>
<td>1.83 a</td>
</tr>
<tr>
<td></td>
<td>High</td>
<td>1.88 a</td>
<td>1.88 a</td>
<td>1.85 a</td>
</tr>
<tr>
<td></td>
<td>SE</td>
<td>0.04</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

†Means followed by the same letter, lower case letters within the same column and uppercase letters in the same row do not differ statistically by the LSMEANS test (P > 0.05).
IVDOM

In vitro digestible organic matter concentration increased from 2001 to 2003 and treatments also interacted with year (Table 3.10). Greater intensity of management resulted in higher IVDOM in 2002 and 2003, but not in 2001. Similar trends occurred for plant N and plant P concentration. This response may be due to decreasing herbage allowance (kg forage kg\(^{-1}\) animal live weight) with increasing management intensity. On High pastures, the interval between cattle visits to a particular patch was likely less than on Low pastures. As a result, the average age of plant tissue was also likely lower for High than Low, leading to higher IVDOM. Fertilizer amount may have had some impact, but the effect of N fertilizer on digestibility is variable and the causes are complex (Wilson, 1982). Tillering may increase at higher N rates (Chapman and Lemaire, 1993) contributing to the formation of new tissue resulting in higher IVDOM (Coleman et al., 2004). The relationship between herbage IVDOM and CP concentrations expressed as DOM/CP ratio is important in determining animal N status and need for supplementation (Moore, 1992; Lima et al., 1999). Moore et al. (1999) suggested that IVDOM:CP ratios below 7 indicate that there is unlikely to be an animal response to N supplementation. In the present research, IVDOM:CP ratio averaged 4.8, 4.3, and 3.7 for Low, Moderate, and High treatments, respectively, indicating no limitation of N relative to digestible energy for any of the treatments. If this ratio is low, an energy-protein imbalance may increase N losses to the environment due to greater N excretion by the animal. Depending upon cost and availability, readily available sources of supplemental energy should be considered for animals grazing pastures receiving high rates of N. This may result not only in higher animal performance but also in less N excretion and loss to the environment.
Table 3.10. In vitro digestible organic matter (IVDOM) concentration in hand-plucked samples from continuously stocked bahiagrass pastures managed at different intensities during 2001-2003.

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Year</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>2001</td>
<td>2002</td>
<td>2003</td>
</tr>
<tr>
<td>Low</td>
<td>419 a B†</td>
<td>488 b A</td>
<td>496 c A</td>
</tr>
<tr>
<td>Moderate</td>
<td>433 a B</td>
<td>494 b A</td>
<td>517 b A</td>
</tr>
<tr>
<td>High</td>
<td>436 a C</td>
<td>529 a B</td>
<td>558 a A</td>
</tr>
</tbody>
</table>

†Means followed by the same letter, lower case letters within the same column and uppercase letters in the same row do not differ statistically by the LSMEANS test (P > 0.05).

Herbage IVDOM was greater for the Low treatment in Zone 1 than Zone 3, but values did not differ among zones for the other treatments (Table 3.11). Because Low pastures received the least amount of fertilizer, a soil nutrient concentration gradient from Zone 1 to Zone 3 may have impacted this response. Additionally, the lower herbage accumulation rate on Low pastures in conjunction with animals spending much time around shade and water (Zone 1) could have resulted in more frequent visits to grazing patches in Zone 1 and less mature herbage.

Table 3.11. In vitro digestible organic matter concentration in hand-plucked samples from different pasture zones in continuously stocked bahiagrass pastures during 2001-2003.

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Zone</th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>1</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td></td>
<td>g kg⁻¹</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Low</td>
<td>478 b A†</td>
<td>466 b AB</td>
<td>459 c B</td>
<td></td>
</tr>
<tr>
<td>Moderate</td>
<td>488 ab A</td>
<td>476 b A</td>
<td>480 b A</td>
<td></td>
</tr>
<tr>
<td>High</td>
<td>502 a A</td>
<td>509 a A</td>
<td>511 a A</td>
<td></td>
</tr>
</tbody>
</table>

†Means followed by the same letter, lower-case letters within the same column and upper-case letters in the same row do not differ statistically by the LSMEANS test (P > 0.05).
Experiment 2

Herbage accumulation and mass

Rotationally stocked pastures had similar herbage accumulation rates among treatments, but across the 3-yr the average accumulation rate for the rotational treatments was greater than for continuous stocking. Accumulation rate for the four rotational treatments averaged 70 kg DM ha\(^{-1}\) d\(^{-1}\) compared to 42 kg DM ha\(^{-1}\) d\(^{-1}\) for the continuous High treatment (P=0.0019) (Table 3.12).

Table 3.12. Herbage accumulation rates on rotationally stocked bahiagrass pastures with different grazing periods or continuous stocking during 2001-2003.

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Herbage accumulation (kg DM ha(^{-1}) d(^{-1}))</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rotational†</td>
<td></td>
</tr>
<tr>
<td>1 day</td>
<td>65</td>
</tr>
<tr>
<td>3 days</td>
<td>68</td>
</tr>
<tr>
<td>7 days</td>
<td>72</td>
</tr>
<tr>
<td>21 days</td>
<td>75</td>
</tr>
<tr>
<td>Effect‡</td>
<td>NS (P &gt; 0.10)</td>
</tr>
<tr>
<td>Continuous</td>
<td>42</td>
</tr>
</tbody>
</table>

Contrast Rotational vs. Continuous (P value) 0.002

†Length of grazing period.
‡Polynomial contrast for length of grazing period effect for rotational treatments. SE = 3.5 kg DM ha\(^{-1}\) d\(^{-1}\).

Frequency, intensity, and timing of defoliation often interact strongly. Richards (1993) stated that “The amount and type of tissue removed, and when the loss occurs in relation to plant development and the prevailing environment, are most important in determining the impact of defoliation on plants”. Experiments date back to the 1930s comparing rotational vs. continuous methods (Hodgson et al., 1934), but in many cases the differences between methods were not clear (Davis and Pratt, 1956; Grant et al.,
The idea of rotational stocking is to allow a period for forage regrowth without the animal interfering in reestablishment of carbohydrate levels and LAI, allowing the plant to reach the steeper part of the growth curve resulting in a faster regrowth. In the present study, defoliation interval likely played a role in the herbage accumulation response.

Parsons and Penning (1988) reported an increase in the average growth rate of perennial ryegrass (*Lolium perenne* L.) as regrowth interval increased from approximately 13 d to 21 d, but growth rate changed little as the regrowth interval was extended from 21 d to 32 d. The authors attributed these responses to a rapid increase in canopy photosynthesis and rate of production of new leaves after defoliation, without a corresponding increase in the rate of leaf death until approximately 21 d of regrowth. As a result, net herbage accumulation was greater at the intermediate period of regrowth, i.e., 21 d. Chapman and Lemaire (1993) pointed out that when time period between defoliation events is less than the leaf lifespan, leaf material below defoliation height will senesce and decompose but that produced above defoliation height will be present at harvest. On the other hand, when interval between defoliations is longer than mean lifespan, a proportion of leaf material produced since the previous defoliation is lost to senescence and the difference between primary production and harvestable production increases. Thus, appropriate defoliation interval and grazing height maximize forage growth and utilization.

Considering the results obtained in the current experiment, rotational stocking with a 21-d regrowth period appeared to favor net herbage accumulation more than the defoliation intervals and grazing heights that occurred under continuous stocking. Herbage allowance (kg forage kg\(^{-1}\) of animal live weight) in the High treatment was
lower than in the other continuously stocked treatments because of greater stocking rate. Considering that herbage allowance plays a role in the frequency of defoliation for a given patch, the period of return of the grazing animals to the same patch in the High management intensity and continuously stocked pastures probably was not long, likely less than the 14 d allowed for forage regrowth inside the cages. As a result, the cage technique may have even underestimated the differences between continuous and rotational methods.

Similar to what occurred in Experiment 1, herbage accumulation rate increased from 2001 to 2003 (Figure 3.4). The same explanation likely holds here, i.e., the increase in soil nutrient concentration (Chapter 4 and Chapter 7) contributed to increasing herbage accumulation after first experimental year. Soil P, for example, averaged 5.3 mg kg\(^{-1}\) at the beginning of the experiment in 2001 and after 3 yr of grazing soil P averaged 10.2 mg kg\(^{-1}\) for the rotational and High treatments (Chapter 4). Soil K also increased from 28 mg kg\(^{-1}\) in 2001 to 108 mg kg\(^{-1}\) in 2003 at the 0- to 8-cm soil depth. Lower rainfall in 2001 (1008 mm) when compared to the 30-yr average (1341 mm) and the other experimental years (1237 mm in 2002 and 1346 in 2003), probably also had some effect in reducing herbage accumulation rates in 2001.

Pre-graze herbage mass was not affected by length of grazing period and averaged 4180 kg DM ha\(^{-1}\) across the four rotational stocking treatments. There were year effects similar to those observed in Experiment 1 (Table 3.13). Post-graze herbage mass decreased with increasing length of grazing period, with the lowest value observed for the 21-d grazing period (Table 3.14). Considering that pre-graze herbage mass was similar for all treatments and other factors like stocking rate and N fertilization were also the
same, lower post-graze herbage mass implies that either herbage accumulation was lower or forage utilization was higher for the 21-d treatment. A possible explanation is a lower herbage accumulation during the longer grazing periods because of frequent return of the cattle to the grazing patch; therefore, the use of the herbage accumulation during the resting period may not be adequate for the longer grazing period (21 days).

Figure 3.4. Herbage accumulation rates on rotationally stocked bahiagrass pastures during different grazing seasons. Means followed by the same letter do not differ statistically by the LSMEANS procedure (P > 0.05). SE = 2.8 kg DM ha$^{-1}$ d$^{-1}$.

Table 3.13. Average pre- and post-graze herbage mass on rotationally stocked bahiagrass pastures during three grazing seasons.

<table>
<thead>
<tr>
<th>Year</th>
<th>Pre-herbage mass</th>
<th>Post-herbage mass</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>kg DM ha$^{-1}$</td>
<td></td>
</tr>
<tr>
<td>2001</td>
<td>3440 b</td>
<td>2360 a</td>
</tr>
<tr>
<td>2002</td>
<td>3050 c</td>
<td>1860 c</td>
</tr>
<tr>
<td>2003</td>
<td>4740 a</td>
<td>2100 b</td>
</tr>
<tr>
<td>SE</td>
<td>239</td>
<td>110</td>
</tr>
</tbody>
</table>

*Means followed by the same letter within the same column do not differ statistically by the LSMEANS test (P > 0.05).*
Table 3.14. Post-graze herbage mass on rotationally stocked bahiagrass pastures differing in length of grazing period.

<table>
<thead>
<tr>
<th>Treatment†</th>
<th>Pre-herbage mass (kg DM ha⁻¹)</th>
<th>Post-herbage mass (kg DM ha⁻¹)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 day</td>
<td>3530</td>
<td>2100</td>
</tr>
<tr>
<td>3 days</td>
<td>4020</td>
<td>2310</td>
</tr>
<tr>
<td>7 days</td>
<td>3880</td>
<td>2250</td>
</tr>
<tr>
<td>21 days</td>
<td>3550</td>
<td>1770</td>
</tr>
<tr>
<td>SE</td>
<td>250</td>
<td>115</td>
</tr>
</tbody>
</table>

Effect (P value)‡  NS (P > 0.10)  Linear (P = 0.01)

†Length of grazing period.
‡Polynomial contrast for length of grazing period effect for rotational treatments.

Herbage nutritive value

Plant nitrogen concentration

There were no zone effects on plant N concentration, but there was a treatment x year interaction (Table 3.15), with N concentrations generally increasing after the first experimental year. Lower N rate in 2001 than 2002 and 2003 for all of these treatments likely explains this response. In 2001, a linear increase in N concentration occurred with increasing grazing period, but no significant effect was observed in the following years. Continuous stocking did not differ from rotational stocking in terms of plant N concentration. Values observed in this experiment were above the average of 857 samples collected from soil fertility trials in nine counties throughout Central Florida, which had an average of 17.4 ± 4.4 g N kg⁻¹ for low yielding bahiagrass and 15.7 ± 3.1 g N kg⁻¹ for high yielding bahiagrass (Payne et al., 1990). The high N fertilization used in the present experiment (360 kg N ha⁻¹ yr⁻¹) likely explain most of that difference.
Table 3.15. Nitrogen concentration in hand-plucked samples from one continuously and four rotationally stocked bahiagrass pasture treatments during 2001-2003.

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Year</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>2001</td>
</tr>
<tr>
<td>Rotational†</td>
<td>------</td>
</tr>
<tr>
<td>1 day</td>
<td>20.2 B</td>
</tr>
<tr>
<td>3 days</td>
<td>20.8 C</td>
</tr>
<tr>
<td>7 days</td>
<td>20.7 B</td>
</tr>
<tr>
<td>21 days</td>
<td>21.5 C</td>
</tr>
<tr>
<td>Effect‡ (P value)‡</td>
<td>Linear (P &lt; 0.03)</td>
</tr>
<tr>
<td></td>
<td>(P &gt; 0.10)</td>
</tr>
<tr>
<td>Continuous</td>
<td>20.0 B</td>
</tr>
<tr>
<td>Contrast Rotational vs. Continuous (P value)</td>
<td>0.27</td>
</tr>
</tbody>
</table>

†Length of grazing period.
‡Polynomial contrast for length of grazing period effect for rotational treatments.
§Means followed by the same letter within a row do not differ (P>0.05) by the SAS least square mean test (PDIFF). SE = 0.6 g kg⁻¹.

**Plant phosphorus concentration**

There were no zone effects or interactions with zone, but there was a treatment x year interaction for plant P. In 2002, P concentration in the plant decreased linearly with increasing grazing period, but no effect occurred in 2001 and 2003. Plant P concentration increased from 2001 to 2003 (Table 3.16). Phosphorus build up due to P fertilization and also P cycling to more available forms could explain increasing plant-P concentrations from the beginning to the end of the experiment. Continuous stocking was not different from rotational stocking for all evaluated years in terms of plant P concentration.
Table 3.16. Phosphorus concentration in hand-plucked samples from rotationally stocked bahiagrass pastures during 2001-2003.

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Year</th>
<th>2001</th>
<th>2002</th>
<th>2003</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rotational†</td>
<td></td>
<td>1.52 C§</td>
<td>1.92 B</td>
<td>2.54 A</td>
</tr>
<tr>
<td>1 day</td>
<td></td>
<td>1.46 C</td>
<td>1.89 B</td>
<td>2.40 A</td>
</tr>
<tr>
<td>3 days</td>
<td></td>
<td>1.45 C</td>
<td>1.73 B</td>
<td>2.43 A</td>
</tr>
<tr>
<td>7 days</td>
<td></td>
<td>1.52 C</td>
<td>1.78 B</td>
<td>2.49 A</td>
</tr>
<tr>
<td>21 days</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Effect‡</td>
<td></td>
<td>NS</td>
<td>Linear</td>
<td>NS</td>
</tr>
<tr>
<td>(P value)</td>
<td></td>
<td>(P &gt; 0.10)</td>
<td>(P &lt; 0.05)</td>
<td>(P &gt; 0.10)</td>
</tr>
<tr>
<td>Continuous</td>
<td></td>
<td>1.48 C</td>
<td>1.77 B</td>
<td>2.37 A</td>
</tr>
</tbody>
</table>

Contrast Rotational vs. Continuous (P value) 0.87 0.48 0.39

†Length of grazing period.
‡Polynomial contrast for length of grazing period effect for rotational treatments.
§Means followed by the same letter within a row do not differ (P>0.05) by the SAS least square mean test (PDIFF). SE = 0.04 g kg\(^{-1}\).

IVDOM

There were no zone effects or interactions with zone for herbage IVDOM, but there was a treatment x year interaction (Table 3.17). In general, digestibility increased from 2001 to 2003, as observed in Experiment 1, and treatment differences were more pronounced in 2003. In 2003, IVDOM decreased linearly with increasing grazing period, with no similar effect observed in 2001 and 2002. Higher stocking densities in the short grazing periods may have promoted a more uniform defoliation, and therefore, more uniform regrowth and less occurrence of very mature, undefoliated herbage. In contrast, longer grazing periods like 21 d and High treatments may be more likely to develop patch grazing and some areas of pasture that are excessively mature. Contrast between rotational treatments and continuous High showed higher IVDOM for the rotational treatments (P < 0.02) in 2001, but not in 2002 and 2003.
Table 3.17. In vitro digestible organic matter concentration (IVDOM) in hand-plucked samples from rotationally and continuously stocked bahiagrass pastures during 2001-2003.

<table>
<thead>
<tr>
<th>Year</th>
<th>Treatment</th>
<th>2001</th>
<th>2002</th>
<th>2003</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Rotational †</td>
<td>480 C § 552 B 607 A</td>
<td>472 C 573 B 598 A</td>
<td>483 B 510 A 521 A</td>
</tr>
<tr>
<td></td>
<td>21 days</td>
<td>497 C 547 A 524 B</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Effect ‡</td>
<td>(P value)</td>
<td>NS (P &gt; 0.10)</td>
<td>NS (P &gt; 0.10)</td>
<td>Linear (0.0001)</td>
</tr>
<tr>
<td>Continuous</td>
<td>436 † C 529 B 558 A</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Contrast Rotational vs. Continuous (P value)</td>
<td>0.02</td>
<td>0.13</td>
<td>0.83</td>
<td></td>
</tr>
</tbody>
</table>

†Length of grazing period.
‡Polynomial contrast for length of grazing period effect for rotational treatments.
§Means followed by the same letter within a row do not differ (P>0.05) by the SAS least square mean test (PDIFF). SE = 10 g kg⁻¹.

Conclusions

Under continuous stocking, herbage responses differed among pasture zones. Herbage accumulation and herbage nutritive value were greater in the zone closest to the shade and water, while herbage mass was lowest in Zone 1. Greater accumulation and nutritive value in Zone 1 likely reflects the greater concentration of nutrients in zones closer to shade and water. Lower herbage mass in Zone 1 is reflective of greater time spent by cattle in this zone (Chapter 4). Also, increasing management intensity increased herbage accumulation and herbage nutritive value, particularly after the first experimental year. This is an indication that nutrient build up in the soil is likely to occur when intensively managed pasture-based production systems are adopted, affecting herbage responses across years. The results obtained in this research do not support the use of N fertilization above 120 kg N ha⁻¹ yr⁻¹ for bahiagrass pastures in North Central Florida.
In Experiment 2, herbage accumulation was lower in continuously stocked pastures when compared to rotational ones, but there were no differences among rotational strategies. Herbage nutritive value (N, P, and IVDOM) increased after first experimental year, but it was not affected by grazing method (continuous vs. rotational) or length of grazing period (rotational treatments) in more than 1 out of 3 yr. Herbage response was similar among pasture zones in Experiment 2, indicating a more uniform regrowth and chemical composition in more intensively managed pasture systems and rotationally stocked pastures.

Considering that no additional herbage accumulation response occurred with N fertilizer greater than 120 kg ha\(^{-1}\) yr\(^{-1}\) and the advantages in terms of uniformity of soil nutrient concentration for rotational stocking with short grazing periods (Chapter 5), a potential system to optimize beef cattle production on bahiagrass pastures in North Central Florida is a rotational system with short grazing periods (< 7 d), a 21-d resting period, and N fertilizer applied at approximately 120 kg N ha\(^{-1}\) yr\(^{-1}\).
CHAPTER 4
ANIMAL BEHAVIOR AND SOIL NUTRIENT REDISTRIBUTION IN CONTINUOUSLY STOCKED PENSACOLA BAHIA GRASS PASTURES GRAZED AT DIFFERENT INTENSITIES

Introduction

A small proportion of the nutrients ingested by grazing livestock are retained in animal tissues or exported in animal products; most nutrients are returned to the pasture in excreta (Wilkinson and Lowrey, 1973; Haynes and Williams, 1993). Grazing animals modify nutrient distribution in pasture soils by ingesting nutrients in forages and returning them to different locations across the pasture surface. Additionally, excreta is not uniformly deposited and a higher density of deposition occurs around lounging areas (Mathews et al., 1994a; Mathews et al., 1999; West et al., 1989; White et al., 2001).

Nutrients also are excreted in different proportions in dung and urine. Most of the P and Mg, for example, are excreted in the dung, while most of the K is excreted in the urine (Mathews et al., 2004).

Enhancing uniformity of soil nutrient distribution across the pasture is an important goal of grazing management. Expected results include higher nutrient-use efficiency, more economical farming production, and less environmental pollution due to lower nutrient loading of ground water. Peterson and Gerrish (1996) suggested that short grazing periods with high stocking rates enhance uniformity of excreta distribution, however, in warmer climates the results are not always consistent with this conclusion (Mathews et al., 1994b; Mathews et al., 1999). Under high temperature conditions, animals stayed in small areas of the pasture congregating under shade and close to
watering points, regardless of stocking rate or grazing method (Mathews et al., 1994b; Mathews et al., 1999; White et al., 2001). Additional research effort linking soil responses and animal behavior to pasture management practices is needed in order to better understand nutrient dynamics in grazed ecosystems (Mathews et al., 1999). Thus, the objectives of this study were to evaluate the effects of different pasture management practices on animal behavior and soil nutrient distribution across continuously stocked ‘Pensacola’ bahiagrass (*Paspalum notatum* Flügge) pastures.

**Materials and Methods**

**Experimental Site**

A grazing experiment was performed at the Beef Research Unit, northeast of Gainesville, FL, at 29°43’ N lat on Pensacola bahiagrass pastures. Soils were classified as Spodosols (sandy siliceous, hyperthermic Ultic Alaquods from the Pomona series or sandy siliceous, hyperthermic Aeric Alaquods from the Smyrna series) with average pH of 5.9. Mehlich-I extractable soil P, K, Ca, and Mg average concentrations at the beginning of the experiment were 5.3, 28, 553, and 98 mg kg⁻¹, respectively.

**Treatments and Design**

This experiment evaluated the effect of three management intensities of continuously stocked bahiagrass pastures on animal behavior and soil nutrient distribution in different pasture zones, defined according to their distance from shade and water locations. Treatments were combinations of stocking rate and N fertilization, and are defined here as management intensities.

The three management intensities tested were Low (40 kg N ha⁻¹ yr⁻¹ and 1.2 animal units [AU, one AU = 500 kg live weight] ha⁻¹ target stocking rate), Moderate (120 kg N ha⁻¹ yr⁻¹ and 2.4 AU ha⁻¹ target stocking rate), and High (360 kg N ha⁻¹ yr⁻¹ and 3.6
AU ha$^{-1}$ target stocking rate). These treatments were selected because Low approximates current bahiagrass management practice in Florida cow-calf systems, Moderate represents the upper range of current practice, and High is well above what is currently in use. Actual heifer weights were greater than anticipated at the beginning of the grazing seasons resulting in greater SR. The actual average stocking rates for the 3 yr were 1.4, 2.8, and 4.2 AU ha$^{-1}$ for Low, Moderate, and High, respectively. A strip-split plot arrangement in a completely randomized block design was used and each treatment was replicated twice. Management intensity was the main plot and the zones were the strip-split plot. Zones were previously described (Figure 3.1). The bahiagrass pastures were continuously stocked from 26 June to 16 Oct. 2001 (112 d), 8 May to 23 Oct. 2002 (168 d), and 12 May to 27 Oct. 2003 (168 d). Dry spring and early summer conditions in 2001 delayed the start of the study. Due to the shorter grazing season of 2001, the High treatment received only 270 kg N ha$^{-1}$ in that year.

Two crossbred (Angus x Brahman) yearling heifers were assigned to each experimental unit. Pasture area varied according to the treatment and decreased as the management intensity increased (Chapter 3). Artificial shade (3.1 m x 3.1 m) was provided on each of the experimental units and cattle had free-choice access to water and a salt-based mineral mixture. The water troughs were always located under the artificial shade and the mineral mix troughs (one per pasture) were moved randomly throughout the pasture. Nitrogen fertilization dates and rates were the same as described in Chapter 3.

**Response Variables**

Soil samples were characterized in three zones of each experimental unit immediately prior to the beginning (spring) and immediately after the end (autumn) of
each of the three grazing seasons (2001-2003). In each zone of all pastures, a composite was prepared from 20 samples (2-cm diameter) for the 0- to 8-cm depth and for the 8- to 23-cm depth, taken along a zigzag line within the zone. The composite soil samples were split with one sample air dried and analyzed for Mehlich I P, K, and Mg. The other sample was frozen, and following a subsequent 2-M KCl extraction (2:1), shaken for 1 h, filtered in Whatman paper filter Number 5, stored in plastic vials and frozen until laboratory analysis for NH$_4$ and NO$_3$ using a semi-automated colorimetric analysis (EPA method 353.2). A sub-sample was taken from each frozen soil sample to determine soil moisture. Results were corrected for soil moisture and are expressed as mg kg$^{-1}$ dry soil.

Animal behavior was monitored continuously by observers over 12-h periods (0700 to 1900 h) for each treatment. Two heifers per experimental unit were observed. Observers were located outside the pasture to minimize influence on cattle behavior. All treatments in one replicate were observed simultaneously in a given day. The second replicate was observed approximately 1 wk later except for the first observation in 2002 when the two replicates were observed during the same day. A total of nine complete animal behavior evaluations were performed during 2002 and 2003, five in 2002 and four in 2003 (Table 4.1). Behavior observations were not made in 2001.

Behavior observations included quantity of time spent grazing and lounging in each zone, as well as location (zone) and time of every dung and urine event. The three zones were delimited by colored flags in a way that allowed the observers to visualize each zone without disturbing the heifers’ behavior. Indices were calculated by dividing the percentage of an activity (total time spent per zone or dung and urine events) that
occurred in a given zone by the percentage of the pasture area occupied by that particular zone.

Table 4.1. Animal behavior observation dates during 2002 and 2003.

<table>
<thead>
<tr>
<th>Evaluation</th>
<th>Observation dates</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>21 May 2002</td>
</tr>
<tr>
<td>2</td>
<td>4 and 11 June 2002</td>
</tr>
<tr>
<td>3</td>
<td>26 June and 3 July 2002</td>
</tr>
<tr>
<td>4</td>
<td>12 and 19 August 2002</td>
</tr>
<tr>
<td>5</td>
<td>22 and 29 September 2002</td>
</tr>
<tr>
<td>6</td>
<td>9 and 16 June 2003</td>
</tr>
<tr>
<td>7</td>
<td>30 June and 7 July 2003</td>
</tr>
<tr>
<td>8</td>
<td>15 and 22 August 2003</td>
</tr>
<tr>
<td>9</td>
<td>27 September and 4 October 2003</td>
</tr>
</tbody>
</table>

Statistical Analyses

Statistical analyses of animal behavior and soil nutrient concentration were performed using Proc Mixed from SAS institute (SAS Inst. Inc., 1996) and the LSMEANS procedure used to compare treatment means. Zonal soil samples were analyzed using the final soil nutrient concentration (October 2003) as the response variable and the initial concentrations (June 2001) as a co-variate. Animal behavior data were analyzed including evaluation date in the model. Multivariate regression was performed for some behavioral responses and weather variables using Proc Reg from SAS.

Results and Discussion

Animal Behavior

Management intensity did not affect animal behavior on continuously stocked bahiagrass pastures, but grazing behavior did differ in the pasture zones and at different evaluation intervals. Cattle spent more time in Zone 3 followed by Zone 1 and Zone 2 (Table 4.2). Zone 3 represented 96, 92, and 88% of the pasture area for Low, Moderate,
and High treatments, respectively, and cattle spent more time grazing in Zone 3 (Table 4.3). On the other hand, Zone 1 represented only 1, 2, and 3% of pasture area for Low, Moderate, and High treatments, respectively, but cattle spent approximately 24% of the total time in Zone 1 during observation periods (Table 4.2). The total time index, which is calculated by dividing the percentage of the total time spent in a given zone by the percentage of the pasture area occupied by that zone, was greater in Zone 1 when compared to the other zones, showing that proportionally the heifers spent more time close to the water and shade (Table 4.2). The urine and dung distribution indices, which are the percentage of dung or urine event that occurred in a given zone divided by the percentage of the pasture area occupied by that particular zone, indicate a concentration of both urine and dung events in Zone 1, when compared to the other zones (Table 4.2). Shade and water troughs were located in Zone 1, and animals congregated there during the warmer periods of the day to minimize heat stress associated with high temperature and humidity. Although animal behavior has not been well documented, several studies across a range of environments and grazing methods have shown that nutrient accumulation is greater near shade and water, with shade being more important (Sugimoto et al., 1987; West et al., 1989; Gerrish et al., 1993; Macoon, 1999; Mathews et al., 1999; White et al., 2001).
Table 4.2. Total time cattle spent per zone, total time index, urine distribution index, and dung distribution index on continuously stocked bahiagrass pastures during 2002-2003.

<table>
<thead>
<tr>
<th>Zone</th>
<th>Total time per zone, min evaluation</th>
<th>Total time index‡</th>
<th>Urine distribution index‡</th>
<th>Dung distribution index‡</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>164 b†</td>
<td>9.8 a</td>
<td>6.3 a</td>
<td>5.7 a</td>
</tr>
<tr>
<td>2</td>
<td>53 c</td>
<td>3.9 b</td>
<td>2.1 b</td>
<td>2.8 b</td>
</tr>
<tr>
<td>3</td>
<td>476 a</td>
<td>3.5 b</td>
<td>0.8 b</td>
<td>0.8 b</td>
</tr>
</tbody>
</table>

†Means followed within a column by the same letter do not differ (P>0.05) by the SAS least squares mean test (PDIFF).
‡Indices were calculated by dividing the percentage of an activity (total time spent per zone or dung and urine events) that occurred in a given zone by the percentage of the pasture area occupied by that particular zone.

Table 4.3. Grazing time in pasture zones, defined based on distance from shade and water locations, on different evaluation dates on continuously stocked bahiagrass pastures during 2002-2003.

<table>
<thead>
<tr>
<th>Evaluation dates</th>
<th>Zone 1</th>
<th>Zone 2</th>
<th>Zone 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>4 and 11 June 2002</td>
<td>6 a B†</td>
<td>34 a B</td>
<td>358 a A</td>
</tr>
<tr>
<td>22 and 29 Sept. 2002</td>
<td>20 a C</td>
<td>77 a B</td>
<td>207 c A</td>
</tr>
<tr>
<td>30 June and 7 July 2003</td>
<td>16 a B</td>
<td>34 a B</td>
<td>276 b A</td>
</tr>
<tr>
<td>27 Sept. and 4 Oct. 2003</td>
<td>26 a B</td>
<td>38 a B</td>
<td>356 a A</td>
</tr>
</tbody>
</table>

†Means followed by the same letter, lower case letter within a column and upper case letters within a row, do not differ (P>0.05) by the SAS least squares mean test (PDIFF).

Environmental conditions may be the most important non-canopy factor affecting grazing behavior, and grazing behavior can have a major impact on nutrient redistribution in pastures (Sollenberger et al., 2002). In this study, time spent under the shade ranged from 30 min evaluation⁻¹ to 230 min evaluation⁻¹, and a multivariate regression including weather data explained 50% of the variation in this response (Table 4.4). A Pearson correlation analysis indicated that the time spent under the shade was positively correlated with air temperature (0.53) and with Temperature-Humidity Index (0.54). Therefore, it is likely that in warmer more humid environments greater nutrient accumulation is likely to occur under shade and close to water locations than in cooler,
drier environments (Mathews et al., 1994a; Mathews et al., 1999). Nutrient accumulation near shade was studied for pastures in which Holstein heifers grazed bahiagrass in humid southwestern Japan (Sugimoto et al., 1987). On warm, summer days when temperatures exceeded 27°C, 44 to 53% of urinations and 26 to 29% of defecations occurred in shaded areas. In autumn, when maximum air temperature did not exceed 23.5°C, only 11% of urine and dung deposits occurred in shade areas. This may help to explain the apparently greater success achieved in using grazing management to improve distribution of nutrients in temperate (Peterson and Gerrish, 1996) than in warm climates (Sugimoto et al., 1987; Mathews et al., 1994a; Mathews et al., 1999). Temperatures (average, minimum, and maximum) and relative humidity for the experimental period in 2002 and 2003 are plotted in Figure 4.1.

Table 4.4. Regression equation, $R^2$, and $P$ value relating the time cattle spent under the shade and weather variables.

<table>
<thead>
<tr>
<th>Response variable</th>
<th>Equation $^\dagger$</th>
<th>$R^2$</th>
<th>$P$ value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Time spent under shade</td>
<td>$Y = -682.9 + 0.3\text{Solrad} - 7.7\text{WSP} - 29.4\text{THI}$</td>
<td>0.50</td>
<td>0.03</td>
</tr>
</tbody>
</table>

$^\dagger$Solrad is average solar radiation in W m$^{-2}$, WSP is average wind speed in km h$^{-1}$, and THI is Temperature-Humidity Index (°C)$^\dagger$. All climate data refer to the average from 0700 to 1900 h of each evaluation day.

---

$^\dagger$ Cattle Heat Stress Index was developed by the University of Oklahoma in conjunction with the Intermountain Fire Sciences Lab of the U.S. Forest Service and the formula is

$$THI = T_{\text{air}} - [0.55\times(0.55\times\text{RH/100})]\times(T_{\text{air}}-58.8);$$

Figure 4.1. Average, minimum, and maximum temperatures and relative humidity measured at Alachua Automated Weather Station\(^2\) during the experimental period in 2002 and 2003.

\(^2\) Data obtained from the website [http://fawn.ifas.ufl.edu/](http://fawn.ifas.ufl.edu/) on 12/20/2004
Soil Nutrient Concentration

There was a management treatment by soil depth interaction for soil nitrate, ammonium, and total extractable N concentrations (Table 4.5). The High treatment had greater soil concentrations of NH₄-N and total extractable N at the 0- to 8-cm depth when compared to other pastures. There were no differences among treatments for any soil-N fraction at the 8- to 23-cm depth. Higher inorganic-N concentration as N fertilization increased was expected, particularly when forage growth and N uptake is limited by other factors (Vogel et al., 2002). Franzluebbers and Stuedemann (2003) reported average 5-yr sampling values of 1.6 mg NO₃-N kg⁻¹ soil and 10.8 mg NH₄-N kg⁻¹ soil from the 0- to 6-cm depth for bermudagrass \([Cynodon dactylon (L.) Pers.]\) fertilized with 200 kg N ha⁻¹ yr⁻¹. These NO₃-N values are similar to those obtained in the Moderate treatment in this experiment, but the NH₄ values are closer to the results obtained in the High treatment. Soil textural differences may alter the inorganic-N distribution in the soil profile, due to the influence of texture on soil chemical and physical properties. Ammonium accumulates more at the soil surface due to its interaction with cation exchange sites on soil organic matter complexes and because ammonification reactions from organic matter are concentrated near the soil surface (Franzluebbers and Stuedemann, 2003). Root system density of 1 cm root cm⁻³ of soil or greater, absorbs most of the nitrate if soil moisture is available (Tinker and Nye, 2000).

Inorganic N concentrations were similar among zones at shallower depths, but greater in Zone 2 at the 8- to 23-cm depth (Table 4.6). The NH₄-N and total extractable N were higher at 0 to 8 cm than at 8 to 23 cm for Zones 1 and 3, but not for Zone 2 (Table 4.6). This suggests that either N is moving deeper in the soil profile in Zone 2 or SOM build up is occurring to a greater degree in Zone 2, than in other zones. Soil N enrichment
in Zones 1 and 2 is expected to occur because those are the zones closer to shade and water. Because Zone 1 is where the shade and water are physically located, heavier trampling and fouling occurs there compared to Zone 2. As a result, there are areas with exposed soil and generally less vegetation in Zone 1. In contrast, Zone 2 has greater ground coverage and when accompanied by nutrient enrichment due to cattle excreta may provide a better condition for plant growth and SOM build up at deeper soil layers.

Table 4.5. Effect of pasture management treatment on soil-N concentration at different soil depths in continuously stocked bahiagrass pastures after 3 yr of grazing. Data are means across three zones and two replicates.

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Nitrate nitrogen 0-8 cm</th>
<th>Nitrate nitrogen 8-23 cm</th>
<th>NH$_4$ Nitrogen 0-8 cm</th>
<th>NH$_4$ Nitrogen 8-23 cm</th>
<th>Total Extractable N 0-8 cm</th>
<th>Total Extractable N 8-23 cm</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>mg kg$^{-1}$ soil</td>
<td></td>
<td>mg kg$^{-1}$ soil</td>
<td></td>
<td>mg kg$^{-1}$ soil</td>
<td></td>
</tr>
<tr>
<td>Low</td>
<td>0.7 a‡</td>
<td>3.0 a</td>
<td>0.57</td>
<td>4.1 a</td>
<td>6.2 b</td>
<td>7.1 a</td>
</tr>
<tr>
<td>Moderate</td>
<td>1.4 a</td>
<td>1.3 a</td>
<td>0.61</td>
<td>3.8 a</td>
<td>6.0 b</td>
<td>5.1 a</td>
</tr>
<tr>
<td>High</td>
<td>5.3 a</td>
<td>2.1 a</td>
<td>0.04</td>
<td>2.2 a</td>
<td>14.7 a</td>
<td>4.3 a</td>
</tr>
</tbody>
</table>

‡ Level of $P$ for comparison of the two soil depths within a nutrient and a management intensity treatment.

Table 4.6. Effect of pasture zone on soil-N concentration at different soil depths in continuously stocked bahiagrass pastures after 3 yr of grazing. Data are means across three treatments and two replicates.

<table>
<thead>
<tr>
<th>Zone</th>
<th>Nitrate nitrogen 0-8 cm</th>
<th>Nitrate nitrogen 8-23 cm</th>
<th>NH$_4$ Nitrogen 0-8 cm</th>
<th>NH$_4$ Nitrogen 8-23 cm</th>
<th>Total Extractable N 0-8 cm</th>
<th>Total Extractable N 8-23 cm</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>mg kg$^{-1}$ soil</td>
<td></td>
<td>mg kg$^{-1}$ soil</td>
<td></td>
<td>mg kg$^{-1}$ soil</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>3.1 a‡</td>
<td>1.1 b</td>
<td>0.13</td>
<td>1.8 b</td>
<td>10.6 a</td>
<td>2.9 b</td>
</tr>
<tr>
<td>2</td>
<td>1.7 a</td>
<td>4.0 a</td>
<td>0.42</td>
<td>6.7 a</td>
<td>6.8 a</td>
<td>10.7 a</td>
</tr>
<tr>
<td>3</td>
<td>2.6 a</td>
<td>1.4 b</td>
<td>0.26</td>
<td>1.6 b</td>
<td>9.3 a</td>
<td>3.0 b</td>
</tr>
</tbody>
</table>

‡ Level of $P$ for comparison of the two soil depths within a nutrient and a management intensity treatment.

Soil P concentration was greater for the Moderate treatment at both soil depths (Table 4.7). Phosphorus fertilization was similar between Moderate and High treatments, so that was not the explanation for higher P levels in the Moderate treatment, although greater P fertilization may have contributed to Moderate being greater than Low. Also, a
co-variance analysis was performed using initial soil P levels (June 2001) as a co-variable, therefore, P levels at the beginning of the experiment were not responsible for the difference observed. Potassium and Mg concentrations in the soil were greater in the High treatment at the 0- to 8-cm depth but did not differ at the 8- to 23-cm depth (Table 4.7). While most of the K is found in urine, most of the Mg is found in dung (Mathews et al., 2004). Both nutrients were higher in the High treatment most likely due to the greater stocking rate in that treatment, as opposed to the others. As already stated, nutrients in excreta are highly available and the highest forage utilization that occurred in the High treatment increased nutrient return through excreta.

Table 4.7. Effect of pasture management treatment on soil P, K, and Mg concentrations at different soil depths in continuously stocked bahiagrass pastures after 3 yr of grazing. Data are means across three zones and two replicates.

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Phosphorus</th>
<th>Potassium</th>
<th>Magnesium</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0-8 cm</td>
<td>8-23 cm</td>
<td>P</td>
</tr>
<tr>
<td>Low</td>
<td>11 b ‡</td>
<td>14 b</td>
<td>0.23</td>
</tr>
<tr>
<td>Moderate</td>
<td>19 a</td>
<td>21 a</td>
<td>0.53</td>
</tr>
<tr>
<td>High</td>
<td>15 b</td>
<td>14 b</td>
<td>0.93</td>
</tr>
</tbody>
</table>

† Level of P for comparison of the two soil depths within a nutrient and a management intensity treatment.
‡ Means within a column followed by the same letter are not different (P>0.10).

There was an interaction of zone and depth for soil nutrient concentration (Table 4.8). Phosphorus and K were greater in Zone 1 than in Zone 3 for both depths. Magnesium was greater in Zone 1 than in Zone 3 at the 0- to 8-cm depth, but not different at the 8- to 23-cm depth. Soil nutrient concentration was generally greatest in Zones 1 and 2, showing a clear effect of increasing soil nutrient concentration in areas near shade and water (Table 4.8). Dung and urine indices (Table 4.3) were greater in Zone 1, indicating a higher proportional return of excreta in that area, likely resulting in
its higher soil nutrient concentration. This concentration of soil nutrients could be even worst in larger pastures because of the smaller proportional areas of shade. Mathews et al. (1999) reported increasing soil N, P, K, and Mg around cattle lounging areas on kikuyugrass (*Pennisetum clandestinum* Hochst. ex Chiov.) pasture. Soil P, K, and Mg did not differ between the two depths (Table 4.8).

Table 4.8. Effect of pasture zone on soil P, K, and Mg concentration in different soil depths in continuously stocked bahiagrass pastures after 3 yr of grazing. Data are means across three treatments and two replicates.

<table>
<thead>
<tr>
<th>Zone</th>
<th>Phosphorus</th>
<th>Potassium</th>
<th>Magnesium</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0-8 cm</td>
<td>8-23 cm</td>
<td>P‡</td>
</tr>
<tr>
<td></td>
<td>mg kg soil</td>
<td>mg kg soil</td>
<td>mg kg soil</td>
</tr>
<tr>
<td>1</td>
<td>21 a‡</td>
<td>19 a</td>
<td>0.44</td>
</tr>
<tr>
<td>2</td>
<td>14 b</td>
<td>17 ab</td>
<td>0.33</td>
</tr>
<tr>
<td>3</td>
<td>10 b</td>
<td>13 b</td>
<td>0.17</td>
</tr>
</tbody>
</table>

† Level of P for comparison of the two soil depths within a nutrient and a management intensity treatment.
‡ Means within a column followed by the same letter are not different (P>0.10).

Conclusions

Management intensity did not affect animal behavior, but it did affect soil nutrient concentration. Nitrogen, K, and Mg concentration in the soil were greater at the highest management intensity at the shallower soil depth but not deeper in the soil profile. This is an important indication that although soil fertility is increasing in the surface horizon, nutrient movement to deeper soil horizons is not occurring when higher management intensity is used on bahiagrass pastures. With the exception of soil P, which increased in Moderate pastures compared to Low, there was virtually no change in soil nutrient concentrations associated with an increase in bahiagrass management intensity from the current industry practice (Low) up to the highest level of management currently practiced (Moderate).
Soil nutrient concentration was generally greatest in the pasture zones closer to shade and water, with a higher proportional return of excreta occurring on those areas. Rotation of shade to different pasture areas during the grazing season may improve excreta distribution in continuously stocked swards, reducing the problem of high soil nutrient concentration in small pasture areas.

Weather variables affected animal behavior and therefore excreta return, affecting soil nutrient distribution as an ultimate result. Selection of animals more adapted to heat stress may be a potential tool to reduce the weather effect on animal behavior.
CHAPTER 5
STOCKING METHODS, ANIMAL BEHAVIOR, AND SOIL NUTRIENT REDISTRIBUTION: HOW ARE THEY LINKED?

Introduction

Stocking method is an important component of the grazing system because it may affect animal behavior and soil nutrient redistribution (Peterson and Gerrish, 1996). These authors suggested that short grazing periods and high stocking densities promote a more uniform excreta distribution on the pasture than do other stocking methods. The rationale is that the higher stocking density, obtained by the subdivision of the pasture, leads to greater competition for forage among the animals, reducing their time spent under the shade or close to watering areas (Mathews et al., 1999).

Climate and stocking method may interact. In temperate areas, short grazing periods and high stocking rate may improve nutrient distribution; however, in warmer climates this is not always the case (Mathews et al., 1994b; Mathews et al., 1999). In tropical and subtropical climates, the animals may congregate under shade and closer to watering points during the warmer part of the day, regardless of stocking density (Mathews et al., 1994b; Mathews et al., 1999; White et al., 2001), reducing the effect of the stocking method. Moving artificial shades and watering points is an option for improving nutrient distribution (Russelle, 1997), but it may not be practical for more extensive systems. Sollenberger et al. (2002) suggested that if there are advantages of rotational stocking in terms of nutrient distribution or having more paddocks in a rotational system in a warm climate, these may accrue due to animals being forced to
utilize a greater number of lounging points (one in each paddock) as opposed to achieving greater uniformity of excreta deposition within each paddock.

Grazing experiments in many cases fail to link management practices with animal behavior and soil nutrient distribution. Thus, the objective of this research is to investigate the effect of different stocking methods and the grazing environment on animal behavior and soil nutrient concentration in different pasture zones based on their distance from shade and water.

**Materials and Methods**

**Experimental Site**

The research was performed at the Beef Research Unit, northeast of Gainesville, FL, at 29°43’ N lat on ‘Pensacola’ bahiagrass (*Paspalum notatum* Flügge) pastures. Soils were classified as Spodosols (sandy siliceous, hyperthermic Ultic Alaquods from the Pomona series or sandy siliceous, hyperthermic Aeric Alaquods from the Smyrna series) with average pH of 5.9. Mehlich-I extractable soil P, K, Ca, and Mg average concentrations at the beginning of the experiment were 5.3, 28, 553, and 98 mg kg⁻¹, respectively.

**Treatments and Design**

Treatments were four rotational and one continuous stocking strategy, and in all experimental units, three zones were identified according to distance from shade and water locations. Treatments were imposed in 2001, 2002, and 2003. The four rotational stocking strategies differed in terms of length of the grazing period (1, 3, 7, and 21 d), or, in other words, the number of paddocks in the rotational system. All four treatments had the same resting period of 21 d. The continuous stocking treatment was the High treatment described in Chapters 3 and 4. The five treatments were replicated twice using
a strip-split plot arrangement in a completely randomized block design. Stocking methods were the main plot and the three zones were the strip-split plot. Zones were described in Chapter 3. Stocking rate and N fertilization on all treatments were the same as for the High management intensity described in Chapter 4, i.e., a stocking rate of 4.2 AU ha\(^{-1}\) and N fertilization of 360 kg ha\(^{-1}\) yr\(^{-1}\). Only one paddock from a given rotational strategy was part of the experiment, and the size of the paddock reflected the length of the grazing period. Paddock sizes were 454, 1250, 2500, and 5000 m\(^2\) for 1-, 3-, 7-, and 21-d treatments, respectively. These sizes were calculated based on a pasture size of 1 ha which would in practice be subdivided into 22, 8, 4, and 2 paddocks of the sizes indicated for the 1, 3, 7, and 21-d treatments, respectively. The area for the High treatment was 3333 m\(^2\).

At the beginning of each grazing season, two crossbred (Angus x Brahman) yearling heifers were allocated to the continuously stocked treatment. Groups of five or six heifers were formed in order to obtain groups with similar total heifer live weight to graze the rotational experimental units. The heifer live weight of each group was calculated so that stocking rate was the same as on High treatment pastures. Because the rotational treatments represented an overall pasture size of 1 ha and the continuous treatment a size of 0.33 ha, there were approximately three times the amount of heifer live weight on the rotational vs. the continuous treatments. The target stocking rate for all treatments was 3.6 AU ha\(^{-1}\), but the initial weight of the heifers was greater than expected and actual stocking rates achieved were 4.4, 4.1, and 4.0 AU ha\(^{-1}\) in 2001, 2002, and 2003, respectively.
Fertilization followed the same schedule for the High management intensity described in Chapter 3. Water, shade, and minerals were available for each experimental unit as described in Chapter 3.

**Response Variables**

Soil samples were collected in three zones of each experimental unit immediately prior to the beginning (spring) and immediately after the end (autumn) of each of the three grazing seasons (2001-2003). In each zone of all experimental units, a composite was prepared from 20 samples (2-cm diameter core) for the 0- to 8-cm depth and for the 8- to 23-cm depth, taken along a zigzag line within the zone. The composite soil samples were split with one subsample air dried and analyzed for Mehlich I P, K, and Mg. The other subsample was frozen for NH$_4$ and NO$_3$ determination as described in Chapter 4.

Animal behavior was monitored continuously by observers over 12-h periods (0700 to 1900 h) for each treatment. Two heifers per experimental unit were observed continuously during each 12-h period. Observers were located outside the pasture or paddock to minimize effect on animal behavior. Because of the grazing calendar for the rotational treatments and the number of observers required, one replicate of each treatment was observed during a given day. The second replicate was observed 1 wk later. A total of eight complete animal behavior evaluations were performed during 2002 and 2003, four in 2002 and four in 2003 (Table 5.1). Behavior observations were not made in 2001.

Behavior observations included quantity of time spent grazing and lounging in each zone, as well as location (zone) and time of every dung and urine event. The three zones were delimited by colored flags in a way that allowed the observers to visualize each zone without disturbing the heifers’ behavior. Dung and urine distribution indices were
calculated by dividing the percentage of dung or urine events that occurred in a given zone by the percentage of the pasture or paddock area occupied by that particular zone. In the same way, the total time index and grazing time index were calculated, i.e., dividing the total time spent per zone (or the grazing time per zone) by the percentage of the pasture or paddock area occupied by that particular zone.

Table 5.1. Animal behavior observation dates during 2002 and 2003.

<table>
<thead>
<tr>
<th>Evaluation</th>
<th>Animal behavior observation date</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>4 and 11 June 2002</td>
</tr>
<tr>
<td>2</td>
<td>26 June and 3 July 2002</td>
</tr>
<tr>
<td>3</td>
<td>12 and 19 Aug. 2002</td>
</tr>
<tr>
<td>4</td>
<td>22 and 29 Sept. 2002</td>
</tr>
<tr>
<td>5</td>
<td>9 and 16 June 2003</td>
</tr>
<tr>
<td>6</td>
<td>30 June and 7 July 2003</td>
</tr>
<tr>
<td>7</td>
<td>15 and 22 Aug. 2003</td>
</tr>
<tr>
<td>8</td>
<td>27 Sept. and 4 Oct. 2003</td>
</tr>
</tbody>
</table>

The spatial distribution of dung was also monitored in three treatments, 1 d, 7 d, and High, by a second method. Dung deposits from the preceding 24-h period were identified by spray painting existing dung patches and returning to the pasture 24 h later. Flags were placed on the new dung patches, and their actual X and Y coordinates in the pasture or paddock were quantified using three tape measures (one each along the opposite sides of the pasture/paddock and another running between these two and perpendicular to them). Treatments from the same replicate were evaluated during the same 24-h period to avoid confounding environmental effects such as temperature and humidity with animal behavior. A total of six complete evaluations were performed, three in 2002 and three in 2003. In the first evaluation of 2002, the 7-d treatment was not included (Table 5.2).
Table 5.2. Observation dates for spatial distribution of dung.

<table>
<thead>
<tr>
<th>Evaluation</th>
<th>Observation dates</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2 and 9 Sept. 2002†</td>
</tr>
<tr>
<td>2</td>
<td>23 and 30 Sept. 2002</td>
</tr>
<tr>
<td>3</td>
<td>16 and 22 Oct. 2002</td>
</tr>
<tr>
<td>4</td>
<td>10 and 17 June 2003</td>
</tr>
<tr>
<td>5</td>
<td>28 Sept. and 5 Oct. 2003</td>
</tr>
<tr>
<td>6</td>
<td>20 and 27 Oct. 2003</td>
</tr>
</tbody>
</table>

†The 7-d treatment was not observed

Statistical Analyses

Statistical analyses of the animal behavior and soil nutrient concentration response variables were performed using Proc Mixed from SAS (SAS Inst. Inc., 1996), and the LSMEANS procedure was used to compare treatment means. Zonal soil samples were analyzed using the final soil nutrient concentration (October 2003) as the response variable and the initial concentrations (June 2001) as a co-variate. Animal behavior data were analyzed including evaluation date in the model. Multivariate regression between some behavioral responses and climate data was performed using Proc Reg from SAS.

The dung spatial distribution statistical analysis was performed after dividing each pasture in each evaluation day into 100 quadrats of equal size, allocating each individual dung record according to its X and Y coordinates in the respective quadrat. In order to evaluate the possibility of adjusting the observed frequencies to the Poisson or to the negative binomial models, a Dispersion Index (Krebs, 1999) was estimated for each experimental unit at each evaluation day. The Dispersion Index (DI) is defined as:

\[ DI = \frac{\text{Variance}_{\text{observed}}}{\text{Mean}_{\text{observed}}} = \frac{S^2}{X} \]

The null hypothesis was that the Poisson distribution applied to the observed frequencies. It was not rejected when the variance was not different from the mean, i.e.,
DI was not different than 1 and the distribution model was considered randomly distributed (Braz, 2001). In order to statistically test DI, the chi-square test was used as follows:

\[
\chi^2_{\text{observed}} = DI(n-1)
\]

Where:

\[
\chi^2_{\text{observed}} = \text{chi-square}_{\text{observed}}
\]

DI = Dispersion Index

n = number of quadrats counted (100 quadrats)

The chi-square value was obtained in statistical tables with n-1 degrees of freedom.

The two-tail chi-square test was used to test the null hypothesis, as following:

If \( \chi^2_{0.025} < \chi^2_{\text{observed}} < \chi^2_{0.975} \) \( \Rightarrow \) the variance is not different from the mean and DI is 1; therefore, the dung patches are randomly distributed. In this case, the Poisson distribution adequately describes the dataset, and the null hypothesis is true.

If \( \chi^2_{\text{observed}} \leq \chi^2_{0.025} \) \( \Rightarrow \) the variance is less than the mean and DI is close to zero; therefore, in this case the dung patches are uniformly distributed on the pasture.

If \( \chi^2_{\text{observed}} \geq \chi^2_{0.025} \) \( \Rightarrow \) the variance is greater than the mean and DI is greater than 1; therefore, in this case the dung patches are clustered and the negative binomial distribution describes the dataset adequately.

After calculating the DI for each treatment individually by replication and evaluation day, the data were transformed to 1/x in order to normalize the distribution and then analyzed using Proc Mixed from SAS.
Results and Discussion

Animal Behavior

There was treatment by zone interaction for dung and urine distribution (Tables 5.3 and 5.4). Dung and urine distribution indices were greater in Zone 1 than Zone 3 for both the 21-d and the continuous treatments. In contrast, there was no zone effect for shorter grazing period rotational strategies (7 d or less), indicating better excreta distribution for these treatments than for the 21 d and continuous High treatments. The distribution index increased linearly as length of grazing period of the rotational treatments increased in Zones 1 and 2 for dung and Zone 1 for urine but was not affected by grazing period in Zone 3.

Table 5.3. Treatment by zone interaction for dung distribution index on rotationally and continuously stocked bahiagrass pastures during 2002 and 2003.

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Zone 1</th>
<th>Zone 2</th>
<th>Zone 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rotational†</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1 day</td>
<td>1.0 A§</td>
<td>0.8 A</td>
<td>2.1 A</td>
</tr>
<tr>
<td>3 days</td>
<td>1.4 A</td>
<td>1.4 A</td>
<td>0.8 A</td>
</tr>
<tr>
<td>7 days</td>
<td>2.3 A</td>
<td>0.6 A</td>
<td>1.0 A</td>
</tr>
<tr>
<td>21 days</td>
<td>4.1 A</td>
<td>3.1 A</td>
<td>0.8 B</td>
</tr>
<tr>
<td>Effect‡</td>
<td>Linear‡</td>
<td>Linear</td>
<td>NS¶</td>
</tr>
<tr>
<td>(P value)</td>
<td>(&lt; 0.01)</td>
<td>(0.01)</td>
<td></td>
</tr>
<tr>
<td>Continuous</td>
<td>4.4 A</td>
<td>1.4 B</td>
<td>0.8 B</td>
</tr>
<tr>
<td>Contrast Rotational vs. Continuous (P value)</td>
<td>0.13</td>
<td>0.91</td>
<td>0.27</td>
</tr>
</tbody>
</table>

†Length of grazing period.
‡Polynomial contrast for effect of length of grazing period of rotational treatments.
§Means followed by the same letter within a row do not differ (P>0.05) by the SAS least squares mean test (PDIFF). SE = 0.6
¶Not significant (P > 0.10).
Table 5.4. Treatment by zone interaction for urine distribution index on rotationally and continuously stocked bahiagrass pastures during 2002 and 2003.

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Zone 1</th>
<th>Zone 2</th>
<th>Zone 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rotational†</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1 day</td>
<td>1.4 A§</td>
<td>0.6 A</td>
<td>2.3 A</td>
</tr>
<tr>
<td>3 days</td>
<td>2.5 A</td>
<td>1.2 A</td>
<td>0.7 A</td>
</tr>
<tr>
<td>7 days</td>
<td>3.7 A</td>
<td>1.5 A</td>
<td>0.8 A</td>
</tr>
<tr>
<td>21 days</td>
<td>9.6 A</td>
<td>2.7 B</td>
<td>0.7 B</td>
</tr>
<tr>
<td>Effect‡  (P value)</td>
<td>Linear‡</td>
<td>NS§</td>
<td>NS</td>
</tr>
<tr>
<td>Contrasting Rotational vs. Continuous (P value)</td>
<td>0.64</td>
<td>&lt; 0.01</td>
<td>0.19</td>
</tr>
</tbody>
</table>

†Length of grazing period.
‡Polynomial contrast for effect of length of grazing period of rotational treatments.
§Means followed by the same letter within a row do not differ (P>0.05) by the SAS least squares mean test (PDIFF). SE = 1.3
¶Not significant (P > 0.10).

There also was a treatment by zone interaction for total time index (Table 5.5).

There was no difference among zones in total time index for the 1-d grazing period treatment, but for the other treatments the index was greatest for Zone 1. Because there is a correlation between time spent per zone and number of excreta events in that zone (White et al., 2001), the better distribution of time spent per zone relative to zone area in the shortest grazing period treatment supports the smaller nutrient indices observed in Zone 1 for that treatment. There was a linear increase in the total time index for both Zones 1 and 2 with increasing length of grazing period (Table 5.5). The time index for continuous stocking was greater than the average index of the rotational treatments for Zone 1, with the index more closely resembling that of the 21-d rotational treatment than any other.
Table 5.5. Total time index per zone on rotationally and continuously stocked bahiagrass pastures during 2002 and 2003.

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Zone 1</th>
<th>Zone 2</th>
<th>Zone 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rotational†</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1 day</td>
<td>1.8 A</td>
<td>0.7 A</td>
<td>0.9 A</td>
</tr>
<tr>
<td>3 days</td>
<td>3.3 A</td>
<td>0.8 B</td>
<td>0.7 B</td>
</tr>
<tr>
<td>7 days</td>
<td>4.4 A</td>
<td>0.7 B</td>
<td>0.9 B</td>
</tr>
<tr>
<td>21 days</td>
<td>13.3 A</td>
<td>1.4 B</td>
<td>0.7 B</td>
</tr>
<tr>
<td>Effect‡ (P value)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Linear</td>
<td>(P &lt; 0.01)</td>
<td>(P = 0.01)</td>
<td>(P = 0.58)</td>
</tr>
<tr>
<td>Continuous</td>
<td>9.3 A</td>
<td>0.9 B</td>
<td>0.7 B</td>
</tr>
</tbody>
</table>

Contrast Rotational vs. Continuous (P value) | P < 0.01 | P = 0.26 | P = 0.09

†Length of grazing period.
‡Polynomial contrast for effect of length of grazing period of rotational treatments.
§Means followed by the same letter within a row do not differ (P > 0.10) by the SAS least square mean test (PDIFF). SE = 1.2
¶Total time index = % time spent per zone/% area occupied by the zone.
#Not significant (P > 0.10).

Evaluation date affected the total time cattle spent in the three pasture zones (Table 5.6), time spent under shade (Table 5.7), and time spent grazing (Table 5.8). During mid-summer evaluation dates (July/August), animals spent more time in Zone 1 and less time in Zone 3, when compared with other dates (Table 5.6). Animals also spent more time under the shade (Table 5.7) and less time grazing Zone 3 (Table 5.8) in these same mid-summer evaluations. Total time grazing averaged 338 ± 21 min eval⁻¹ which is approximately 48% of total evaluated time. Considering this relatively large period of time, if management practices alter grazing behavior they most likely will also alter nutrient distribution.

Heat stress has a pronounced effect on animal behavior and performance. At high temperature, the principal mechanism to reduce heat stress is evaporative cooling, which
is influenced by humidity and wind speed and by physiological factors such as respiration rate, and density and activity of sweating glands (Blackshaw and Blackshaw, 1994). Reducing feed intake, seeking shade, and increasing drinking water are behavioral mechanisms cattle develop to reduce heat stress (Blackshaw and Blackshaw, 1994). It is not surprising therefore that more time spent under the shade and less time spent grazing were characteristic of mid-summer evaluations.

Temperature, relative humidity, and cattle heat stress index were measured from 1000 to 1500 h of each evaluation day. The heat stress index takes in account both temperature and relative humidity to estimate cattle stress (Mader et al., 2000; Osborne, 2003). Mader et al. (2000) considered the following ranges for this index: normal, < 23.3; alert, 23.9-25.6; danger, 26.1-28.3; emergency, > 28.9 (in °C). The same authors recommended adoption of management practices such as providing ample water, avoiding handling cattle, changing feeding patterns (feedlot), providing shade, improving airflow (feedlot), providing water mist, and controlling biting flies. Except for 11 June and 12 August 2002 which had an index < 26.1, all other evaluation dates shown in Table 5.7 presented heat stress index > 26.1. A regression equation relating the time cattle spent under the shade and weather variables (Table 5.9) included air temperature, wind speed, and temperature-humidity index in the model, but the $R^2$ was not high (0.49).
Table 5.6. Total time cattle spent per zone at different evaluations on rotationally and continuously stocked bahiagrass pastures during 2002 and 2003.

<table>
<thead>
<tr>
<th>Evaluation date</th>
<th>Zone 1</th>
<th>Zone 2</th>
<th>Zone 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>4 and 11 June 2002</td>
<td>142 b</td>
<td>101 a</td>
<td>475 a</td>
</tr>
<tr>
<td>26 June and 3 July 2002</td>
<td>269 a</td>
<td>113 a</td>
<td>334 b</td>
</tr>
<tr>
<td>12 and 19 August 2002</td>
<td>229 a</td>
<td>126 a</td>
<td>357 b</td>
</tr>
<tr>
<td>22 and 29 Sept. 2002</td>
<td>236 a</td>
<td>128 a</td>
<td>345 b</td>
</tr>
<tr>
<td>9 and 16 June 2003</td>
<td>148 b</td>
<td>93 a</td>
<td>345 b</td>
</tr>
<tr>
<td>30 June and 7 July 2003</td>
<td>246 a</td>
<td>124 a</td>
<td>338 b</td>
</tr>
<tr>
<td>15 and 22 August 2003</td>
<td>122 b</td>
<td>133 a</td>
<td>446 a</td>
</tr>
<tr>
<td>27 Sept. and 4 Oct. 2003</td>
<td>151 b</td>
<td>112 a</td>
<td>457 a</td>
</tr>
</tbody>
</table>

†Means followed by the same letter, lower case letters within a column and upper case letters within a row, do not differ (P>0.10) by the SAS least square mean test (PDIFF). SE = 30 min evaluation−1.

Table 5.7. Time cattle spent under the shade and environmental conditions at different evaluations on rotationally and continuously stocked bahiagrass pastures during 2002 and 2003.

<table>
<thead>
<tr>
<th>Evaluation date</th>
<th>Time spent under shade, min eval.−1</th>
<th>Average Temp. (°C)‡</th>
<th>Relative humidity (%)‡</th>
<th>Heat Stress Index3 (°C)‡</th>
</tr>
</thead>
<tbody>
<tr>
<td>4 and 11 June 2002</td>
<td>85 b†</td>
<td>33.0 and 26.8</td>
<td>52.5 and 76.8</td>
<td>28.3 and 25.3</td>
</tr>
<tr>
<td>26 June and 3 July 2002</td>
<td>203 a</td>
<td>28.4 and 31.9</td>
<td>70.2 and 57.0</td>
<td>26.2 and 27.9</td>
</tr>
<tr>
<td>12 and 19 August 2002</td>
<td>180 a</td>
<td>26.2 and 30.2</td>
<td>84.5 and 70.3</td>
<td>25.3 and 27.7</td>
</tr>
<tr>
<td>22 and 29 Sept. 2002</td>
<td>189 a</td>
<td>31.2 and 32.3</td>
<td>57.3 and 57.2</td>
<td>27.4 and 28.2</td>
</tr>
<tr>
<td>9 and 16 June 2003</td>
<td>93 b</td>
<td>31.5 and 29.4</td>
<td>60.0 and 76.2</td>
<td>27.9 and 27.5</td>
</tr>
<tr>
<td>30 June and 7 July 2003</td>
<td>189 a</td>
<td>31.7 and 32.4</td>
<td>62.3 and 58.5</td>
<td>28.2 and 28.4</td>
</tr>
<tr>
<td>15 and 22 August 2003</td>
<td>68 b</td>
<td>28.0 and 28.5</td>
<td>82.3 and 77.8</td>
<td>26.7 and 26.9</td>
</tr>
<tr>
<td>27 Sept. and 4 Oct. 2003</td>
<td>88 b</td>
<td>29.4 and 29.4</td>
<td>71.8 and 59.2</td>
<td>27.2 and 26.2</td>
</tr>
</tbody>
</table>

†Means followed by the same letter within a column do not differ (P>0.05) by the SAS least square mean test (PDIFF). SE = 30 min evaluation−1.
‡Average from 1000 to 1500 h. Heat Index scale (°C): normal <23.3; alert 23.9-25.6; danger 26.1-28.3; emergency >28.9 (Mader et al., 2000).

3Cattle Heat Stress Index was developed by the University of Oklahoma in conjunction with the Intermountain Fire Sciences Lab of the U.S. Forest Service and the formula is THI = tair – [0.55*(0.55*relh/100)]*(tair-58.8); where THI is Temperature-Humidity Index, tair is air temperature in Farenheit, and relh is percent relative humidity. Osborne, P. 2003. Managing Heat Stress Returns Dividends [Online]. Available from West Virginia University http://www.wvu.edu/~agexten/forglvst/heatstress.pdf (verified 12/21/2004).
Table 5.8. Total grazing time at different evaluations on rotationally and continuously stocked bahiagrass pastures during 2002 and 2003.

<table>
<thead>
<tr>
<th>Evaluation date</th>
<th>Zone 1</th>
<th>Zone 2</th>
<th>Zone 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>4 and 11 June 2002</td>
<td>27 a B</td>
<td>68 a B</td>
<td>295 a A</td>
</tr>
<tr>
<td>26 June and 3 July 2002</td>
<td>35 a C</td>
<td>75 a B</td>
<td>204 de A</td>
</tr>
<tr>
<td>12 and 19 August 2002</td>
<td>27 a B</td>
<td>64 a B</td>
<td>211 cde A</td>
</tr>
<tr>
<td>22 and 29 September 2002</td>
<td>23 a C</td>
<td>81 a B</td>
<td>247 bc A</td>
</tr>
<tr>
<td>9 and 16 June 2003</td>
<td>22 a B</td>
<td>56 a B</td>
<td>187 e A</td>
</tr>
<tr>
<td>30 June and 7 July 2003</td>
<td>22 a C</td>
<td>74 a B</td>
<td>226 bcd A</td>
</tr>
<tr>
<td>15 and 22 August 2003</td>
<td>32 a C</td>
<td>73 a B</td>
<td>259 ab A</td>
</tr>
<tr>
<td>27 Sept. and 4 Oct. 2003</td>
<td>35 a B</td>
<td>76 a B</td>
<td>285 a A</td>
</tr>
</tbody>
</table>

†Means followed by the same letter, lower case letters within a column and capital letters within a row do not differ (P>0.10) by the SAS least square mean test (PDIFF). SE = 15 min evaluation⁻¹.

Table 5.9. Regression equation, R², and P value of the time cattle spent under the shade and climate variables.

<table>
<thead>
<tr>
<th>Response variable</th>
<th>Equation†</th>
<th>R²</th>
<th>P value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Time spent under shade</td>
<td>( Y = -126.7 + 27.3T_{air} - 9.7W_{SP} - 15.7THI )</td>
<td>0.49</td>
<td>0.04</td>
</tr>
</tbody>
</table>

†Tair is average air temperature in °C, WSP is average wind speed in km h⁻¹, and THI is Temperature-Humidity Index (°C). These climate data refer to the average from 0700 to 1900 h of each evaluation day.

There was a treatment by zone interaction for the grazing time index, with a small linear increase for the index occurring in Zone 2 and a small linear decrease occurring in Zone 3, as length of the grazing period increased. No effect was observed in Zone 1 (Table 5.10). Perhaps of greater importance than these differences is the very narrow range in grazing time index (0.9 – 1.6) across zones and treatments. These data indicate that time cattle spent grazing in a zone was roughly proportional to the area encompassed by the zone. Thus the greater total time index observed for Zone 1 than Zones 2 and 3 of the longer grazing period rotational stocking and the continuous stocking treatments.
(Table 5.5) occurred due to non-grazing activities (e.g., time under shade and lounging) in Zone 1.

Table 5.10. Grazing time index during 12-h evaluation periods on different pasture zones of rotationally and continuously stocked bahiagrass pastures during 2002 and 2003.

<table>
<thead>
<tr>
<th>Treatment</th>
<th align="right">Zone 1</th>
<th align="right">Zone 2</th>
<th align="right">Zone 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rotational †</td>
<td align="right"></td>
<td align="right"></td>
<td align="right"></td>
</tr>
<tr>
<td>1 day</td>
<td align="right">1.0 A §</td>
<td align="right">0.9 A</td>
<td align="right">1.2 A</td>
</tr>
<tr>
<td>3 days</td>
<td align="right">1.1 A</td>
<td align="right">1.1 A</td>
<td align="right">0.9 A</td>
</tr>
<tr>
<td>7 days</td>
<td align="right">1.1 A</td>
<td align="right">1.0 A</td>
<td align="right">1.0 A</td>
</tr>
<tr>
<td>21 days</td>
<td align="right">1.2 AB</td>
<td align="right">1.6 A</td>
<td align="right">0.9 B</td>
</tr>
<tr>
<td>Effect ‡ (P value)</td>
<td align="right"></td>
<td align="right"></td>
<td align="right"></td>
</tr>
<tr>
<td>Linear</td>
<td align="right">(&gt; 0.10)</td>
<td align="right">(0.003)</td>
<td align="right">(0.06)</td>
</tr>
<tr>
<td>Continuous</td>
<td align="right">1.4 A</td>
<td align="right">1.4 A</td>
<td align="right">0.9 B</td>
</tr>
<tr>
<td>Rotational vs. Continuous (P value)</td>
<td align="right">0.41</td>
<td align="right">0.03</td>
<td align="right">&lt; 0.0001</td>
</tr>
</tbody>
</table>

†Length of grazing period.
‡Polynomial contrast for effect of length of grazing period of rotational treatments.
§Means followed by the same letter within a row do not differ (P > 0.10) by the SAS least squares mean test (PDIFF). SE = 0.2
¶Not significant (P > 0.10).
§Grazing time index = % total grazing time in each zone/% area occupied by the zone.

Soil Nutrient Concentration

A treatment by depth interaction occurred for soil N at the end of the 3-yr period. Linear increases in nitrate and total soil extractable N with increasing length of grazing period occurred at both depths (Table 5.11). The continuous High and 21-d rotational treatments generally presented similar soil N values, which were greater than the ones observed for the short-grazing period treatments, especially for the 0- to 8-cm depth. Considering that all treatments received the same amount of N fertilizer, treatment differences are likely due to the grazing management applied. The 21-d rotational and the
High had more animal time in each paddock which likely explain greater soil-N concentration for those treatments. Mathews et al. (1999) compared the effect of short (3-3.5 d) and long (20-22 d) grazing periods on the soil nutrient distribution using a similar zonal sampling. Those authors did not find any difference between grazing periods in terms of soil nutrient distribution, but that experiment was done over only 2 yr and the stocking rate was lower (1000 kg liveweight ha\(^{-1}\)) when compared to the present experiment (1800 kg liveweight ha\(^{-1}\)). In another study, Mathews et al. (1994a) comparing rotational stocking with short- and long-grazing periods vs. continuous stocking did not observe difference in terms of soil nutrient distribution among methods. In that research, however, the shade structures and waterers were moved every 2 d along the length of Zone 1 in all treatments in order to improve excreta distribution. In the current study, shade and watering points remained fixed throughout the study, much like one might expect to find in producers’ pastures. Moving shades to improve excreta distribution is a recommended practice (Ellington and Wallace, 1991), however, it is not likely to be adopted by the farmers. In the current study, total extractable N and NH\(_4\)-N were greater at the 0- to 8-cm depth than for 8 to 23 cm, but NO\(_3\)-N did not differ between these two depths (Table 5.11). Nitrate is more mobile in the soil profile while NH\(_4\) interacts with soil colloids due to its positive charge (Tinker and Nye, 2000; Brady and Weil, 2002). Since SOM is greater at shallower depths, NH\(_4\)-N released after the ammonification reaction likely was adsorbed by negative charges on soil particles, presenting higher values at the 0- to 8-cm depth.
Table 5.11. Soil N concentration at different soil depths of rotationally and continuously stocked bahiagrass pastures after 3 yr of grazing. Data are means across three zones and two replicates.

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Nitrate Nitrogen</th>
<th>NH₄ Nitrogen</th>
<th>Total Extractable N</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0-8 cm 8-23 cm</td>
<td>0-8 cm 8-23 cm</td>
<td>0-8 cm 8-23 cm</td>
</tr>
<tr>
<td>Rotational†</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1-day</td>
<td>0.7 0.2 0.93</td>
<td>5.6 3.4 0.05</td>
<td>6.3 3.6 0.02</td>
</tr>
<tr>
<td>3-days</td>
<td>2.8 0.5 0.39</td>
<td>3.4 2.4 0.09</td>
<td>6.1 2.8 0.01</td>
</tr>
<tr>
<td>7-days</td>
<td>3.9 2.4 0.42</td>
<td>2.5 1.3 0.09</td>
<td>6.4 3.7 0.02</td>
</tr>
<tr>
<td>21-days</td>
<td>7.7 3.4 0.15</td>
<td>7.2 4.0 0.02</td>
<td>14.9 7.4 &lt;0.01</td>
</tr>
<tr>
<td>Effect‡ (P value)</td>
<td>Linear (&lt;0.01)</td>
<td>Linear (0.04)</td>
<td>NS§ (0.09)</td>
</tr>
<tr>
<td>Continuous</td>
<td>5.3 2.1 0.10</td>
<td>9.4 2.2 &lt;0.01</td>
<td>14.7 4.3 &lt;0.01</td>
</tr>
<tr>
<td>Rot vs. Cont (P value)</td>
<td>0.09 0.61</td>
<td>0.07 0.69</td>
<td>0.07 0.81</td>
</tr>
</tbody>
</table>

†Length of grazing period.
‡Polynomial contrast for effect of length of grazing period of rotational treatments
§Not significant (P > 0.10)
*Level of P for comparison of the two soil depths within a nutrient and a management intensity treatment.

A zone by depth interaction also occurred for soil N. Total-extractable N concentrations at the 0- to 8-cm depth were greatest in Zone 1, but there were no zone differences observed at the 8- to 23-cm depth (Table 5.12). The total-extractable N concentrations obtained in this research are lower than the ones reported by Mathews et al. (1999) for areas within 15 m of the shade, and differences are likely due to different soil characteristics between the two sites.

Treatments did not differ for soil P, K, and Mg concentrations, but pasture zone interacted with soil depth (Table 5.13). Phosphorus, K, and Mg concentrations were greater in Zone 1 at the 0- to 8-cm depth, but not at the 8- to 23-cm depth (Table 5.13), probably as a result of excreta deposition by cattle on the soil surface. Phosphorus and Mg are excreted mainly through dung and higher density of dung deposition in Zone 1 in
21-d and continuous High treatments may explain the higher soil nutrient concentration in those zones. Similar results were obtained by West et al. (1989) who suggested that a distinct zone of nutrient enhancement within 20 m of the water source should be either avoided or sampled separately when sampling pastures for fertilizer recommendations.

Table 5.12. Effect of pasture zones on soil N concentration at different soil depths in bahiagrass pastures grazed using different stocking methods for 3 yr. Data are means across three treatments and two replicates.

<table>
<thead>
<tr>
<th>Zone</th>
<th>Nitrate Nitrogen</th>
<th></th>
<th></th>
<th>NH₄ Nitrogen</th>
<th></th>
<th></th>
<th>Total Extractable N</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0-8 cm</td>
<td>8-23 cm</td>
<td>P</td>
<td>0-8 cm</td>
<td>8-23 cm</td>
<td>P</td>
<td>0-8 cm</td>
<td>8-23 cm</td>
</tr>
<tr>
<td>1</td>
<td>5.4 a‡</td>
<td>1.9 a</td>
<td>0.14</td>
<td>8.2 a</td>
<td>2.2 a</td>
<td>&lt;0.01</td>
<td>13.7 a</td>
<td>4.1 a</td>
</tr>
<tr>
<td>2</td>
<td>2.5 b</td>
<td>2.3 a</td>
<td>0.89</td>
<td>2.6 b</td>
<td>4.0 a</td>
<td>0.35</td>
<td>5.1 b</td>
<td>6.3 a</td>
</tr>
<tr>
<td>3</td>
<td>4.3 a</td>
<td>0.9 a</td>
<td>0.07</td>
<td>6.0 a</td>
<td>1.7 a</td>
<td>&lt;0.01</td>
<td>10.3 b</td>
<td>2.7 a</td>
</tr>
</tbody>
</table>

† Level of P for comparison of the two soil depths within a nutrient and a management intensity treatment.
‡ Means within a column followed by the same letter are not different (P>0.10).

Table 5.13. Effect of pasture zone on soil P, K, and Mg concentration at different soil depths in bahiagrass pastures grazed using different stocking methods for 3 yr. Data are means across three treatments and two replicates.

<table>
<thead>
<tr>
<th>Zone</th>
<th>Phosphorus</th>
<th></th>
<th></th>
<th>Potassium</th>
<th></th>
<th></th>
<th>Magnesium</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0-8 cm</td>
<td>8-23 cm</td>
<td>P</td>
<td>0-8 cm</td>
<td>8-23 cm</td>
<td>P</td>
<td>0-8 cm</td>
<td>8-23 cm</td>
</tr>
<tr>
<td>1</td>
<td>17 a‡</td>
<td>16 a</td>
<td>0.70</td>
<td>181 a</td>
<td>107 a</td>
<td>0.07</td>
<td>171 a</td>
<td>118 a</td>
</tr>
<tr>
<td>2</td>
<td>8 b</td>
<td>14 a</td>
<td>0.07</td>
<td>77 b</td>
<td>74 a</td>
<td>0.95</td>
<td>127 ab</td>
<td>124 a</td>
</tr>
<tr>
<td>3</td>
<td>6 b</td>
<td>13 a</td>
<td>0.03</td>
<td>67 b</td>
<td>77 a</td>
<td>0.80</td>
<td>95 b</td>
<td>141 a</td>
</tr>
</tbody>
</table>

† Level of P for comparison of the two soil depths within a nutrient and a management intensity treatment.
‡ Means within a column followed by the same letter are not different (P>0.10).

**Dung Spatial Distribution**

The dung spatial distribution evaluation showed that the stocking strategies have different degrees of clustering, and no evaluation date effect was observed. The 1-d treatment presented the lowest Dispersion Index (DI), which means that the variance was closer to the mean than in the other treatments. Therefore, less clustering and more uniformity in the dung distribution occurred for the 1-d treatment, which followed a
Poisson distribution model. Both the 7-d and High treatment followed a negative binomial distribution model, which describes the clustering and overlaying of dung pads. Thus, the 1-d promoted a more uniform dung distribution than the 7-d and High treatment. Peterson and Gerrish (1996) suggested that rotational stocking with short grazing periods and high stocking densities enhance uniformity of excreta distribution, and the current study supports this conclusion.

Table 5.14. Dispersion Index and distribution models followed by the dung spatial distribution in Pensacola bahiagrass pastures managed using different strategies.

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Dispersion Index ‡</th>
<th>Distribution Model</th>
</tr>
</thead>
<tbody>
<tr>
<td>1-d</td>
<td>1.12 a †</td>
<td>Poisson</td>
</tr>
<tr>
<td>7-d</td>
<td>1.67 c</td>
<td>Negative Binomial</td>
</tr>
<tr>
<td>High</td>
<td>1.31 b</td>
<td>Negative Binomial</td>
</tr>
</tbody>
</table>

†Means within a column followed by the same letter are not different (P > 0.05) by the LSMEANS procedure from SAS.
‡Dispersion Index is calculated by dividing the variance by the mean of dung pads distributed in 100 quadrats per pasture.

Conclusions

Stocking method influenced animal behavior and soil nutrient distribution. Short-grazing periods promoted greater uniformity in time spent by cattle and soil nutrient redistribution among pasture zones when compared to long-grazing periods. The excreta distribution in the short-grazing period rotational treatment (1 d) followed a Poison distribution model while the distribution in the 7-d rotational and the continuous (High) followed a negative binomial distribution, further supporting the conclusion that the short-grazing period treatment resulted in more uniform distribution. Continuous stocking presented results similar to rotational stocking with a 21-d grazing period, showing greater density of excreta deposition and greater accumulation of soil N in areas closest to
shade and water. These results show greater potential for grazing management practices to affect nutrient redistribution in pastures than previous work by Mathews et al. (1994a), likely because the shade structures were not moved during the current experiment, which is a practice commonly observed among producers. In the work by Mathews et al. (1994a), shade and water locations were systematically moved every 2 d for all treatments, reducing the impact of grazing management. Data from the current study, therefore, support the conclusion that rotational stocking with short grazing periods is a potential practice to improve nutrient distribution in bahiagrass pastures. Soil nutrient accumulation occurred at a shallow depth (zero- to 8-cm) but not deeper in the soil profile (8- to 23-cm) in zones closer to shade and water.

Environment may affect animal behavior and, as a result, nutrient distribution. Animals spent more time in lounging areas during warmer days, leading to greater excreta deposition in small pasture areas where the shade and water were located. Besides shade and watering areas, lounging sites are also potential areas for nutrient enrichment due to higher density of excreta deposition. Adapted animals may enhance uniformity of excreta deposition by spending less time in lounging areas.
CHAPTER 6
LITTER DYNAMICS IN GRAZED PENSACOLA BAHIAGRASS PASTURES MANAGED AT DIFFERENT INTENSITIES. I. DEPOSITION AND DECOMPOSITION

Introduction

Plant litter is an important pathway of nutrient return to the soil in grazed ecosystems. In extensively managed and utilized pastures in many warm-climate areas, nutrient dynamics in the plant litter pool have a major influence on pasture productivity and persistence. When compared to nutrients from animal excreta, those from litter are more evenly distributed across the pasture (Rezende et al., 1999), but nutrients in litter are not as readily available to plants (Haynes and Williams, 1993). In pasture ecosystems, the deposition and decomposition of below- and above-ground plant litter during the growing season exert a continuous influence on nutrient supply to plants. This contrasts with row-crop systems in which the influence of litter occurs primarily as periodic pulses.

Management intensity affects the pathway of nutrient return on pastures. Increasing stocking rate (SR) at a given forage growth rate increases the proportion of nutrient returned via excreta vs. litter (Thomas, 1992). The rate of flow of nutrients among nutrient pools increases with greater SR because the nutrients in dung and urine are more readily available than in litter (CIAT, 1990; Haynes and Williams, 1993; Cantarutti and Boddey, 1997; Braz et al., 2003). Nitrogen fertilization may also play a role by increasing litter deposition, litter quality, and litter decomposition. Litter quality may be defined as a conjunction of indicators (e.g., low C:N and lignin:N ratios) that when combined enhance litter decomposition.
There is a lack of information regarding management intensity effects on litter dynamics, particular in sub-tropical and tropical environments. Thus, the objective of this study was to determine the effect of management intensity, defined in terms of N fertilization and SR, on litter production and litter decomposition in continuously stocked ‘Pensacola’ bahiagrass (*Paspalum notatum* Flügge) pastures.

**Material and Methods**

**Experimental Site**

A grazing experiment was conducted at the Beef Research Unit, northeast of Gainesville, FL, at 29°43’ N lat on Pensacola bahiagrass pastures. Soils were classified as Spodosols (sandy siliceous, hyperthermic Ultic Alaquods from the Pomona series or sandy siliceous, hyperthermic Aeric Alaquods from the Smyrna series) with average pH of 5.9. Mehlich-I extractable soil P, K, Ca, and Mg average concentrations at the beginning of the experiment were 5.3, 28, 553, and 98 mg kg$^{-1}$, respectively.

**Treatments and Design**

Treatments were imposed during 2003 and 2004 and included three management intensities of continuously stocked bahiagrass pastures. These intensities were defined in terms of combinations of SR and N fertilization and were Low (40 kg N ha$^{-1}$ yr$^{-1}$ and 1.2 animal units [AU, one AU = 500 kg live weight] ha$^{-1}$ target SR), Moderate (120 kg N ha$^{-1}$ yr$^{-1}$ and 2.4 AU ha$^{-1}$ target SR), and High (360 kg N ha$^{-1}$ yr$^{-1}$ and 3.6 AU ha$^{-1}$ target SR). These treatments were selected because Low approximates current bahiagrass management practice in Florida cow-calf systems. Moderate represents the upper range of current producer practice, and High is well above what is currently in use. Actual SR was calculated based on initial and final live weights during each grazing season. These SR were 1.4, 2.8, and 4.1 AU ha$^{-1}$ in 2002, and 1.3, 2.6, and 4.0 AU ha$^{-1}$ in 2003 for Low,
Moderate, and High treatments, respectively. These values deviated from target values because initial heifer liveweight was greater than anticipated. A randomized complete block design was used and each treatment was replicated twice.

Two crossbred (Angus x Brahman) yearling heifers were assigned to each experimental unit. Pasture area varied according to treatment, decreasing from 1 to 0.5 to 0.33 ha as the management intensity increased from Low to Moderate to High (Chapter 3). Artificial shade (3.1 m x 3.1 m) was provided on each of the experimental units and cattle had free-choice access to water and a salt-based mineral mixture. The water troughs were always located under the artificial shade, and the mineral troughs were repositioned several times each week at random locations throughout the pasture. Nitrogen fertilization dates and rates were described in Chapter 3.

Response Variables

Existing litter, deposited litter, and herbage mass

Litter production was measured based on the technique described by Bruce and Ebersohn (1982) and also used by Thomas and Asakawa (1993) and Rezende et al. (1999). Litter was defined as dead plant material on the surface of the soil, no longer attached to the plant. Existing litter in the pasture was determined at 28-d intervals by sampling six circular quadrats (0.55 m²) in areas that represented the average herbage mass in each pasture. The existing litter contained within each quadrat was raked and collected, dried (72 h at 60°C), and weighed. After clearing the sites of litter, exclusion cages were placed there, and 14 d later the deposited litter within the cleared area was similarly collected, dried, and weighed. In order to correct for sand contamination, final weights were expressed on an organic matter (OM) basis. While raking the sites to recover either existing or deposited litter, some green material was collected along with
the litter. Correction for green herbage was performed by separating green material from litter. Every 28 d, six new 0.55-m² areas were chosen in each pasture for measurement of existing and deposited litter. This procedure was repeated five times in each grazing season. The evaluation dates are listed in Table 6.1. Litter, within litter type (existing litter and deposited litter), from the six caged sites per pasture was composited for each evaluation date. Dry matter (DM) and OM analyses were performed using the procedure described by Moore and Mott (1974). Herbage mass of the pastures was estimated using the same procedures described in Chapter 3.

Table 6.1. Existing and deposited litter evaluation dates during 2002 and 2003.

<table>
<thead>
<tr>
<th>Evaluation</th>
<th>2002</th>
<th>2003</th>
</tr>
</thead>
<tbody>
<tr>
<td>Existing litter</td>
<td>12 June; 10 July; 6 Aug; 4 Sep; 2 Oct</td>
<td>4 June; 2 July; 30 July; 27 Aug; 24 Sep</td>
</tr>
<tr>
<td>Deposited litter</td>
<td>27 June; 24 July; 21 Aug; 18 Sep; 16 Oct</td>
<td>18 June; 16 July; 13 Aug; 10 Sep; 8 Oct</td>
</tr>
</tbody>
</table>

**Litter decomposition**

Litter decomposition was estimated using a litter bag technique. For the purposes of this measurement, litter was defined as the senescent leaves still attached to the plant. The reason for this approach was to avoid collecting litter on the ground that was already degraded to an unknown extent. The litter was obtained by cutting standing herbage from each of the six experimental units during May of each grazing season. Herbage from each experimental unit was kept separate from the others and was oven-dried (60°C for 72 h) but not ground so that surface area remained as similar as possible to the original litter. Green and senescent herbage was hand-separated thereafter, and the senescent fraction (6 g per bag) was placed into polyester bags with 75 µm mesh size and measuring 15 x 20 cm. The bags were heat sealed and incubation times were 0, 4, 8, 16, 32, 64, and 128 d.
Each incubation time, with the exception of Day zero, was replicated six times within each experimental unit, resulting in 36 bags per experimental unit. Empty bags were also incubated for the different periods in order to correct the bag weight after incubation. Litter bags were placed on the ground in sets of six, one for each incubation time, and covered with existing litter from that experimental unit. The sites where bags were placed were chosen to represent the average herbage mass of the pasture, based on disk settling height. Cages were placed over the sites where each set of six bags was located to protect them from grazing animals. Thus, a total of six cages per pasture were used for the litter bag experiment, one cage for each complete set of incubation times. Herbage inside the cage was clipped biweekly throughout the 128-d period in order to maintain the herbage height inside the cage as close as possible to the average canopy height of the pasture, and the clipped material was removed. The 128-d periods were from 22 July to 27 Nov. 2002 and 23 July to 28 Nov. 2003.

At the end of each incubation time, the six litter bags per pasture for that time were collected, oven-dried (60°C for 72 h), and composited within an experimental unit. The composited samples were milled to pass a 1-mm screen and analyzed for DM and OM using the procedure described by Moore and Mott (1974). Percentage of remaining biomass was calculated based on the OM content prior to and after the incubation period.

The double exponential model (Weider and Lang, 1982) was used to fit the biomass decay curve using Proc Nlin from SAS® Institute (SAS Inst. Inc., 1996), and it was described by Equation 1:

\[ \chi = Ae^{-kt} + (1 - A)e^{-kt} \]  
(Equation 1)

Where:
\[ \chi = \text{Proportion of remaining biomass at time } t \]

\[ A = \text{Constant} \]

\[ k_1 \text{ and } k_2 = \text{Decay constants} \]

After solving the above equation, the output parameters (A, k_1, and k_2) of each experimental unit were used to calculate their respective relative decomposition rate (k) using Equation 2 described by Weider and Lang (1982):

\[
k = \frac{-k_1 A e^{-k_1 t} - k_2 (1 - A) e^{-k_2 t}}{A e^{-k_1 t} + (1 - A) e^{-k_2 t}} \quad \text{(Equation 2)}
\]

The time period used to calculate k was 14 d (approximates the length of time that the deposited litter stayed on the ground) for the estimation of the monthly litter deposition rate and 128 d (the total length of the incubation) for treatment comparisons across the entire season.

**Rate of litter deposition**

The estimation of the rate of litter deposition was performed using the approach described by Rezende et al. (1999) with some modifications in respect to the use of the relative rate of decomposition. According to Rezende et al. (1999), the litter on the ground at any time is a function of the litter deposition minus the litter decomposition that occurred within a given period. Therefore, in the case of litter deposited in an area which had been cleared of litter, the quantity of litter (dX) present after the increment of time ‘dt’ is:

Litter on the ground = litter deposited – disappeared litter, or:

\[
dX = L dt - kX dt \quad \text{(Equation 3)}
\]

Where:

\[ L \text{ is the true daily rate of litter deposition in g m}^{-2} \text{ d}^{-1}. \]
X is the quantity of litter on the ground at any time (g m\(^{-2}\)).

k is the relative decomposition rate.

dt is the period of time after clearing the site of existing litter.

The daily rate of litter deposition was calculated using deposited litter 14 d after an area was cleared as X. The relative decomposition rate used was obtained from the decomposition model for the litter bag data and using 14 d as the incubation period.

**Statistical Analyses**

Herbage mass, existing litter, and litter deposition were organized by evaluation period within each year and analyzed using a repeated measures procedure in Proc Mixed from SAS (SAS Inst. Inc., 1996). The LSMEANS procedure was used to compare treatment means.

For the litter bag study, after fitting the double exponential model for each experimental unit within each grazing season, the output parameters were analyzed using Proc Mixed from SAS® with year considered a fixed effect. Means were compared using the LSMEANS procedure of SAS®.

**Results and Discussion**

**Herbage Mass**

There was a treatment by evaluation date interaction for herbage mass (Figure 6.1). Low and Moderate treatments followed a similar trend of increasing herbage mass through September, but herbage mass in the High treatment did not change (P > 0.10) throughout the grazing season.

Changes in herbage mass reflect the net result of different processes: herbage growth, herbage senescence, and animal intake. Bahiagrass growth rate reaches its peak by mid-summer (Beaty et al., 1963; Gates et al., 2001), and the growth rate slows as the
season progresses into the fall. Beginning in August, herbage mass was greater on Low than High pastures, but High and Moderate treatments differed only in June (Figure 6.1). In the High treatment, the greater herbage accumulation rate (Chapter 3) than in Low was compensated for by a three-fold higher SR (Figure 6.1). Because of lower SR in the Low and Moderate treatments, however, herbage mass increased through September, at which time slowing herbage accumulation rates resulted in a decrease in herbage mass.

![Figure 6.1. Effect of management intensity and evaluation date on herbage mass of grazed Pensacola bahiagrass pastures during 2002-2003. Means followed by same letter, within an evaluation date, are not different (P>0.10) by the SAS LSMEANS test. SE = 490 kg DM ha\(^{-1}\).](image)

**Existing Litter**

There was management intensity by evaluation date interaction for existing litter (Figure 6.2). The High management intensity had least existing litter in June and July, and greatest existing litter, along with the Low treatment, by September and October.
Existing litter is the net result of the deposited litter and the litter decomposed within a given period of time. When the deposition of litter is greater than its degradation, litter accumulates. When degradation is greater, existing litter decreases. Less existing litter in the High treatment at the beginning of the season was likely due to greater litter decomposition rates during the cool season and the spring prior to initiation of grazing. Higher N fertilization and better quality of the deposited litter from the previous grazing season (same treatments were imposed on these pastures in 2001, the year preceding the start of this study in 2002) may explain higher decomposition rates for the High treatment. Existing litter was high for the Low treatment during the majority of the grazing season, and the lower SR for Low compared to other treatments may partially explain this result. Lower SR (e.g., on the Low treatment) and the greater herbage mass often cause more litter to be deposited due to a lesser forage utilization rate and an increase in mature, senescent herbage (Reardon and Merril, 1976; Thomas, 1992). Rezende et al. (1999) found a significant increase in litter deposition when SR was halved from 4 to 2 animals ha⁻¹. In the current experiment, however, there were other factors influencing the response. Decreasing SR was accompanied by decreasing N fertilization, resulting in lower litter quality and slowing decomposition in the Low treatment (Chapter 7). In addition, the range in herbage mass across treatments was relatively small because as SR increased so did N fertilization rate.

Accumulation of existing litter (Figure 6.2) started later for the Low and Moderate treatments (September) when compared to the High treatment (July). This occurred because the rate of litter deposition was greater at the beginning of the season for High than for Low and Moderate (Figure 6.3). Despite the variation within the season, existing
litter did not differ between years (P > 0.54), and averaged 1570 kg ha\(^{-1}\) across treatments. Rezende et al. (1999) reported values of existing litter ranging from 800 to 1500 kg DM ha\(^{-1}\) in creeping signalgrass \([Brachiaria humidicola\) (Rendle) Schweick.\] pastures in pure stand or mixed with desmodium \([Desmodium heterocarpon\) (L.) DC. subsp. \(ovalifolium\) (Prain) Ohashi] or tropical kudzu \([Pueraria phaseoloides\) (Roxb.) Benth]. The same authors also found seasonal effects on amount of existing litter.

![Figure 6.2](image-url)  
**Figure 6.2.** Effect of management intensity and evaluation date on existing litter of grazed Pensacola bahiagrass pastures during 2002-2003. Means followed by same letter, within each evaluation date, are not different (P>0.10) by the SAS LSMEANS test. SE = 356 kg OM ha\(^{-1}\).

**Litter Deposition Rate**

There was a treatment by evaluation date interaction for litter deposition rate (Figure 6.3). Interaction occurred because there were no differences among treatments in September, but at all other evaluation dates treatment differences did occur (Figure 6.3).
High had greater litter deposition rates than Moderate at all dates except in September. Low had a lesser litter deposition rate than High only in July. The consistently high rates of litter deposition throughout the season in the High treatment were reflected in a gradual increase in existing litter for the High treatment (starting from August, Figure 6.2). The average (across treatments and dates) litter deposition rate for the grazing season was 27 kg OM ha\(^{-1}\) d\(^{-1}\), which multiplied by the grazing season length (168 d) results in approximately 4540 kg OM ha\(^{-1}\) deposited during this period. Collected litter was mainly leaves, sheath, and to a lesser extent the rhizomes. Thomas and Asakawa (1993) reported values ranging from 2830 to 11800 kg DM ha\(^{-1}\) of litter deposited from May to December in creeping signalgrass and gambagrass (*Andropogon gayanus* Kunth) pastures, respectively.

![Figure 6.3](image)

Figure 6.3. Effect of management intensity and evaluation date on rate of litter deposition on grazed Pensacola bahiagrass pastures during 2002-2003. Means followed by the same letter, within each evaluation date, are not different (P>0.10) by the SAS LSMEANS test. SE = 6.8 kg OM ha\(^{-1}\) d\(^{-1}\).
Litter Decomposition Rate

The relative decomposition rate (k) of the litter during the 128-d incubation trial increased with management intensity (Figure 6.4). Nitrogen fertilization has been reported to increase residue mineralization rate (Kalburjti et al., 1997; Lupwayi and Haque, 1999). Increasing SR increases the proportion of nutrients returning to the pasture via excreta (Thomas, 1992), and those nutrients are more available than those returned via C4 grass litter (Haynes and Williams, 1993). Therefore, litter decomposition rates are also expected to be greater when higher SR is adopted.

Relative decomposition rate depends on litter quality, soil temperature, soil moisture, and amount of nutrients available. This includes the proportion of the total C remaining in the litter, as k is greater at the beginning of the incubation period (Gijsman et al., 1997). In the current study, litter biomass loss over the 128-d incubation followed a double exponential model (Figure 6.5). Loss was rapid at the beginning of the incubation; approximately 15% of the litter biomass was lost after only 8 d. The k value averaged 0.0148 g g⁻¹ d⁻¹ during the first 14 d vs. 0.0022 g g⁻¹ d⁻¹ over the entire 128 d of incubation. The fast rate of decay early in the period results from the decomposition of more soluble compounds, but the k value tends to stabilize, or decrease slowly, after the more soluble compounds are decomposed (Heal et al., 1997). Decay rate slowed after this initial period, and biomass loss after 128 d of incubation ranged from 40 to 60%. These values are similar to those reported by Deshmukh (1985) using the litter bag technique to estimate C4 grass litter decomposition in Kenya. Sollenberger et al. (2002) reviewed k in the literature and found values for different tropical grasses ranging from 0.0020 g g⁻¹ d⁻¹ in dictyoneura [Brachiaria dictyoneura (Fig. & De Not.) Stapf] (Thomas and Asakawa, 1993) to 0.0174 g g⁻¹ d⁻¹ in ‘Aruana’ guineagrass (Panicum maximum Jacq.; Schunke,
1998). The $k$ values for tropical legumes ranged from $0.0017 \text{ g g}^{-1} \text{ d}^{-1}$ in desmodium (Thomas and Asakawa, 1993) to $0.0603 \text{ g g}^{-1} \text{ d}^{-1}$ in *Arachis repens* Handro (Ferreira et al., 1997). These values originated from trials in the summer rainy season, however, different incubation periods, different approaches used to obtain the incubation material, and varied environmental conditions across sites make comparison difficult.

Considering the $k$ values obtained after 128 d of incubation, the litter half-life in the Low treatment was 433 d while the litter half-life in the High treatment was 231 d. This higher turnover rate observed for the litter from the High management intensity results in greater nutrient supply from litter in the High treatment but also less capacity to immobilize nutrients. Although litter decomposition rates for DM varied among treatments, the output parameters from the double exponential model were similar ($P > 0.10$). These results, however, need to be linked with litter production in order to provide a better understanding of the contributions of the litter pool in terms of supply and immobilization of nutrients.

![Figure 6.4. Litter relative decomposition rate on Pensacola bahiagrass pastures managed at a range of intensities during 2002-2003. Means with the same letter are not different by the LSMEANS test ($P > 0.10$). SE = 0.0008 g g$^{-1}$ d$^{-1}$.](image)
Figure 6.5. Litter biomass remaining on Pensacola bahiagrass pastures managed at a range of intensities during 2002-2003. Pearson correlation coefficient = 0.91.

**N Returned Via Litter: Immobilized vs. Mineralized**

A perspective on the importance of the litter pool in terms of N immobilization and mineralization was obtained by linking the litter deposition results to the N-release curves (Chapter 7). Considering an average rate of litter deposition of 27 kg ha\(^{-1}\) d\(^{-1}\) for 2002 and 2003, and litter N concentration of 12.7, 14.3, and 21.6 g kg\(^{-1}\) for Low, Moderate, and High (Chapter 7), respectively, the amount of N returned through the litter pool was estimated for a period of 140 d. Nitrogen released during this period by the litter pool was estimated using the decomposition parameters for N in 2003 (\(B_0 = 0.9338\) and \(k = 0.00287\), which are the single exponential model parameters). The total N released is the sum of the N released during a 140-d period, calculated in 10 cycles of 14 d. Because litter first deposited had 140 d to decompose while the litter deposited during the 10\(^{th}\)
cycle had only 14 d, different extents of decomposition were accounted for when the final amount of N released was estimated.

The results of this estimation are shown in Figure 6.6. Nitrogen immobilized and mineralized by the litter pool increased with management intensity. The N contribution by the above-ground litter pool to the pasture was not large, ranging from 12 to 20 kg N ha\(^{-1}\) (140 d\(^{-1}\)). The amount of recalcitrant N was greatest in the High treatment where 83 kg N ha\(^{-1}\) was returned through the litter but only 20 kg N ha\(^{-1}\) was mineralized (Figure 6.6). This shows the importance of the litter as a buffering pool (Wedin, 1996), potentially reducing N losses to the environment in highly fertilized pasture systems.

Synchrony, i.e., matching the supply of nutrients via residue decomposition and nutrient uptake by the crop, is a way to maximize nutrient-use efficiency and has been reviewed in the literature (Myers et al., 1994; Myers et al., 1997). Lack of synchrony is of concern in two situations: when the supply comes too late for the demand, and when the supply comes earlier than demand (Myers et al., 1997). In row-crop systems, asynchrony is more likely because of the relatively narrow window for supply and demand to coincide. In warm-climate perennial pastures, however, the root system is present year-round and can take up nutrients whenever they are available. Also, residue deposition is distributed more uniformly throughout the year as opposed to occurring in short-term pulses of nutrients. The small amount of nutrient supplied by the above-ground plant litter, however, reinforces its importance as a buffering pool in addition to being a nutrient supplier to the pasture.
Figure 6.6. Estimation of the N returned through the litter and the N actually released to Pensacola bahiagrass pastures managed at a range of intensities.

Conclusions

Management intensity altered litter dynamics in continuously stocked Pensacola bahiagrass pastures. Herbage mass increased as the season progressed for Low and Moderate treatments, but not for High. Lower management intensity generally resulted in greater existing litter, but increasing management intensity from Low to High altered litter deposition and decomposition rates, and seasonal fluctuations in existing litter occurred as a result of the balance between the two. Existing litter was greater for all treatments at the beginning and at the end of the grazing season compared to mid-season, but after declining following the onset of grazing it started to re-accumulate earlier in the season for the High treatment, because of earlier peaks in litter deposition rate for that treatment. Increasing management intensity reduced the amount of existing litter at the
beginning of the grazing season likely due to greater rates of litter decomposition between seasons in more intensive systems. Although the pastures were not grazed between grazing seasons, treatments applied during the grazing season likely had some effect on litter dynamics between seasons. At the end of the season, greater litter deposition than decomposition rates resulted in litter re-accumulation for all treatments. In terms of nutrient supply, the above-ground plant litter supplies relatively small quantities of N for plant growth, but it acts as an important buffering pool by immobilizing the N and mineralizing it later, reducing potential N losses, particularly in an N-rich environment. Changes in the litter dynamics as a result of an applied management practice affect the amount and form of nutrients returning to the soil and have implications not only in the supply of nutrients to the plants but also in the loss of nutrients to the environment.
Introduction

Litter quality and decomposition play a major role in nutrient dynamics in pasture ecosystems. Immobilization and mineralization processes are directly linked to litter quality, and they are important determinants of the availability of nutrients to pasture plants. A high litter quality is defined as the litter that undergoes faster decomposition. This quality may be monitored by indicators such as C:N, lignin:N, and C:P ratios. The lower they are, the faster the decomposition is. Litter of C₄ grasses is low in quality which results in potential N immobilization (Thomas and Asakawa, 1993), which in turn may lead to pasture degradation in low N-input systems (Rezende et al., 1999). In contrast, litter may play an important role in immobilizing nutrients and reducing nutrient losses to the environment in highly fertilized pastures (Wedin, 1996). Litter quality is often characterized based on its concentration of C, N, P, lignin, polyphenols, and their ratios (Heal et al., 1997; Thomas and Asakawa, 1993), and these litter quality indicators are related to the nutrient mineralization and immobilization processes (Palm and Rowland, 1997).

Nitrogen fertilization and stocking rate may affect not only the amount of litter produced but also its decomposition rates. Greater litter quality, because of higher nutrient uptake and greater availability of soil nutrients in fertilized systems, may increase litter turnover resulting in greater nutrient supply to the pasture via litter
Stocking rate (SR) may also affect litter decomposition rates by altering soil nutrient availability (Thomas, 1992), and by modifying sward structure creating a different microclimate (Hirata et al., 1991). Therefore, management practices affect nutrient dynamics in pasture ecosystems, but little attention has been given to this topic in grazing trials (Mathews et al., 1994). Thus, the objective of this study was to evaluate the effect of pasture management intensity, defined in terms of N fertilization and SR, on above-ground plant litter nutrient dynamics and litter quality.

**Material and Methods**

**Experimental Site**

A grazing experiment was performed at the Beef Research Unit northeast of Gainesville, FL, at 29°43’ N lat on ‘Pensacola’ bahiagrass (*Paspalum notatum* Flügge) pastures. Soils were classified as Spodosols (sandy siliceous, hyperthermic Ultic Alaquods from the Pomona series or sandy siliceous, hyperthermic Aeric Alaquods from the Smyrna series) with average pH of 5.9. Mehlich-I extractable soil P, K, Ca, and Mg average concentrations at the beginning of the experiment were 5.3, 28, 553, and 98 mg kg⁻¹, respectively.

**Treatments and Design**

This experiment was conducted during 2002 and 2003 and tested the effect of three management intensities of continuously stocked bahiagrass pastures on litter nutrient disappearance and litter quality. Management intensities were defined in terms of combinations of stocking rate and N fertilization.

The three management intensities tested were Low (40 kg N ha⁻¹ yr⁻¹ and 1.2 animal units [AU, one AU = 500 kg live weight] ha⁻¹ target stocking rate), Moderate (120 kg N ha⁻¹ yr⁻¹ and 2.4 AU ha⁻¹ target stocking rate), and High (360 kg N ha⁻¹ yr⁻¹ and 3.6
AU ha\(^{-1}\) target stocking rate). These treatments were selected because Low approximates current bahiagrass management practice in Florida cow-calf systems. Moderate represents the upper range of current producer practice, and High is well above what is currently in use. Actual SR was calculated based on initial and final live weights during each grazing season. These SR were 1.4, 2.8, and 4.1 AU ha\(^{-1}\) in 2002, and 1.3, 2.6, and 4.0 AU ha\(^{-1}\) in 2003 for Low, Moderate, and High treatments, respectively. These values deviated from target values because initial heifer liveweight was greater than anticipated. A randomized complete block design was used and each treatment was replicated twice. Animal management, N fertilization, and facilities were described in Chapter 6.

**Response Variables**

**Existing litter and deposited litter**

Litter quality was characterized in two experiments. In the first experiment, existing litter in the pasture was sampled at 28-d intervals from circular quadrats (0.55 m\(^{2}\)) in areas that represented the average herbage mass of each pasture. Six quadrats were placed per pasture. The existing litter contained within each quadrat was raked, collected, and dried (72 h at 60\(^{\circ}\)C). After clearing the site, restriction cages were placed there and after 14 d the deposited litter within the quadrat was collected and dried (Chapter 6). Existing and deposited litter were defined as dead plant material on the surface of the soil, no longer attached to the plant. Samples were composited across the six caged sites per pasture within a litter type in preparation for lab analysis. Chemical composition analysis included dry matter (DM), organic matter (OM), C, N, P, neutral detergent fiber (NDF), acid detergent fiber (ADF), and lignin for existing and deposited litter.
Litter bag trial

In the second experiment, litter nutrient disappearance was estimated using a litter bag technique. In this experiment, litter was defined as the senescent leaves still attached to the plant. The reason for this approach was to avoid collecting litter on the ground that was already degraded to an unknown extent. The litter was obtained by cutting standing herbage from each of the six experimental units during May of each grazing season. Herbage from each experimental unit was kept separate from the others and oven-dried (60°C for 72 h). Green and senescent herbage was hand-separated thereafter, but the litter was not ground so that the surface area remained as similar as possible to the original litter. The senescent fraction (6 g per bag) was placed into polyester bags with 75-µm mesh size and measuring 15 x 20 cm. The bags were heat sealed, and incubation times were 0, 4, 8, 16, 32, 64, and 128 d. Each incubation time, with the exception of Day zero, was replicated six times within each experimental unit, resulting in 36 bags per experimental unit. Empty bags were also incubated for the different periods in order to correct the bag weight after incubation. Litter bags were placed on the ground in sets of six, one for each incubation time, and covered with existing litter from that experimental unit. These sites were chosen to represent the average herbage mass of the pasture, based on settling height of an aluminum disk. Cages were placed over the sites where each set of six bags was located to protect them from grazing animals. Thus, a total of six cages per pasture were used, one for each complete set of incubation times. Herbage inside the cage was clipped biweekly throughout the 128-d period in order to maintain the herbage height inside the cage as close as possible to the average herbage height of the pasture, and the clipped material was removed from the site.
The 128-d incubation periods were from 22 July to 27 Nov. 2002 and 23 July to 28 Nov. 2003. At each incubation time, the six litter bags for that time on a given pasture were collected, oven-dried (60°C for 72 h), and composited samples within an experimental unit were milled to pass a 1-mm screen. Chemical composition analyses included DM, OM, C, N, P, NDF, ADF, lignin, and acid detergent insoluble N (ADIN).

In both experiments, DM and OM analyses were performed using the procedure described by Moore and Mott (1974). Carbon, N, and ADIN (litter bag only) analyses were done using dry combustion with a Carlo Erba NA-1500 C/N/S analyzer. Phosphorus was determined by micro-Kjeldahl digestion and read in the auto-analyzer using a colorimetric procedure. Fiber analysis was run in an ANKOM fiber analyzer (ANKOM Technology, 2003a; ANKOM Technology, 2003b; ANKOM Technology, 2003c). In the case of the litter bag experiment, the percentage of remaining nutrient was calculated based on the content of each nutrient prior to and after the incubation period.

**Statistical Analyses**

Composition data for existing litter and deposited litter were organized by 28-d periods within each year and analyzed using a repeated measures procedure in Proc Mixed from SAS (SAS Inst. Inc., 1996). The LSMEANS procedure was used to compare treatment means.

In the litter bag trial, non-linear models were used to fit the decay curves using Proc Nlin from SAS® Institute (SAS Inst. Inc., 1996). Before choosing the model, each data set was plotted to observe the pattern of distribution. Decay curves usually followed the double or single exponential functions, and nutrient concentration data followed the two-stage model. The double exponential model was used first to explain the decay curves, and whenever it wasn’t significant (P < 0.10), the single exponential decay model
was used to fit the data. This happened when nutrient immobilization occurred to a greater extent at the beginning of the incubation periods, as in the total N decay curve.

The double exponential model (Weider and Lang, 1982) was used for P loss, and it was described by Equation 1:

\[ \chi = Ae^{-kt_1} + (1 - A)e^{-kt_2} \]  
\[ \text{Equation 1} \]

Where:

\( \chi \) = Proportion of remaining biomass at time t

\( A \) = Constant

\( k_1 \) and \( k_2 \) = Decay constants

After solving the above equation, the output parameters (\( A, k_1, \) and \( k_2 \)) of each experimental unit were used to calculate their respective relative decomposition rates (\( k \)) using Equation 2 described by Weider and Lang (1982):

\[ k = \frac{-k_1Ae^{-kt_1} - k_2(1 - A)e^{-kt_2}}{Ae^{-kt_1} + (1 - A)e^{-kt_2}} \]  
\[ \text{Equation 2} \]

The time used to calculate \( k \) was 128 d which corresponds to the total length of each incubation trial.

The single exponential model (Wagner and Wolf, 1999) was used for total N decay and C:N ratio and it was described by Equation 3:

\[ \chi = B_0e^{-kt} \]  
\[ \text{Equation 3} \]

Where:

\( \chi \) = Proportion of remaining biomass at time t

\( B_0 \) = constant

\( k \) = Decay constant
The two-stage model described by McCartor and Rouquette (1977) was used to fit nutrient concentration over time. Pearson correlation coefficients were calculated for all models applied, correlating the observed data with the expected data from the models. After fitting the appropriate model for each experimental unit within each grazing season, the output parameters were analyzed using Proc Mixed from SAS® with year considered a fixed effect. Means were compared using the LSMEANS procedure of SAS®.

Results and Discussion

Existing Litter and Deposited Litter

N concentration

Existing and deposited litter N concentrations were approximately 50% greater for the High management intensity than for the other treatments (Table 7.1). These greater N values reflect the importance of the litter as a buffering pool, potentially reducing N losses to the environment (Wedin, 1996; Wedin, 2004) and supplying it later to plants and microbes.

The potential litter mineralization may be estimated based on litter C and N concentration. Considering the average rate of litter deposition (Chapter 6) and the deposited litter N concentration (12.7 g kg⁻¹) for the Low treatment (Table 7.1), the amount of N cycled through the above-ground deposited litter was approximately 58 kg N ha⁻¹. Carbon concentration in deposited litter was relatively constant averaging 506 g kg⁻¹ on an OM basis (or 436 g kg⁻¹ on a DM basis). With this N amount (58 kg N ha⁻¹), 2750 kg of above-ground litter (DM basis) would be decomposed by soil microorganisms, considering a microbial C:N ratio of 8:1 and that 1/3 of the metabolized C is actually incorporated into microbial biomass. The remaining 2/3 would be utilized
during the respiratory process (Brady and Weil, 2002; p.508). The average (across treatments and dates) litter deposition rate for the grazing season was 27 kg OM ha\(^{-1}\) d\(^{-1}\) (Chapter 6), which multiplied by the grazing season length (168 d) results in approximately 4540 kg OM ha\(^{-1}\) deposited during this period. The undegraded remaining biomass (i.e., 4540 – 2750 = 1790 kg ha\(^{-1}\)) tends to accumulate and act as a sink for the N from pasture pools (e.g., soil OM, excreta) or other nutrient inputs like fertilizers. This value (1790 kg ha\(^{-1}\)) is close to the average existing litter for 2002 and 2003 which was 1570 kg ha\(^{-1}\).

Below-ground litter was not accounted for in these calculations; therefore, the N immobilization potential is even greater than reported. Nitrogen immobilization may lead to pasture degradation in low N input systems (Fisher et al., 1994). Pasture degradation is usually related to decreasing soil N availability caused by an accumulation of low quality plant litter and, consequently, by an increase in net N immobilization due to greater numbers and activity of soil microorganisms (Cantarutti, 1996; Robbins et al., 1989; Robertson et al., 1993a; Robertson et al., 1993b). Nitrogen fertilization or legume introduction are ways to overcome and reverse this process.

Table 7.1. Effect of management intensity on N concentration (OM basis) of existing litter and deposited litter during 2002 and 2003.

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Existing litter</th>
<th>Deposited litter</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>g kg(^{-1})</td>
<td></td>
</tr>
<tr>
<td>Low</td>
<td>14.1 b(^{†})</td>
<td>12.7 b</td>
</tr>
<tr>
<td>Moderate</td>
<td>15.8 b</td>
<td>14.3 b</td>
</tr>
<tr>
<td>High</td>
<td>22.9 a</td>
<td>21.5 a</td>
</tr>
<tr>
<td>SE</td>
<td>0.9</td>
<td>0.9</td>
</tr>
</tbody>
</table>

\(^{†}\)Means within a column followed by the same letter are not different (\(P>0.10\)) by the SAS LSMEANS test.
C:N ratio and lignin:N ratio

Management intensity interacted with evaluation date to affect litter C:N ratio for both existing litter and deposited litter (Figure 7.1). The C:N ratio was lowest for the High treatment in all evaluations of existing and deposited litter, and there were no differences among dates within years for this treatment (P > 0.10). Interaction occurred because during the mid-season the C:N ratio for the Low and Moderate treatments started to increase, and the change was greatest for Low for both existing and deposited litter (Figure 7.1). Therefore, at the beginning of the season the C:N ratio of Low and Moderate was similar, but at the end of the season Low presented a higher C:N ratio.

Carbon concentration did not differ among treatments, but N concentration did differ, both for existing and deposited litter (Table 7.1). Thus, the higher N concentration in the litter resulted in lower C:N ratio for the High treatment (Figure 7.1).

The C:N and lignin:N ratios are considered important components of decomposition models (Palm and Rowland, 1997), with lower values associated with more rapid decomposition. The C:N ratio in plant residues ranges from between 10:1 to 30:1 in legumes and young green leaves to as high as 600:1 in some kinds of sawdust (Brady and Weil, 2002). It is generally accepted that C:N ratio less than 20:1 favors mineralization whereas C:N ratio greater than 30:1 favors immobilization (Wagner and Wolf, 1999), but fungi and bacteria can decompose residues with far higher ratios (Heal et al., 1997). Data from the current study showed that at lower management intensity (Low and Moderate treatments) the litter C:N ratio was greater than 30:1, presenting potential for N immobilization, while at the High intensity the C:N ratios were less than 30:1 (22:1 for existing litter). The C:N ratio was well-established by the 1920s as a general index of litter quality and it still has widespread use. It is now generally accepted,
however, that form of the C in plant cells, the concentration of other nutrients, and the composition of secondary plant compounds, can all be significant in decomposition processes (Heal et al., 1997).

Figure 7.1. Management intensity by evaluation date interaction effect on C:N ratio of existing litter and deposited litter on grazed Pensacola bahiagrass pastures during 2002-2003. Means followed by same letter, within each evaluation date, are not different (P>0.10) by the SAS LSMEANS test. Existing litter SE = 2.3; Deposited litter SE = 2.5.
The lignin:N ratio differed among management intensities with lower values observed for the High treatment in both existing and deposited litter (Table 7.2). Lignin concentration did not differ (P > 0.10) among treatments, averaging 92 g kg\(^{-1}\) for existing litter and 84 g kg\(^{-1}\) for deposited litter. Therefore, the lower lignin:N ratio observed in the litter from the High treatment is related to its greater N concentration. The lignin:N ratio of residues with low polyphenol concentration is a useful indicator of net N mineralization rates and it also regulates the synchrony between soil N supply and plant uptake, reducing N losses (Thomas and Asakawa, 1993; Becker and Ladha, 1997; Whitmore and Handayanto, 1997). Lignin concentration varies widely, increasing with senescence of plant materials and as litter decomposition proceeds. Values in fresh, non-senescent leaves of a broad range of plants ranged from 50 to 200 g kg\(^{-1}\), while those of senesced litter range from 100 to 400 g kg\(^{-1}\) (Palm and Rowland, 1997). Thomas and Asakawa (1993) reported lignin:N values ranging from 13.8 to 31.5 in litter collected from pastures of four different tropical grass species. These values are higher than the ones obtained in this experiment which ranged from 4.4 to 5.8 (Table 7.2), and the main difference was the litter N concentration reported from Thomas and Asakawa (1993) which was in the range of 2.7 to 6.9 g N kg\(^{-1}\) (contrasting with the 12.7 to 22.9 g N kg\(^{-1}\) range obtained in this experiment). It is interesting to note that the lignin:N ratio of existing and deposited litter were very similar within a treatment despite decomposition processes occurring for a longer time in existing litter. This suggests that both lignin and N are relatively recalcitrant components of bahiagrass litter.
Table 7.2. Effect of management intensity on lignin:N ratio of existing litter and deposited litter during 2002-2003.

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Existing litter</th>
<th>Deposited litter</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low</td>
<td>5.8 a</td>
<td>5.9 a</td>
</tr>
<tr>
<td>Mod</td>
<td>5.7 a</td>
<td>6.0 a</td>
</tr>
<tr>
<td>High</td>
<td>4.4 b</td>
<td>4.4 b</td>
</tr>
<tr>
<td>SE</td>
<td>0.4</td>
<td>0.3</td>
</tr>
</tbody>
</table>

†Means within a column followed by the same letter are not different ($P>0.10$) by the SAS LSMEANS test.

**P concentration and C:P ratio**

Existing and deposited litter P concentrations were higher and C:P ratios lower for the High treatment than for Moderate and Low (Table 7.3). Considering that P fertilization was the same among Moderate and High treatments and those treatments only received 17 kg P ha$^{-1}$ more than Low over the 2 yr, the primary reason why P was higher in the High treatment is the higher SR and N fertilization. Increasing SR increases the proportion of nutrients returned via excreta relative to litter (Thomas, 1992), and nutrients in excreta are more readily available than those in plant litter (Haynes and Williams, 1993), particularly below-ground litter. Nitrogen fertilization may increase the rates of soil OM mineralization, increasing P availability. As a result of these processes, soil P availability increased leading to greater plant P uptake.

Phosphorus mineralization and immobilization processes are especially important to understand because organic P is the soil P pool for which management has the greatest potential to increase the efficiency of P recycling in tropical pastures (Beck and Sánchez, 1994; Guerra et al., 1995; Friesen et al., 1997; Novais and Smyth, 1999; Oberson et al., 1999). The C:P ratio ranged from 394 (High treatment) to 662 (Low treatment). When C:P ratio is below 200:1, mineralization predominates, whereas above 300:1 immobilization is greatest (Dalal, 1979; McLaughlin and Alston, 1986; Novais and
Smyth, 1999). Therefore, P immobilization by the litter pool was expected to occur even for the High treatment.

Table 7.3. Effect of management intensity on P concentration (OM basis) and C:P ratio of existing litter and deposited litter during 2002 and 2003.

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Existing litter</th>
<th>Deposited litter</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>P (g kg⁻¹)</td>
<td>C:P</td>
</tr>
<tr>
<td>Low</td>
<td>0.8 b †</td>
<td>649 a</td>
</tr>
<tr>
<td>Mod</td>
<td>0.9 b</td>
<td>599 b</td>
</tr>
<tr>
<td>High</td>
<td>1.3 a</td>
<td>433 c</td>
</tr>
<tr>
<td>SE</td>
<td>0.04</td>
<td>19.4</td>
</tr>
</tbody>
</table>

†Means within a column followed by the same letter are not different (P > 0.10) by the SAS LSMEANS test.

**NDF and ADF concentration**

Management intensity interacted with evaluation date affecting NDF and ADF concentration in the existing litter (Figure 7.2). The High treatment had less seasonal variability in existing litter NDF and ADF concentrations, while those of Low and Moderate decreased significantly during July and August. Litter NDF and ADF concentration is a function of the deposited litter quality and also of the rate of litter decomposition. Greater decomposition rates, associated with the High treatment, increase NDF and ADF because fiber compounds are recalcitrant, particularly ADF (Heal et al., 1997).

There were no treatment effects but there was an evaluation date effect for NDF and ADF concentration in the deposited litter. Deposited litter NDF increased from 620 to 710 g kg⁻¹ and ADF from 310 to 360 g kg⁻¹ from the beginning to the end of the grazing season. Because this material was all deposited within 14 d of sampling date, this response was most likely due to the decreasing nutritive value of standing herbage that occurred as the grazing season progressed (Chapter 3).
Figure 7.2. Effect of management intensity and evaluation date on neutral detergent fiber (NDF) and acid detergent fiber (ADF) concentration of existing litter on grazed Pensacola bahiagrass pastures during 2002-2003. Means followed by same letter, within each evaluation date, are not different (P>0.10) by the SAS LSMEANS test. NDF SE = 224 g kg⁻¹; ADF SE = 119 g kg⁻¹.
Litter Bag Trial

Litter chemical composition at Days 0 and 128

The litter chemical composition at Days 0 and 128 is presented for characterization purposes (Table 7.4). Non-linear models will be used later in this Chapter to explain how the changes occurred during the incubation period. There was an interaction between treatment and incubation periods for N, P, ADIN, and lignin concentration. In general, the concentration of N, ADIN, and lignin increased over the 128-d incubation period for all treatments (Table 7.4). Interaction occurred because these variables were similar (P > 0.10) among treatments at Day 0 but not at Day 128, with greater values observed in the High treatment. Lignin and ADIN are considered recalcitrant materials and are slowly decomposed during the incubation period (Ruffo and Bollero, 2003). Because ADIN was a major component of total N, as will be explored later in this Chapter, the N might also be considered a recalcitrant compound. The concentration effect occurs because soluble compounds decompose faster leaving the more recalcitrant ones behind (Heal et al., 1997; Whitmore and Handayanto, 1997). Faster decomposition rate in the High treatment (Chapter 6) combined with greater N fertilization and SR are the likely reasons for greater increase of the recalcitrant materials in the High treatment. Litter P decreased significantly (P < 0.10) in concentration only for the Moderate treatment, but there were trends in the same direction for Low and High (P ≤ 0.16; Table 7.4).

Litter NDF and C:N ratio decreased from Day 0 to Day 128, but litter ADF and litter lignin:N ratio increased during this same period (Table 7.5). Decline in C:N ratio occurs because while C is lost during decomposition, N concentration increases because it is bound to the fiber and also because of immobilization by microbes. The difference between NDF and ADF is because NDF contains hemicellulose (Van Soest, 1985).
Hemicellulose is more degradable than lignin and ADF (Heal et al., 1997). Therefore, because of their more recalcitrant nature, ADF and lignin increased over time, while litter NDF decreased.

Table 7.4. Litter chemical composition (N, P, ADIN, and lignin concentrations) at the beginning and at the end of the 128-d incubation period at different management intensities. Data are averages of 2 yr.

<table>
<thead>
<tr>
<th>Treatments</th>
<th>Low 0 d</th>
<th>Low 128 d</th>
<th>P+</th>
<th>Moderate 0 d</th>
<th>Moderate 128 d</th>
<th>P</th>
<th>High 0 d</th>
<th>High 128 d</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>N</td>
<td>14.6</td>
<td>23.9</td>
<td>&lt; 0.01</td>
<td>14.8</td>
<td>22.5</td>
<td>&lt; 0.01</td>
<td>16.5</td>
<td>30.5</td>
<td>&lt; 0.01</td>
</tr>
<tr>
<td>P</td>
<td>1.5</td>
<td>1.4</td>
<td>0.10</td>
<td>1.6</td>
<td>1.1</td>
<td>&lt; 0.01</td>
<td>1.4</td>
<td>1.2</td>
<td>0.16</td>
</tr>
<tr>
<td>ADIN</td>
<td>6.3</td>
<td>24.3</td>
<td>&lt; 0.01</td>
<td>6.5</td>
<td>21.8</td>
<td>&lt; 0.01</td>
<td>8.0</td>
<td>32.4</td>
<td>&lt; 0.01</td>
</tr>
<tr>
<td>Lignin</td>
<td>48</td>
<td>258</td>
<td>&lt; 0.01</td>
<td>52</td>
<td>249</td>
<td>&lt; 0.01</td>
<td>54</td>
<td>304</td>
<td>&lt; 0.01</td>
</tr>
</tbody>
</table>

†P value for comparison between incubation periods within the same treatment and response variable. Nitrogen standard error (SE) = 1.1 g kg⁻¹; Phosphorus SE = 0.15 g kg⁻¹; ADIN SE = 1.7 g kg⁻¹; Lignin SE = 9.8 g kg⁻¹.

Table 7.5. Litter NDF and ADF concentrations and C:N and lignin:N ratio at Days 0 and 128 during 2002 and 2003.

<table>
<thead>
<tr>
<th>Incubation periods</th>
<th>Day 0</th>
<th>Day 128</th>
<th>P value†</th>
</tr>
</thead>
<tbody>
<tr>
<td>NDF, g kg⁻¹</td>
<td>735</td>
<td>650</td>
<td>0.09</td>
</tr>
<tr>
<td>ADF, g kg⁻¹</td>
<td>366</td>
<td>437</td>
<td>0.07</td>
</tr>
<tr>
<td>C:N</td>
<td>30</td>
<td>19</td>
<td>&lt; 0.01</td>
</tr>
<tr>
<td>Lignin:N</td>
<td>3.2</td>
<td>9.4</td>
<td>0.05</td>
</tr>
</tbody>
</table>

†P value for comparison between incubation periods within the same response variable. NDF SE = 8.2 g kg⁻¹; ADF SE = 6.7 g kg⁻¹; C:N SE = 2.15; Lignin:N SE = 0.4.

Litter N disappearance

Total N disappearance followed a single exponential model, and there were differences due to year but not among treatments (Figure 7.3). Net N immobilization occurred at the beginning of the incubation period in both years, but to a greater extent in 2002 when net N immobilization occurred up to 64 d compared to only 8 d in 2003. Litter
quality plays a role in N immobilization, particularly in low N input, C4 grass systems (Fisher et al., 1994; Cantarutti, 1996), and may lead to pasture degradation. Net N mineralization varied from 20 to 30% after 128 d of incubation, resulting in a small contribution of N from the litter pool to the pasture. Instead, the litter pool acted as an N sink, which was particularly important for the High treatment where rates of 360 kg N ha$^{-1}$ yr$^{-1}$ were applied. Therefore, N losses to the environment were probably reduced because of N immobilization by the litter pool. In green panic (*Panicum maximum* Jacq. var. trichoglume) pastures in Australia, net N mineralization did not occur until 50 to 100 d after litter deposition. Even after a year only 20 to 30% of all litter N was released in the soil, primarily due to microbial immobilization (Robbins et al., 1989). In southern Bahia state, Brazil, Cantarutti (1996) determined that incubation of soil samples with herbage of creeping signalgrass [*Brachiaria humidicola* (Rendle) Schweick.], desmodium, and combinations of the two led to significant net N immobilization. During the first week of incubation, 60 to 80% of all soil mineral N was immobilized in the microbial biomass, and 30 to 50% remained immobilized after 150 d. At the same time, the author verified an increase of N in the microbial biomass of 12 to 36%. This reinforced the hypothesis that a large proportion of soil mineral N was effectively immobilized and that competition existed between plants and microorganisms for the available N.
Figure 7.3. Total N disappearance from litter incubated on Pensacola bahiagrass pastures managed at a range of intensities during 2002 and 2003. Pearson correlation coefficient in 2002 = 0.59; Pearson correlation coefficient in 2003 = 0.77.
Litter P disappearance

Phosphorus decomposition, like DM, was described using a double exponential decay model, and no treatment differences were detected (Figure 7.4). Some P immobilization occurred at the beginning of the incubation period, but after 128 d of incubation approximately 60% of net P mineralization had occurred. The average litter P concentration on Day 0 was 1.5 g kg\(^{-1}\) and it decreased to 1.2 g kg\(^{-1}\) by Day 128 (Table 7.4). Assuming the average rate of litter deposition (i.e., 27 kg OM ha\(^{-1}\) d\(^{-1}\)), the litter deposited in 140 d was 3780 kg OM ha\(^{-1}\). Therefore, the amount of P returned through this above-ground litter was approximately 5.7 kg ha\(^{-1}\) during the 140-d period. If an average of 50% of this P was released, only 2.9 kg ha\(^{-1}\) would be made available to the pasture from litter during this period. This may be an overestimation due to the shorter time period available for degradation of litter P deposited later in the grazing season. Therefore, the above-ground litter contribution to P supply in these pastures was of limited importance.

The potential for P immobilization, however, particularly by the below-ground litter is high. Gijsman et al. (1997) reported root C:P ratio up to 1780 in creeping signalgrass grown on an Oxisol while microbial C:P ratio in these soils ranged from 34 to 50. When considering C:P ratio, values below 200:1 result in mineralization predominating, whereas above 300:1 immobilization is greatest (Dalal, 1979; McLaughlin and Alston, 1986; Novais and Smyth, 1999). Considering that the P concentration in the litter on Day 0 was 1.5 g kg\(^{-1}\) and the C concentration was 430 g kg\(^{-1}\), the average C:P ratio on Day 0 was 287, and increased with length of the decomposition period. Other factors such as lignin and polyphenol concentrations may play a role in P mineralization rates. For example, mineralization rates were greater for rice [Oryza sativa
(L.)] (0.6 g P kg\(^{-1}\)) and *Stylosanthes capitata* Vog. (0.7 g P kg\(^{-1}\)) residues than for cowpea *[Vignia unguiculata* (L.) Walp.] (2.7 g P kg\(^{-1}\)); the latter has greater lignin-polyphenol concentrations (Friesen et al., 1997). The authors, however, considered that different P mineralization rates have less importance in pasture systems because forage grasses have an extensive root system to take up P released in the soil during any time of the year. Additionally, it has been suggested that root exudation of acid phosphatases (e.g., phytase) could provide an efficient mechanism for wide adaptation of signalgrass (*Brachiaria decumbens* Stapf.; planted on over 40 million ha) to the low inorganic P supplying soils of Latin America (Rao et al., 1999).

![Graph](image)

Figure 7.4. Total P disappearance from litter incubated on Pensacola bahiagrass pastures managed at a range of intensities during 2002-2003. Pearson correlation coefficient = 0.88.

**Litter N concentration: total N and ADIN**

Total N concentration in the litter increased during the incubation period for all treatments, but it increased to a greater extent for the High treatment (Figure 7.5). Increasing N concentration over an incubation period has been reported in the literature
Although N concentration increased over time, most of this N was not available for decomposition because it was chemically bound to the cell wall (Figure 7.6). The availability of C and N, rather than their total concentration in the residue, plays a critical role in residue decomposition and nutrient release (Ruffo and Bollero, 2003). Greater increase in N concentration for the High treatment likely was due to greater N availability in these pastures resulting in higher N immobilization by the litter. Whitmore and Handayanto (1997) related the increase in lignin with the increase in the protein binding capacity of residues. The High treatment, as will be explored later in this chapter, also had a greater increase in lignin concentration over time, probably due to a higher decomposition rate, therefore, the N binding capacity was also likely to be greater in the High pastures. As a result, N concentration increased to a greater extent for the litter in the High treatment.

Figure 7.5. Total N concentration in litter incubated on Pensacola bahiagrass pastures that were managed at a range of intensities during 2002-2003. Pearson correlation coefficient for Low = 0.74; Moderate = 0.63; High = 0.85.
The ADIN concentration also increased across the incubation period for all treatments, but it increased to the greatest extent for the High treatment (Figure 7.6). Greater decomposition rate for the High treatment resulted in faster decomposition of more soluble compounds, increasing ADF as a result of a concentration effect. The proportion of ADIN in total N at the beginning of the incubation was approximately 200 g kg\(^{-1}\), but this value increased to 400 to 500 g kg\(^{-1}\) after 64 d of incubation (Figure 7.7). This reinforces the argument that despite the increase in N concentration over time, almost half of this N was bound to the ADF, therefore, it had low availability for microbial decomposition. Ruffo and Bollero (2003) indicated that C and N mineralization rates are positively correlated to their soluble fractions in the NDF and ADF and that large concentrations of NDF and ADF reduce biomass decomposition and slow C and N release rates.

![Figure 7.6](image)

Figure 7.6. Acid detergent insoluble N (ADIN) in litter incubated on Pensacola bahiagrass pastures managed at a range of intensities during 2002-2003. Pearson correlation coefficient for Low = 0.88; Moderate = 0.85; High = 0.92.
Figure 7.7. Acid detergent insoluble N (ADIN) concentration in total N in litter incubated on Pensacola bahiagrass pastures managed at a range of intensities during 2002-2003. Pearson correlation coefficient for Low = 0.91; Moderate = 0.84; High = 0.86.

Litter lignin and lignin-to-N ratio

Ash-free lignin concentration also increased across the incubation time, and similarly to ADIN, it increased to the greatest extent for the High treatment (Figure 7.8). Lignin plays an important role in the decomposition process because of all naturally produced organic chemicals, lignin is probably the most recalcitrant (Hammel, 1997). Heal et al. (1997) reported that litter decomposition is mainly controlled by the rate of lignin decomposition, and that this rate, in turn, is increased by high cellulose concentration and decreased by a high N concentration. Keyser et al. (1978) demonstrated that the ligninolytic system of lignin-decomposer fungi is synthesized in response to N starvation. Therefore, the greater lignin concentration for the High treatment was not only because of higher decomposition rates resulting in more rapid decomposition of soluble compounds leaving lignin behind, but also due to lower lignin decomposition rates resulting from more N available in the High pastures. Lignin concentration 64 d after decomposition initiated was greater than 250 g kg$^{-1}$ in the High
treatment. Information on forage fed to animals suggest that once lignin concentration surpasses 150 g kg\(^{-1}\), decomposition is impaired because lignin is covering and thus protecting the cellulose from attack (Chesson, 1997). Lignin methods of analysis might be subject to errors. The Klason procedure, for example, may overestimate lignin values if it is used on plant tissues that contain other high molecular weight components that are not removed in the initial extraction and acid treatment. Interfering substances of this type may include proteins and tannins (Hammel, 1997). High concentration of insoluble protein bound to the fiber at longer incubation periods may have influenced the lignin analysis, resulting in an overestimation of lignin concentration.

Figure 7.8. Ash-free lignin concentration in litter incubated on Pensacola bahiagrass pastures managed at a range of intensities during 2002-2003. Pearson correlation coefficient for Low = 0.87; Moderate = 0.90; High = 0.89.

Lignin-to-N ratio also increased over the incubation period, but unlike ADIN and lignin, it was lowest for the High treatment (Figure 7.9). Lignin-to-N ratio is an indicator of residue decomposition, presenting a negative correlation with biomass loss (Thomas and Asakawa, 1993). Magid et al. (1997) suggested, however, that the lignin:N ratio is
not a critical determinant of the short- to medium-term decomposition rates, but it may be very important in governing the long-term decay. Heal et al. (1997) pointed out that cereal and legume straws and litter from annual crops usually contain less than 100 to 150 g kg\(^{-1}\) of lignin and hence C:N ratios of 50 to 100 are reasonable predictors of decomposition rates in that case, because the higher ratios mainly reflect lower N concentration in tissues rather than changes in C form. When lignin is increasing over time, however, the lignin-to-N ratio may be a better indicator of C availability to microorganisms. Although lignin concentration was greater for the High treatment, lignin:N ratio was lower, indicating a better quality litter resulting in faster decomposition rates for the litter at the High management intensity.

![Figure 7.9](image)

**Figure 7.9.** Lignin-to-N ratio in litter incubated on Pensacola bahiagrass pastures managed at a range of intensities during 2002-2003. Pearson correlation coefficient for Low = 0.62; Moderate = 0.63; High = 0.69.

**Litter C:N ratio**

Litter C:N ratio decreased across the incubation period. The single exponential model fit this response with differences between years (Figure 7.10). Decreasing C:N ratio over time is expected because the more soluble C compounds decompose rapidly,
but N immobilization by the low quality residue and the N bound to the fiber reduce N losses. No treatment differences were observed for C:N ratio (P > 0.10). Residue quality in 2002 at the start of the incubation period was lower than in 2003 (Figure 7.10). This is likely the reason why N immobilization occurred to a greater extent in 2002 than in 2003 (Figure 7.3). The N immobilization at the beginning is the reason why the double exponential model did not fit well for the N loss and C:N ratio curves over incubation time. Final C:N ratios were less than 20 in 2003, thus, net N mineralization of that litter should occur. The high lignin value at the end, however, likely was controlling the decomposition rate. Although C:N ratio remains a critical parameter in decomposition models, several studies have demonstrated important interactions with other factors including the form of the C in the plant cells as an energy source, the concentration of other nutrients, and the composition of various secondary plant compounds (Heal et al., 1997).
Figure 7.10. Carbon-to-N ratio in litter incubated on Pensacola bahiagrass pastures managed at a range of intensities during 2002 and 2003. Pearson correlation coefficient in 2002 = 0.62; in 2003 = 0.71.
Conclusions

Increasing management intensity resulted in better litter quality, as indicated by the lower litter C:N and lignin:N ratios and the higher N and P concentrations in the High treatment. Seasonal fluctuations in litter quality occurred to a greater extent in the Low and Moderate treatments, as indicated by the C:N ratio, with lower litter quality observed by the end of the grazing season. Litter quality was generally low across treatments, presenting potential to immobilize nutrients like N and P, particularly at the beginning and at the end of the grazing season.

In the litter bag trial, the litter quality at the beginning of the incubation period was similar among management intensities, but it differed at the end, suggesting that N immobilization is a major factor altering bahiagrass litter quality. Litter had higher N concentration, particularly at the end of the incubation period, but the N was mostly unavailable for microbial decomposition because it was bound to the ADF. Lignin concentration increased with incubation period and it was likely in the control of the decomposition process in the longer incubation periods. As a result, in the longer incubation periods, the lignin:N ratio was likely a better indicator of litter decomposition than C:N ratio.

The improvement in litter quality with increasing management intensity results in faster litter turnover and enhancement in nutrient supply to plants and microbes. It is not yet clear if the reduced nutrient immobilization capacity of high quality litter results in greater nutrient losses or if the relatively slow rate of nutrient release, compared to fertilization, simply provides greater opportunity for the grass root system to capture these nutrients. Because roots and rhizomes are an important nutrient pool in Pensacola bahiagrass pastures, additional investigation is needed to obtain information about below-
ground litter quality and decomposition rates as affected by pasture management practices. This will enable better understanding of nutrient dynamics in the total system.
CHAPTER 8
CHARACTERIZATION OF SOIL ORGANIC MATTER FROM PENSACOLA BAHIAGRASS PASTURES GRAZED FOR FOUR YEARS AT DIFFERENT MANAGEMENT INTENSITIES

Introduction

Soil organic matter (SOM) affects soil physical, chemical, and biological properties, and it is an important indicator of ecosystem sustainability (Greenland, 1994). Land management affects SOM by altering residue deposition and decomposition. When residue deposition is greater than decomposition, SOM accumulates. When residue decomposition is greater, SOM is reduced (Johnson, 1995). Thus, sustainable land management should include practices that elevate, or at least maintain, the appropriate SOM for a given soil (Greenland, 1994; Hassink, 1997). Using this criterion, well-managed pastures are sustainable production systems because SOM has been observed to increase over time. Additionally, because the C input in highly productive pastures is expected to be greater when compared to low-input systems, it should also be expected that SOM increases more in intensively managed pasture systems (Barrow, 1969; Malhi et al., 1997; Bernoux et al., 1999; Pulleman et al., 2000; Batjes, 2004).

Often SOM has been characterized by chemical fractionation (fulvic acid, humic acid, humin), however, the applicability of this fractionation for agroecosystems is restricted. Humic and fulvic acid have limited influence on short-term soil processes (e.g., nutrient availability, CO₂ evolution) due to low turnover rate. Because of that, it is difficult to establish relationships between those fractions and crucial processes in the soil like SOM mineralization and aggregate formation (Feller and Beare, 1997). Physical
fractionation of SOM, by size or density, with subsequent analysis of the OM associated with each fraction, has become a more common method to characterize SOM (Feller and Beare, 1997; Tiessen et al., 2001). The importance of this fractionation is that SOM mineralization rates increase as light fractions become more dominant, i.e., C and N mineralization rates are positively correlated with the amount of C and N in the light fraction and in the microbial biomass. In addition, the light fraction is more sensitive to changes in management which alters the residue deposition. Therefore, early detection of SOM changes may be achieved by the physical fractionation method (Hassink, 1995; Six et al., 2002).

There are very few studies that have evaluated the effect of C₄ grass pasture management on characteristics of SOM. Thus, the objective of this study was to characterize the SOM, by density fraction and particle size, from ‘Pensacola’ bahiagrass (*Paspalum notatum* Flügge) pastures managed at different N fertilization levels, stocking rates, and stocking methods. Because pre-treatment SOM data are not available, particular attention will be paid to the light density fraction of SOM, the fraction in which differences are likely associated with the treatments imposed.

**Material and Methods**

**Experimental Site**

The experiment was performed at the Beef Research Unit, northeast of Gainesville, FL, at 29°43’ N lat on Pensacola bahiagrass pastures. Soils were classified as Spodosols (sandy siliceous, hyperthermic Ultic Alaquods from the Pomona series or sandy siliceous, hyperthermic Aeric Alaquods from the Smyrna series) with average pH of 5.9. Mehlich-I extractable soil P, K, Ca, and Mg average concentrations at the beginning of the experiment were 5.3, 28, 553, and 98 mg kg⁻¹, respectively.
Treatments and Design

The treatments evaluated were three management intensities of continuously stocked bahiagrass pasture and one rotational stocking strategy imposed on the same grass. Continuously stocked treatments were defined in terms of stocking rate (SR) and N fertilization, the combination of which was termed management intensity. The rotational stocking treatment had a 7-d grazing period and a 21-d resting period.

The three management intensities tested in the continuous stocking treatments were Low (40 kg N ha⁻¹ yr⁻¹ and a target SR of 1.2 animal units [AU, one AU = 500 kg live weight] ha⁻¹ SR), Moderate (120 kg N ha⁻¹ yr⁻¹ and a target SR of 2.4 AU ha⁻¹ SR), and High (360 kg N ha⁻¹ yr⁻¹ and a target SR of 3.6 AU ha⁻¹ SR). Actual average stocking rates during the 4 yr for Low, Moderate, and High were 1.4, 2.8, and 4.2 AU ha⁻¹, respectively. They were higher than the treatment targets because the animals available for the study were heavier than expected. The rotational stocking treatment had the same combination of SR and N fertilization as the continuously stocked High treatment. A randomized complete block design was used, and each treatment was replicated twice. The bahiagrass pastures were stocked from 2001 to 2004, and the soil samples for SOM characterization were collected during the fourth year of grazing.

Two crossbred (Angus x Brahman) yearling heifers were assigned to each experimental unit in the continuously stocked treatments. Pasture area varied according to treatment, decreasing as the management intensity increased (Chapter 3). The rotational treatment was represented by a single paddock of the entire rotational system and during the resting period the cattle grazed other similarly managed bahiagrass pastures at the experimental station. Artificial shade (3.1 m x 3.1 m) was provided on each experimental unit and cattle had free-choice access to water and a mineral mixture. The water troughs
were always located under the artificial shade and the mineral mix troughs were repositioned several times each week at random locations throughout the pasture. Nitrogen fertilization dates and rates were the same as indicated in Chapter 3.

**Response Variables**

Soil samples were collected from all eight pastures on 11 Aug. 2004 from a 0- to 8-cm depth and air dried. Each sample was a composite of 40 soil cores collected in a zig-zag line across an experimental unit (pasture). After air drying, each soil sample was sieved through a 2-mm screen, with the particles greater than 2 mm discarded. From the particles less than 2 mm, a 100-g subsample was taken and sieved for 5 min in a Ro-Tap™ sieve shaker producing 240 oscillations min⁻¹, using sieves with mesh sizes of 53, 150, and 250 µm which were stacked on the top of each other. Following this procedure, the weight of the different soil class sizes was taken to calculate the particle size distribution. From the sieved material, 10 g of the different class sizes (250 to 2000 µm or coarse sand, 150 to 250 µm or medium sand, and 53 to 150 µm or fine sand) was used to perform the OM fractionation. Particles less than 53 µm (silt and clay) were not fractionated because the decantation with water was not efficient for this particle size.

The OM fractionation was accomplished by decantation and density separation (light and heavy fractions) with water. The physical separation was performed by adapting the methods reported by Meijboom et al. (1995), using water instead of Ludox gel. From the 10 g of each class size, the mineral particles were separated from the organic particles by decantation with distilled deionized water. After decantation, the OM suspension of a given class size was poured into a glass funnel. A plastic hose was attached to its end with clips preventing leaking, and a 24-h settling period followed. The light OM density fraction was considered the material that was floating or suspended in
the water, and the heavy density fraction was the material deposited at the bottom of the funnel and in the plastic hose. After the 24-h settling period, the light OM suspension was poured into another funnel with Whatman filter paper Number 5. The same procedure was applied to the heavy density fraction which was recollected by opening the clips and pouring the deposited material in a similar funnel and filter paper described for the light fraction. After filtering, the light and heavy OM fractions with the filter paper were put into a drier (65°C) for 24 h, placed into a desiccator for 1 h, and the sample weight determined thereafter. Because of the small amount of material recovered, particularly in the light fraction, correction for mineral contamination in the recovered fractions was performed by class size and replication using the protocol detailed by Moore and Mott (1974). A scheme for the particle size distribution and SOM physical separation by density fraction is shown in Figure 8.1.

The light and heavy OM density fractions from the different particle size classes were analyzed for their C and N concentration by dry combustion using a Carlo Erba NA-1500 C/N/S analyzer. The samples of particles less than 53 µm were also analyzed for C and N using the same procedure. Concentrations of C and N per kg of soil were calculated by estimating the C and N content (quantity of OM recovered multiplied by C and N concentration in the SOM) per unit of each particle size and then multiplying the result by the proportion of each given particle size in the soil particle size distribution. Because no SOM density fractionation was performed for particles < 53 µm, the results reported for this class size refer only to the C and N concentration in the bulk soil. The mineral residue recovered after the decantation process was analyzed for C concentration.
using the weight-loss-on-ignition method (Magdoff et al., 1996). A C concentration in the SOM of 580 g kg\(^{-1}\) was assumed (Wagner and Wolf, 1999; p.252).

Undisturbed soil cores (two per depth per experimental unit) were also randomly collected for soil bulk density determination at three soil depths: 0 to 6 cm, 6 to 12 cm, and 12 to 18 cm. These depth increments were chosen based on the ring heights of the core sampler.

**Statistical Analyses**

Statistical analyses were performed using Proc GLM and Proc Mixed of SAS (SAS Inst. Inc., 1996). The GLM procedure was used to analyze the particle size proportion data. Original particle size proportion was transformed to Y values in order to correct for
the interdependence among variables (compositional data). The Y values were estimated for the different particle sizes using the following transformation:

\[ Y_1 = \ln\left(\frac{P_1}{1 - P_3}\right); \quad Y_2 = \ln\left(\frac{P_2}{1 - P_1 - P_2}\right); \quad Y_3 = \ln\left(\frac{P_3}{1 - P_1 - P_2 - P_3}\right) \]

Where,

\( Y_1, Y_2, \) and \( Y_3 \) were transformed particle size class proportions, the 250 to 2000 \( \mu m \), 150 to 250 \( \mu m \), and 53 to 150 \( \mu m \), respectively, and \( P_1 = \) original proportion of particles 250 to 2000 \( \mu m \); \( P_2 = \) original proportion of particles from 150 to 250 \( \mu m \); \( P_3 = \) original proportion of particles from 53 to 150 \( \mu m \). These transformed data \( (Y_1, Y_2, \) and \( Y_3) \) were then analyzed using Proc GLM in SAS as compositional data. Means were compared using the Duncan’s test with a P value of 0.05.

The Mixed procedure was used to analyze the C and N concentration in the SOM and in the soil. Because soil pre-existing condition affects mainly the heavy SOM fraction and no pre-existing SOM fractionation data were available to use as a co-variate, only the light SOM was statistically analyzed for treatment comparisons and the LSMEANS procedure was used to compare treatment means.

**Results and Discussion**

**Particle Size Distribution and Bulk Density**

The particle size distribution of soil from 0- to 8-cm depth did not differ among treatments (Figure 8.2). Soils at the experimental site are classified as Spodosols, mainly from the Pomona and Smyrna series. In these sandy soils, large particles predominate. As shown in Figure 8.2, coarse sand (250 to 2000 \( \mu m \)), medium sand (150 to 250 \( \mu m \)), and fine sand (53 to 150 \( \mu m \)) represented 990 g kg\(^{-1}\) of total soil, with coarse sand alone representing 540 g kg\(^{-1}\). The clay and silt size fraction (\(< 53 \mu m\)) represented only 10 g
kg\(^{-1}\) and SOM was likely present to a greater extent in that fraction than in the larger particle size fractions. The capacity of this top soil (0 to 8 cm) to protect OM, however, is low because of the low silt and clay content (Hassink, 1997).

Figure 8.2. Soil particle size distribution from the 0- to 8-cm depth in the Spodosol at the research site.

Soil bulk density (SBD) did not differ among treatments, but it did differ for the different soil depths. Soil bulk density was lower at the shallowest depth (0 to 6 cm) when compared to other depths (Table 8.1). Soil organic matter plays an important role in the SBD. As SOM increases SBD decreases because SOM particles are less dense than soil mineral particles. The major effect of SOM on SBD, however, is the soil aggregate formation promoted by the SOM reduces SBD. Soil organic matter is usually greater at shallower depths resulting in lower SBD at those depths. Increasing SR can result in higher SBD because of the greater number of animals grazing resulting in soil
compaction, particularly at shallower depths (Kelly, 1985), although this is less likely to occur on sandy soils (Hillel, 1998). On the other hand, increasing SOM because of greater fertilizer inputs and increased plant productivity may overcome the effect of greater SR, and this may have been the case in the current study where there were no differences in SBD among treatments.

Table 8.1. Soil bulk density at different depths of a Spodosol at the research site.

<table>
<thead>
<tr>
<th>Soil Depth (cm)</th>
<th>Soil Bulk Density (g cm(^{-3}))</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 to 6</td>
<td>1.12 b(^1)</td>
</tr>
<tr>
<td>6 to 12</td>
<td>1.49 a</td>
</tr>
<tr>
<td>12 to 18</td>
<td>1.55 a</td>
</tr>
<tr>
<td>SE</td>
<td>0.03</td>
</tr>
</tbody>
</table>

\(^1\)Means followed by the same letter do not differ (P > 0.10) by the SAS LSMEANS test.

**Total C, N, and C:N Ratio in the Soil**

The total C, N, and C:N ratio in the soil did not differ among treatments with averages of 11.3 g kg\(^{-1}\), 0.8 g kg\(^{-1}\), and 14.3, respectively (Table 8.2). A total SOM determination may not reflect recent changes in SOM dynamics of a perennial grass sward because it includes both the heavy and light SOM density fractions. Because the heavy density fraction is the major component of the SOM (Six et al., 2002) and it is a function of the previous history of the soil, SOM levels at the initiation of the trial probably affected these results to a greater extent than the changes that occurred after the experiment began. Thus, recent changes may be better observed in the light density fraction (Hassink et al., 1997).
Table 8.2. Total C, N, and C:N ratio in the soil of Pensacola bahiagrass pastures submitted to different management strategies; data collected after 4 yr of imposing the treatments.

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Total C</th>
<th>Total N</th>
<th>C:N</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low</td>
<td>12.9</td>
<td>0.9</td>
<td>14.1</td>
</tr>
<tr>
<td>Moderate</td>
<td>7.1</td>
<td>0.5</td>
<td>13.9</td>
</tr>
<tr>
<td>High</td>
<td>15.5</td>
<td>1.1</td>
<td>14.4</td>
</tr>
<tr>
<td>7d</td>
<td>9.8</td>
<td>0.6</td>
<td>14.9</td>
</tr>
<tr>
<td>SE</td>
<td>4.6</td>
<td>0.3</td>
<td>0.9</td>
</tr>
<tr>
<td>P Level</td>
<td>NS†</td>
<td>NS</td>
<td>NS</td>
</tr>
</tbody>
</table>

†Non-significant (P > 0.10) by the SAS LSMEANS test.

Nitrogen, C, and C:N Ratio in the Light SOM Density Fraction

The C and N concentrations in the light SOM were affected by management practice, but the C:N ratio was not (Table 8.3). There was a trend of increasing C and N concentration in the SOM with increased N fertilization and SR. Carbon and N concentrations were greater for the 7-d treatment when compared to the Low treatment. Carbon and N concentrations in the SOM are a function of the residue deposited, and in this case, roots plus rhizomes is the major pool contributing to soil-deposited residue (Stevenson and Cole, 1999). Therefore, increasing management intensity likely increased residue deposition, due to greater productivity (Chapter 3), and N concentration in the residue because of greater N fertilization primarily and greater SR to a lesser extent.

Herbage accumulation rates were 18, 34, 40, and 72 kg DM ha⁻¹ d⁻¹ for Low, Moderate, High, and 7-d treatments, respectively (Chapter 3). Bahiagrass allocates a large proportion of photoassimilate to the root and rhizome pool (Impitukas and Blue, 1978). Also, roots and rhizomes are important N sinks in fertilized bahiagrass pastures (Impitukas et al., 1984). Therefore, the increase in N concentration in the SOM fraction of the 7-d treatment is likely a result of the increased N concentration in the decaying
roots and rhizomes that are being added to the SOM. In addition, roots and rhizomes have a high C:N ratio, and this may immobilize soil N during the decay process, increasing N concentration in the SOM as a result. The greater C concentration in the SOM observed for the 7-d treatment is possibly a result of organic material decomposed to a lesser extent due to more recent deposition (Table 8.3). Total C, N, and C:N ratio in the heavy SOM and their correspondent standard error were 516 ± 101 g kg\(^{-1}\) SOM, 35 ± 5 g kg\(^{-1}\) SOM, and 14.4 ± 1.3, respectively.

Table 8.3. Total C, N, and C:N ratio in the light SOM of Pensacola bahiagrass pastures subjected to different management strategies; data collected after 4 yr of imposing the treatments.

<table>
<thead>
<tr>
<th>Particle size</th>
<th>C: light SOM g kg(^{-1})</th>
<th>N light SOM g kg(^{-1})</th>
<th>C:N ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low</td>
<td>440 b†</td>
<td>34 b</td>
<td>13.9 a</td>
</tr>
<tr>
<td>Moderate</td>
<td>489 ab</td>
<td>41 ab</td>
<td>13.3 a</td>
</tr>
<tr>
<td>High</td>
<td>488 ab</td>
<td>38 b</td>
<td>13.7 a</td>
</tr>
<tr>
<td>7-d</td>
<td>621 a</td>
<td>56 a</td>
<td>12.9 a</td>
</tr>
<tr>
<td>SE</td>
<td>90</td>
<td>7</td>
<td>0.5</td>
</tr>
</tbody>
</table>

†Means followed by the same letter, within the same column, do not differ (P > 0.10) by the SAS LSMEANS test.

There was a particle size effect for N concentration and C:N ratio in the light SOM, but not for C concentration (Table 8.4). The N concentration in the SOM differed in the light fraction, with lower N concentration observed for particles in the 250 – 2000 µm range. The extent of degradation in the SOM increases with decreasing particle size (Hassink et al., 1997; Six et al., 2002) and N is considered a recalcitrant element as degradation proceeds (Chapter 7). Other recalcitrant compounds like lignin also increase with decomposition (Heal et al., 1997) and may possibly bind to the recalcitrant N. Therefore, the greater N concentration in the smaller, light density fraction particles is possibly a result of N immobilization during the decomposition process. Because C
concentration did not differ among particle sizes, but N concentration did differ, the C:N ratio was different. Greater C:N ratio was observed for particles in the 250 – 2000 µm range because N concentration was smaller for this same class size range (Table 8.4). Recalcitrant materials like polyphenols and lignin are left behind by microbes and they have a large protein-binding capacity (Handayanto et al., 1997). As a result, N is held by these recalcitrant compounds whereas the soluble C is lost rapidly at the beginning, resulting in lower C:N ratio as the decomposition proceeds. The light SOM fraction in the larger particle size (250 to 2000 µm) corresponds to the newly added organic material in the soil and is more prone to decomposition, with positive correlation with the mineralization process (Hassink, 1995).

Meijboom et al. (1995) reported that SOM mineralization rates decrease from the light to the heavy density fractions, i.e., C and N mineralization rates are positively correlated with the amount of C and N in the light fraction and in the microbial biomass. The light fraction is also more sensitive to changes in management which alters the residue deposition. This is the reason why early changes in SOM may be detected by the physical fractionation method (Hassink, 1995; Six et al., 2002), and specifically evaluation of the light fraction.

<table>
<thead>
<tr>
<th>Particle size</th>
<th>C (g kg⁻¹ light SOM)</th>
<th>N (g kg⁻¹)</th>
<th>C:N ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>250 – 2000 µm</td>
<td>491 a †</td>
<td>24 b</td>
<td>20.2 a</td>
</tr>
<tr>
<td>150 – 250 µm</td>
<td>534 a</td>
<td>50 a</td>
<td>10.6 b</td>
</tr>
<tr>
<td>53 – 150 µm</td>
<td>504 a</td>
<td>52 a</td>
<td>9.6 b</td>
</tr>
<tr>
<td>SE</td>
<td>82</td>
<td>7</td>
<td>0.4</td>
</tr>
</tbody>
</table>

†Means followed by the same letter, within the same column, do not differ (P > 0.10) by the SAS LSMEANS test.
Contribution of the Light SOM Fraction to Soil C and N

There was a management by particle size interaction for C and N contribution of the light SOM fraction to the soil (Table 8.5). Increasing management intensity increased C and N contribution in the 250 – 2000 µm class size range, but not in the other sizes analyzed (Table 8.5). The major contribution of C from the light SOM occurred from particles in the 250 – 2000 µm size range, which accounted for more than 90% of the C coming from the light SOM. Preeminence of this size class contribution to soil N was also observed (Table 8.5).

Soil C and soil N contribution are a function of the C and N concentration in the SOM (Table 8.4) and the amount of SOM present. There was an increase in the C and N accumulation in the soil as management intensity increased to the highest level. Well-managed pastures are considered a N and C sink because the residue deposition rate is greater than residue decomposition rate (Batjes and Sombroek, 1997; Fisher et al., 1994). Conant et al. (2003) compared the long-term effect of intensive vs. extensive grazing management on soil-C fractions in the southeastern USA. Total organic-soil C was 22% greater under high than low management intensity. Increasing C and N in the soil has beneficial effects of improving not only soil fertility, but also increasing C sequestration, contributing to the reduction of the greenhouse effect. Fisher et al. (1994) suggested the introduction of deep-rooted C4 grasses as a tool for improving C sequestration in tropical savannas. Despite greater C sequestration with greater SR and N fertilization, economic and environmental consequences of the high management intensity used in this experiment (360 kg ha⁻¹ yr⁻¹ of N and 4.2 AU ha⁻¹) may not be positive. In addition, greater N rate is associated with increased emission of nitrous oxide and greater SR with increased methane emissions (Clark et al., 2005).
Contribution of C and N from the heavy SOM fraction (including particles > 53 and < 2000 µm) and their respective standard errors were 9740 ± 5820 mg kg⁻¹ soil and 655 ± 365 mg kg⁻¹ soil, respectively. Therefore, the heavy density fraction predominates in the soil and in this case is likely a function of pre-existing conditions. In contrast, the light SOM fraction is more sensitive to changes in land management and also correlates with N mineralization in the soil (Hassink, 1997).

The C concentration in the mineral residue did not differ among treatments and particle size, averaging 3.2 g C kg⁻¹ of fraction (SE = 1.1 g kg⁻¹). These results confirm that during the decantation process some of the SOM was not recovered by the density separation process and the amount left behind should be taken into account when total C stock in the soil is calculated.

In this Spodosol, the clay plus silt concentration is low (10 g kg⁻¹), reducing the capacity of the soil to protect the SOM (Hassink, 1997). Physical protection by soil aggregate formation and biochemical protection by the formation of recalcitrant compounds (Six et al., 2002) are likely to be the major mechanisms of SOM protection in this soil. Because only the 0- to 8-cm depth was sampled for this research, underestimation of the C sequestration capacity of the more intensive systems might have occurred. Spodosols are characterized by a spodic horizon which is a subsurface accumulation of illuviated OM and an accumulation of Al oxides, with or without Fe oxides (Brady and Weil, 2002). Thus, additional C sequestration might have occurred but it could have leached to the spodic horizon resulting in an underestimation of the differences among treatments.
Table 8.5. Carbon and N contributions of the light SOM fraction to the soil as affected by management practice and particle size on Pensacola bahiagrass pastures subjected to different management strategies; data were collected after 4 yr of imposing the treatments.

<table>
<thead>
<tr>
<th>Treatment</th>
<th>C</th>
<th>N</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>53 - 150 µm†</td>
<td>150 - 250 µm</td>
</tr>
<tr>
<td>Low</td>
<td>49 a‡</td>
<td>37 a</td>
</tr>
<tr>
<td>Moderate</td>
<td>6 a</td>
<td>24 a</td>
</tr>
<tr>
<td>High</td>
<td>13 a</td>
<td>15 a</td>
</tr>
<tr>
<td>7 d</td>
<td>15 a</td>
<td>25 a</td>
</tr>
<tr>
<td>SE</td>
<td>88</td>
<td></td>
</tr>
</tbody>
</table>

†Particles < 53 µm were not fractionated by density.
‡Means followed by the same letter, within the same column, do not differ (P > 0.10) by the SAS LSMEANS test.
The soil-C and soil-N concentration in particles < 53 µm is shown in Figure 8.3. Both C and N were higher in the Low treatment as opposed to the more intensive treatments. The proportion of particles < 53 µm in the bulk soil among treatments was not different (P > 0.10), but the means were 11 g kg\(^{-1}\) in the Low vs. 8.4 g kg\(^{-1}\) in the other treatments, and the P values were less than 0.15 when comparing Low with the other treatments. Assuming 580 g kg\(^{-1}\) for C concentration in SOM in the A horizon (Wagner and Wolf, 1999), the concentration of SOM in the soil fraction < 53 µm ranged from 160 (7-d rotational) to 260 g kg\(^{-1}\) (Low). Thus, despite the low concentration of particles of this size, their high C and N concentrations cause them to be of importance. Usually the SOM in this class size complexes with clay and silt to form stable compounds (Hassink, 1997). In this Spodosol, however, complexation is reduced because of the very low clay and silt concentrations. Therefore, the SOM is more exposed to microbial degradation in a Spodosol than in a soil high in clay. When the particle-size distribution results were integrated with C and N concentration in particles < 53 µm to determine C and N in the bulk soil, there were differences among treatments (Figure 8.3). The likely faster decomposition rates for the SOM in the more intensive systems explain these results.

A question may arise, however. Is the OM input from particles > 250 and < 2000 µm sufficiently great for the more intensive systems to overcome their faster decomposition rates and still increase SOM levels? Considering the greater participation of particles > 250 and < 2000 µm in the particle size distribution when compared to particles < 53 µm (540 vs. 10 g kg\(^{-1}\), respectively), the higher OM inputs observed for the larger particles likely overcomes the faster decomposition observed in particles < 53 µm.
Therefore the C inputs likely resulted from greater net primary productivity of more intensive systems (Chapter 3), and this greater productivity is able to overcome the faster SOM decomposition rates, resulting in net C accumulation in the soil.

Figure 8.3. Carbon and N concentration in the bulk soil of particles < 53 µm in grazed Pensacola bahiagrass pastures managed at a range of intensities. Standard Error N = 12 mg N kg\(^{-1}\) soil and Standard Error C = 0.23 g C kg\(^{-1}\) soil.

**Conclusions**

Management intensity did not alter total C, N, and C:N ratio in the soil but it did affect these responses in the light SOM fraction. This fraction, showed a consistent pattern, increasing soil-C and soil-N concentrations with increased management intensity. Because the light SOM fraction is indicative of recent changes in the SOM, increasing management intensity can increase soil fertility and C sequestration. Nitrogen fertilization and SR appeared to have a greater effect on C and N accumulation than
stocking method did. Increasing N fertilization and SR resulted in greater C accumulation. Because of economic and environmental implications of the very high N level and SR, however, the use of the highest intensity applied in this experiment (i.e., 360 kg N ha\(^{-1}\) yr\(^{-1}\) and 4.2 AU ha\(^{-1}\)) is not recommended.

Particle size influenced the quality and the stability of the SOM. The C concentration in the SOM did not vary but the N concentration was lower in the larger particles of the light SOM, possibly due to a lesser extent of decomposition. The C:N ratio decreased with particle size as a result.

Although the heavy SOM density fraction was a much larger pool in the soil compared to the light SOM fraction, the light SOM fraction correlates positively with N mineralization in the soil and it reflects recent changes due to land management. In contrast, the heavy SOM fraction represents the historical SOM accumulation and does not change in a short period of time. Therefore, the SOM fractionation process is a potential method to better describe the SOM and its recent changes due to land management.
CHAPTER 9
SUMMARY AND CONCLUSIONS

Bahiagrass (*Paspalum notatum* Flügge) is the most important pasture species in the environmentally sensitive agroecosystems of Florida, yet little is understood about nutrient dynamics in these systems. Research is needed to guide producer pasture management practices and to aid regulators in making informed decisions. Thus, the objectives of this study were i) to determine the effect of management intensity and stocking method on herbage responses in bahiagrass pastures (Chapter 3); ii) to evaluate excreta distribution and soil nutrient redistribution as affected by animal behavior under a range of management intensities and stocking methods (Chapters 4 and 5); iii) to quantify litter production and decomposition in grazed ‘Pensacola’ bahiagrass pastures managed at different intensities (Chapter 6); iv) to evaluate litter disappearance and litter nutrient dynamics in grazed Pensacola bahiagrass pastures (Chapter 7); and v) to describe the physical and chemical characteristics of soil organic matter from Pensacola bahiagrass pastures grazed for 4 yr at different management intensities (Chapter 8).

In order to accomplish these objectives, two grazing experiments were performed from 2001 to 2004. In Experiment 1, yearling cross-breed beef heifers were continuously stocked and managed at different intensities. Management intensity was the combination of stocking rate (SR) and N fertilization. The three management intensities tested were Low (40 kg N ha$^{-1}$ yr$^{-1}$ and 1.4 animal units [AU, one AU = 500 kg live weight] ha$^{-1}$ stocking rate), Moderate (120 kg N ha$^{-1}$ yr$^{-1}$ and 2.8 AU ha$^{-1}$ stocking rate), and High (360 kg N ha$^{-1}$ yr$^{-1}$ and 4.2 AU ha$^{-1}$ stocking rate). In Experiment 2, rotational stocking
was applied and treatments were four grazing periods (1, 3, 7, and 21 d), all with the same resting period of 21 d. The High treatment from Experiment 1 was included in Experiment 2 because it had the same N fertilization and SR. Herbage, soil, and animal responses were sampled (both in Experiments 1 and 2) in three different pasture zones defined based on their distance from shade and water (Zone 1: 0 – 8 m; Zone 2: 8 – 16 m; Zone 3: > 16 m).

**Herbage Responses**

Herbage production and nutritive value responses of Pensacola bahiagrass pastures to a range of management intensities (Experiment 1) and stocking strategies (Experiment 2) were evaluated from 2001 to 2003. Under continuous stocking, herbage responses differed among pasture zones. Herbage accumulation rate and nutritive value were greater in the zone closest to the shade and water (Zone 1), while herbage mass was lowest in Zone 1. Greater accumulation rate and nutritive value in Zone 1 likely reflect the greater concentration of nutrients from animal excreta in zones closer to shade and water. Lower herbage mass in Zone 1 is reflective of greater time spent in this zone by grazing animals (Chapter 4). Also, increasing management intensity from Low to Moderate increased herbage accumulation rate and herbage nutritive value, but the results obtained do not support the use of N fertilization above 120 kg N ha⁻¹ yr⁻¹ for bahiagrass pastures in North Central Florida because there was no further increase in herbage accumulation from Moderate to High.

In Experiment 2, herbage accumulation was lower in continuously stocked pastures when compared to rotational ones, but there were no differences among rotational strategies. Herbage nutritive value (N, P, and IVDOM) increased after the first experimental year, but it was not affected by grazing method (continuous vs. rotational).
or length of grazing period (rotational treatments) in more than 1 out of 3 yr. Herbage response was similar among pasture zones in Experiment 2, indicating a more uniform regrowth and chemical composition in more intensively managed pasture systems and rotationally stocked pastures.

Considering that no additional herbage accumulation response occurred with N fertilizer greater than 120 kg ha$^{-1}$ yr$^{-1}$, and the advantages already mentioned for rotational stocking with short grazing periods, a potential system to optimize beef cattle production on bahiagrass pastures in North Central Florida is to use rotational stocking with short grazing periods (< 7 d), a 21-d resting period, and N fertilizer applied at approximately 120 kg N ha$^{-1}$ yr$^{-1}$.

**Animal Behavior and Soil Nutrient Redistribution**

The environment and management practices may affect animal behavior and soil nutrient distribution. Animal behavior observations and soil characterization were performed in three pasture zones in the two grazing experiments described previously. Soil samples were collected at the beginning and at the end of each grazing season, in the three pasture zones and at two depths (0 - 8 cm and 8 - 23 cm). Animal behavior observations were performed five times in 2002 and four times in 2003 in order to evaluate the environment x treatment interactions.

Under continuous stocking, management intensity did not affect animal behavior, but it did affect soil nutrient concentration. Nitrogen, K, and Mg concentration in the soil were greater at the highest management intensity at the shallower soil depth but not deeper in the soil profile. This is an important indication that although soil fertility is increasing in the surface horizon, nutrient movement into deeper soil horizons was not occurring when higher management intensity was used on bahiagrass pastures. Soil
nutrient concentration was generally greatest in the pasture zones closer to shade and water with a higher proportional return of excreta occurring in those areas. Rotation of shade to different pasture areas during the grazing season may improve excreta distribution reducing the problem of high soil nutrient concentration in small pasture areas. Weather variables affected grazing time in pasture zones and therefore excreta return. Ultimately soil nutrient distribution was also affected. Selection of animals more adapted to heat stress may be a potential tool to reduce the magnitude of the climate effect on animal behavior.

In Experiment 2, stocking methods influenced grazing time, excreta deposition, and soil nutrient distribution. Short-grazing periods promoted greater uniformity in nutrient distribution among pasture zones when compared to long-grazing periods. Also, continuous stocking presented results similar to rotational stocking with a 21-d grazing period, showing greater density of excreta deposition and greater accumulation of soil N in Zone 1. Soil nutrient accumulation occurred at the shallower depth (0 - 8 cm) but not deeper in the soil profile (8 - 23 cm) in zones closer to shade and water. Because short-grazing periods require more paddocks and therefore more shade locations and watering points per unit area, the long-term trend is a more uniform distribution of soil nutrients in the shorter-grazing period treatments.

Environment may affect animal behavior and, as a result, nutrient distribution. Animals spent more time close to shade and water during warmer days, leading to greater excreta deposition in these small pasture areas. Besides shade and watering areas, lounging sites are also potential nutrient-enriched areas due to higher density of excreta
deposition. Better adapted animals may enhance uniformity of excreta deposition by spending less time in lounging areas.

**Litter Production and Decomposition**

Plant litter and animal excreta are the two major pathways of nutrient return to the pasture. Management practices alter the proportion of nutrients returning via excreta and litter, therefore, altering the availability, uniformity of distribution, and losses of nutrients. Litter production and decomposition were measured in Experiment 1 during 2002 and 2003.

Management intensity altered litter dynamics in continuously stocked Pensacola bahiagrass pastures. Herbage mass increased as the season progressed for Low and Moderate treatments, but not for the High treatment because of the greater stocking rate. Lower management intensity consistently resulted in greater existing litter, but increasing management intensity from Low to High altered litter deposition and decomposition rates, and seasonal fluctuations in existing litter occurred as a result of the balance between those two rates. Existing litter was greatest at the beginning and at the end of the grazing season. After declining during the early part of the grazing season, litter began to re-accumulate sooner for the High treatment because of earlier peaks in litter deposition rate for that treatment. Increases in management intensity reduced the amount of existing litter at the beginning of the grazing season; a feature likely caused by greater rates of litter decomposition during fall through spring in more intensive systems. At the end of the season, greater litter deposition than decomposition rates resulted in litter re-accumulation for all treatments.

In terms of nutrient supply, the above-ground plant litter supplies relatively small quantities of N for plant growth, but it acts as an important buffering pool by
immobilizing the N and mineralizing it later on, reducing potential N losses, particularly in an N-rich environment. Changes in litter dynamics due to management practices affect the amount and form of nutrients returning to the soil, having implications not only for the supply of nutrients to the plants but also the losses of nutrients to the environment.

**Litter Quality and Litter Nutrient Dynamics**

The low quality of C₄ grass litter may have different implications depending upon the degree of intensification of the system. In low-input systems, low litter quality may lead to pasture degradation due to nutrient immobilization. In highly fertilized systems, the litter may act as a buffering pool reducing potential nutrient losses. Litter nutrient and biomass disappearance were assessed in Experiment 1 during 2002 and 2003. Increasing management intensity resulted in better litter quality, as indicated by the litter C:N and lignin:N ratios and N and P concentrations. Seasonal fluctuations in litter quality occurred to a greater extent in the Low and Moderate treatments, as indicated by the C:N ratio, with lower litter quality observed by the end of the grazing season. In general, litter quality was sufficiently low that N and P were likely to be immobilized, particularly at the beginning and at the end of the grazing season.

In the litter bag trial, litter quality at the beginning of the incubation period was similar among management intensities but not at the end, suggesting that N immobilization is the major contributor to changing litter quality during incubation. Litter presented a high N concentration, particularly at the end of the incubation period, but the N was mostly unavailable for microbial decomposition because it was bound to the acid detergent fiber.

The improvement in litter quality with increasing management intensity results in faster litter turnover and enhancement in nutrient supply to plants and microbes, however,
it also reduces the nutrient immobilization capacity of the litter, and as a result, nutrient losses may increase. Because roots and rhizomes are an important nutrient pool in Pensacola bahiagrass pastures, additional investigation is needed to determine below-ground litter quality and decomposition rates as affected by pasture management practices to better understand nutrient dynamics in the grazed system.

**Soil Organic Matter**

Soil organic matter (SOM) accumulates when residue deposition is greater than residue decomposition. Early changes in SOM dynamics, however, are not easily detected by determining the total SOM. Physical fractionation by density and particle size may allow detection of SOM changes earlier than the total OM determination. In addition, the light OM fraction is correlated with N mineralization in the soil. The SOM characterization was performed in the continuously stocked pastures (Experiment 1) and in the 7-d rotational pastures (Experiment 2) during the fourth year after treatment initiation. Management intensity altered C and N concentration in the soil with contrasting effects depending upon particle size class. In particles from 53 to 2000 µm, C and N concentration in the soil increased with increasing management intensity but for particles less than 53 µm, C and N concentration in the soil decreased with management intensity. Greater residue deposition with increased management intensity but also faster SOM decomposition rates likely lead to this result. Net C accumulation occurred to a greater extent in more intensive systems because of the greater proportion of large particles in this Spodosol.

Particle size influenced the quality and the stability of the SOM. The C concentration in the SOM decreased from larger to smaller particles in the light fraction.
Nitrogen concentration in the SOM was less affected than the C concentration. The C:N ratio decreased with particle size.

Nitrogen fertilization and stocking rate appeared to have a greater effect on C and N accumulation than stocking method did. Increasing N fertilization and stocking rate resulted in greater C accumulation which has direct influence upon soil fertility and C sequestration.

Soil OM fractionation by density and particle size allowed an early detection of SOM changes in response to changes in pasture management practices. Because the different densities and particle sizes are correlated with the quality and age of the OM deposited, the fractionation detects changes in residue deposition and decomposition in the SOM of different ages. The physical fractionation method is relatively low cost and provides better results than total SOM determination.

**Implications of the Research**

Understanding nutrient cycling responses to pasture management practices allows the utilization of management to improve nutrient-use efficiency resulting in lower production costs and reduced environmental impacts. Rotationally stocked pastures with short grazing periods promoted greater herbage accumulation and more uniform herbage accumulation, herbage nutritive value, cattle grazing time, excreta deposition, and soil nutrient distribution across the pasture when compared to continuously stocked pastures. If continuous stocking is practiced, the results obtained in this experiment do not support the use of more than 120 kg N ha\(^{-1}\) yr\(^{-1}\) for Pensacola bahiagrass in North Central Florida.

In terms of litter dynamics, the low quality of the above-ground litter immobilized nutrients, particularly N, resulting in low net N mineralization. Therefore, the above-ground plant litter pool did not supply large amount of nutrients to plant and microbial
growth, but it did act as a buffering pool reducing N losses, particularly in more intensive systems.

Increasing management intensity increased C and N accumulation in the soil of grazed pastures, and it may be an important tool to improve soil fertility and C sequestration. Because of economical and environmental reasons, however, the adoption of the High treatment tested in this experiment is not recommended only for the sake of C sequestration. The data obtained in this research aid in the assessment of potential environmental impact and nutrient-use efficiency of various grazing management practices as well as provide data needed for modeling nutrient cycling in forage-livestock systems.

**Future Research Recommendations**

Studies of root and rhizome production and decomposition as affected by pasture management practices are needed in order to better understand nutrient dynamics in grazed Pensacola bahiagrass.
Figure A-1. Crude protein concentration in hand-plucked samples from bahiagrass pastures managed at different intensities.
APPENDIX B
IN VITRO ORGANIC MATTER DIGESTIBILITY (IVOMD) WITHIN THE GRAZING SEASON

Figure B-1. In vitro organic matter digestibility (IVOMD) in hand-plucked samples from bahiagrass pastures managed at different intensities.
Figure C-1. Herbage accumulation in bahiagrass pastures managed at different intensities.


Mott, G.O. 1960. Grazing pressure and the measurement of pasture production. p. 606-611. 8th International Grassland Congress. University of Reading, Reading, UK.


BIOGRAPHICAL SKETCH

José Carlos B. Dubeux, Jr. was born on 4 May 1968, in Recife, Pernambuco State, Brazil. He received a B.S. in agronomy (1990) at the Federal Rural University of Pernambuco. After graduation, José spent some time on his small farm working to establish pastures and raise dairy cows. In 1992, José returned to the university to start graduate school. He obtained a Master of Science degree (1995) in animal production from the same university where he obtained his B.S. After completion of this degree, José worked as a research assistant for one year at the Agricultural Research Institute in his state (IPA). In 1996, José started his teaching career, working at the Federal Rural University of Pernambuco as a temporary professor. In 1997, he entered the same university as a permanent faculty member in the Animal Sciences Department teaching courses related to forages and pastures. He also conducted research projects in the same area of interest. In 2001, José received a CNPq fellowship and entered the Agronomy Department at the University of Florida to pursue his PhD degree. During his PhD program, José received the Paul Harris Award in 2003 and 2004 and also the Robert F. Barnes award during the ASA-CSSA-SSSA meeting in Seattle (2004). After completion of his program, José plans to return to his university in Pernambuco and continue his career as a researcher and professor, with interest in nutrient cycling in forage and pasture ecosystems.