



Nutrient cycling in tropical pasture ecosystems

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ABSTRACT

In most forage production systems, essential nutrients required for plant growth are provided by different pools in the ecosystem. In general, warm-climate grasslands are characterized by extensive grazing systems with minimal inputs of commercial fertilizer and supplemental feed, primarily because of unfavorable economics of fertilization or limited availability of fertilizer material. Low soil N availability is a major limitation in tropical and subtropical pasture systems, and it represents one of the main causes of pasture degradation. The major pools of N in grazed grasslands are soil, vegetation, grazing animals, and atmosphere. Fluxes among the various pools are complex and are affected by biotic and abiotic factors such as climate, soil organisms, forage species, and herbivores. Therefore, nutrient cycling is a vital component in maintaining pasture sustainability because it represents an important source of nutrients to warm-season grass pastures. Excreta and litter are the two major pathways for herbage nutrients to return to the soil. Litter quantity and chemical composition are determinants in litter deposition and decomposition and are greatly affected by grazing management practices. The use of warm-season legumes in warm-season grass stands is a potential management practice that can improve litter decomposition and N inputs to warm-season grass pastures. Approximately 70 to 90% of the nutrients consumed by ruminants return to the pastures via excreta deposition; however, nutrient return through excreta is not uniform. Stocking method, portable shade and water systems, and strategic fencing are effective management practices to improve excreta distribution on pastures. The adoption of management practices that improve nutrient cycling is a determining factor to reduce warm-season grass pasture degradation and optimize productivity and persistence.

Key words: excreta, litter, pasture, warm-season grass, warm-season legume

Ciclagem de nutrientes em pastagens tropicais

RESUMO

Em sistemas de pastejo os nutrientes necessários para promover o crescimento das plantas forrageiras são supridos por diferentes compartimentos do ecossistema. Em geral, pastagens em regiões tropicais são caracterizadas por sistemas de pastejo extensivos com a aplicação de níveis reduzidos de fertilizantes nitrogenados e suplementação animal devido principalmente aos retornos econômicos desfavoráveis e à disponibilidade limitada de fertilizantes. Baixa disponibilidade de N no solo está entre as maiores limitações para a produção de forrageiras em áreas tropicais e subtropicais e uma das maiores causas de degradação de pastagens. Os maiores compartimentos de nitrogênio em pastagens são o solo, vegetação, herbívoros e atmosfera. Portanto, ciclagem de nutrientes é vital para fornecer nutrientes para pastagens em regiões tropicais. Excreta e serrapilheira são os dois maiores contribuintes de retorno de nutrientes para o solo. Quantidade e composição química da serrapilheira são determinantes no processo de deposição e decomposição da serrapilheira e são significativamente afetadas por práticas de manejo de pastagens. O consórcio de leguminosas em pastagens tropicais tem potencial de aumentar a taxa de decomposição da serrapilheira e fornecer nitrogênio a gramíneas tropicais. Aproximadamente 70 - 90% dos nutrientes ingeridos por ruminantes retornam ao pasto na forma de excreta; entretanto, o retorno dos nutrientes raramente ocorre de forma uniforme em áreas pastejadas. Método de pastejo, sombras e bebedouro portáteis e cercas construídas em posições estratégicas, são práticas de manejo eficientes para otimizar a distribuição da excreta. A adoção de práticas de manejo de pastagem com o objetivo de otimizar a ciclagem de nutrientes pode ser determinante para reduzir a degradação e aumentar a produtividade e persistência de pastagens em regiões tropicais e subtropicais.

Palavras-chave: excreta, serrapilheira, pastagens, gramíneas tropicais, leguminosas tropicais

Introduction

In most forage production systems, essential nutrients required for plant growth are provided by different pools in the ecosystem. Nutrient cycles among the various pools within an ecosystem, and losses of nutrients during this process may occur (Dubeux Jr et al., 2007). The most important pools involved in nutrient cycling in forage systems are: i. soil organic matter (SOM), ii. live plant biomass, iii. plant residues, and iv. animal excreta. Nutrient addition to forage systems includes commercial fertilizers, atmospheric deposition, and deposition of livestock wastes that contain nutrients derived from supplemental feeds.

Central to nutrient recycling in any ecosystem is the concept of mass balance. Nutrient management in forage systems should account for the inputs and outputs of nutrients to the system (Wedin & Russelle, 2007). Nutrient budgets typically take into consideration all the sources and outputs of a particular element, and the interactions between the various pools. The removal of nutrients from grazing systems as animal products is generally a minor pathway. Conversely, in harvested forage systems where nutrients are not returned to the soil because forage is fed to livestock elsewhere, nutrient removal can be significant. The lesser proportion of herbage nutrients compared to other nutrient pools does not reduce the importance of the herbage pool on pasture nutrient cycling (Rotz et al., 2005). The importance of herbage nutrients in terms of nutrient supply increases because excreta and above-ground litter decompose faster than below ground biomass and SOM (Dubeux Jr et al., 2006a). Numerous studies have reported that the importance of herbage nutrients increases as management intensity increases (e.g., fertilizer use, stocking rate). The herbage pool in intensively managed forage systems can be a more important pathway for nutrient supply for plant growth and microbial activity than SOM mineralization (Dubeux Jr et al., 2004; Lira et al., 2006).

Warm-climate grasslands are generally characterized by extensive grazing systems with low levels of commercial fertilizer and supplemental feed, primarily because of unfavorable economics of fertilization or limited availability of fertilizer material (Dubeux Jr et al., 2007). Extensive areas of planted pastures are degraded in tropical areas of the world, primarily due to inadequate soil N supply (Boddey et al., 2004). Nitrogen is the dominant nutrient constraint on primary production in most forage systems. Hypotheses for the widespread N limitation involve the mass balance of inputs and outputs from terrestrial ecosystems (Wedin & Russelle, 2007). The major factors limiting N inputs in forage ecosystems are high cost of N fertilizer, small or negligible atmospheric contribution, and limited use of N-fixing warm-season legumes. Therefore, efficient nutrient cycling in these ecosystems is vital to maintain the productivity and long-term sustainability of grasslands worldwide.

Nutrient retention in cattle body tissue and nutrient export through beef or milk generally represent less than 30% of total nutrients ingested by cattle (Wilkinson & Lowrey, 1973; Haynes & Williams, 1993). Therefore, most nutrients ingested by cattle return to the pasture via excreta. The proportion of

the nutrients not consumed returns via deposition of senescent plant material, the litter, on the soil. Thus, excreta and litter are the two major pathways of herbage nutrient return to the soil (Thomas, 1992).

The objective of this review was to describe the dynamics of N and C and contribution of cattle excreta and litter in nutrient cycling in tropical and subtropical grassland ecosystems.

Nitrogen and Carbon Dynamics in Grasslands

The major pools of N in grazed grasslands are the soil, vegetation, grazing animals, and atmosphere (Dubeux Jr et al., 2007). Fluxes among the various pools are complex and are affected by biotic and abiotic factors such as climate, soil organisms, forage species, and herbivores (Myers et al., 1986). Considering all terrestrial ecosystems, the atmospheric N pool is 16000 times greater than the sum of soil and biotic N pools (Russelle, 1996). Soil N availability is almost entirely regulated by biotic processes. Because the majority of the soil N is found in organic forms, the importance of soil minerals regulating N availability is less compared to P and K. Conversely, the direct C-N covalent bond of N in organic matter is considerably stronger than the ester bond commonly holding P (Aber & Melillo, 1991). As a result, breaking of the organic C-N bond is expensive to microbial decomposers in terms of energy and enzymes.

Because of the strong role of plant tissue chemistry in regulating the N cycle, in addition to soil N availability, it is critical to consider the characteristics of past and present vegetation. The C:N ratio of plant residues affects both the rate of decomposition and the balance between N mineralization and N immobilization by microbes. Knops et al. (2002) suggested that no net mineralization occurs in decomposition of plant residues if they initially contain less than 0.75% N, which is typical N concentrations for above-ground senesced tissues of unfertilized warm-season grasses. Herbage nutrients (e.g. N and P) represent a minor portion of total nutrients contained in a pasture ecosystem contrasting with SOM which is the major reservoir of pasture nutrients (Dubeux Jr et al., 2004). Dubeux Jr et al. (2004) estimated that in grazed bahiagrass (*Paspalum notatum* Flüge) pastures, approximately 60 and 89% of the total C and N pools, respectively, were associated with SOM, while the remaining fraction was allocated to above- and below-ground vegetation. Nitrogen associated with SOM in grasslands generally ranges from 5000 to over 20000 kg N ha⁻¹ and net mineralization rates generally range from 20 to 80 kg N ha⁻¹ yr⁻¹ (Parton et al., 1987).

Differences in SOM quality between grasslands and forest ecosystems is evident in the greater C:N ratio in grasslands as compared to intact forest (Johnson & Wedin, 1997). Nitrogen cycle in tropical forests is characterized by litter inputs with rapid decomposition, and high availability (Vitousek, 1984). In contrast, the N cycle under grass-dominated ecosystems is characterized by large inputs of low N concentrations associated with organic matter, which can immobilize soil inorganic N (NH₄⁺ and NO₃⁻) and promote N deficiency in plants and microorganisms.

Grasslands account for more than 10% of the total biosphere C storage (Eswaran et al., 1993) and soil is the largest C pool in grassland ecosystems. Thomas & Asakawa (1993) and Stevenson & Cole (1999) reported that SOM contains 30 to 50×10^{11} Mg C compared to 7×10^{11} and 4.8×10^{11} Mg C in the atmosphere and plant/animal biomass, respectively. Tropical grasslands and savannas contain only 6% of global terrestrial biomass (Schlesinger, 1997) and about 15% of global soil organic C (Jobbagy & Jackson, 2000). Worldwide, approximately 22% of global soil organic C is associated with grasslands (Jobbagy & Jackson, 2000).

Grazing management alters C storage in grassland ecosystems by modifying the magnitude and relative allocation of C to above- and below-ground biomass, altering microclimate and the availability of light, water, and nutrients in systems, as well as modifying the functional diversity of plants (Hobbie, 1992). Proper grazing management, which maintains the recommended stubble height and the reserve structures of the forage, can increase soil C accumulation (Derner & Schuman, 1997; Schuman et al., 1999; Lal, 2002; Conant et al., 2003). In non-degraded grasslands, grazing management represents the most important factor that can affect soil C accumulation. In a 2-year study, Dubeux Jr et al. (2006b) reported that greater stocking rate and N fertilization of bahiagrass pastures resulted in accumulation of C in the light density (1.85 g cm^{-3}) SOM fraction. These results demonstrated that SOM in grasslands is subject to short-term changes in grazing management. Silveira et al. (2013) observed that grazing intensity and N fertilization levels on Tifton 85 bermudagrass (*Cynodon* spp.) pastures had no effect on bulk soil total C and N concentration and content. However, greater stubble height and N fertilizer levels resulted in a linear increase in particulate organic C and C and N concentration in the $<53\text{-}\mu\text{m}$ particle-size fraction. In addition, grazing intensity and N fertilization showed significant effects on $\delta^{13}\text{C}$ values and the relative amounts of $\text{C}_3\text{-C}$ vs. $\text{C}_4\text{-C}$. The $\delta^{13}\text{C}$ data indicated that readily decomposable C components ($\text{C}_4\text{-derived C}$) were lost in response to more intensive grazing.

Despite the positive effect of management intensity of SOM levels, the mass of C in above-ground vegetation may decrease with increasing grazing intensity. Schuman et al. (1999) examined the plant–soil C balance in a mixed-grass rangeland (55% cool-season species and 23% warm-season species) under three livestock stocking rates: non-grazed exclosures, light stocking rate (20 steer-days ha^{-1}), and heavy stocking rate (59 steer-days ha^{-1}) and found that total above-ground C mass was 1620, 1280, and 750 kg ha^{-1} , respectively. Conversely, there was an increase in total soil C from 0 to 15 cm from 28,000 to 35,000 kg C ha^{-1} from non-grazed exclosures to grazed areas.

Nutrient Cycling via Litter

Plant litter is one of the major sources of plant nutrients in forage systems. As a result of leaf abscission, stem lodging, and trampling of aerial plant parts by animals (Lodge et al. 2006), litter decomposition is a fundamental process influencing nutrient cycling (Hoorens et al., 2003) in pastures. Accumulation of plant litter may also affect grassland

vegetation community, plant composition and persistence (Patrick et al., 2008).

Litter quality is among the primary drivers of terrestrial decomposition (Aerts, 1997). Differences in initial quality of plant litter may be introduced by plant senescence, which starts when the leaf is still attached to the plant. Plant translocate nutrients and other soluble compounds, such as sugars and phenols, from these leaves before they fall (Berg & McClaugherty, 2008). In grazed swards, portions of the leaves which have not been harvested by animals are senescing (Dubeux Jr et al., 2007). In well-managed grazing situations, the proportion of leaf tissues escaping intake by animals is approximately 30% of the leaf tissue produced (Mazzanti et al., 1994). In the litter, nutrients like N are chemically bound to C. Numerous studies have reported that C:N ratio, lignin and other polyphenol concentrations are important factors affecting the decomposition rate of plant litter (Ball & Drake, 1997).

Dubeux Jr et al. (2006e) evaluated the effects of concomitant increase in stocking rates and N fertilization levels on litter mass, deposition rate, and chemical composition in continuously stocked bahiagrass pastures. Greater stocking rates and N fertilization initially resulted in less litter mass; however, greater litter mass was subsequently observed later in the growing season. Rate of litter deposition decreased from ~ 30 to 20 $\text{kg organic matter d}^{-1}$ for the highly intensive as compared to the low intensity systems, respectively. In addition, Dubeux Jr et al. (2006e) also observed that greater stocking rates and N fertilization levels resulted in litter with greater N concentration (22.9 vs. 14.1 g kg^{-1}) and lesser C:N ratio (20 vs. 40). Liu et al. (2011a) evaluated the effects of post-graze stubble height (8, 16, and 24 cm) and N fertilization levels (50, 150, 250 kg ha^{-1}) on litter mass, deposition rate, and chemical composition on Tifton 85 bermudagrass pastures. Litter mass and deposition rate increased as post-graze stubble height increased from 1730 to 2510 kg ha^{-1} and 10 to 30 $\text{kg ha}^{-1} \text{d}^{-1}$, respectively; however, N fertilization levels had no effect on litter mass and deposition rate. Increasing N fertilization levels increased N litter concentrations and decreased C:N ratio from 43 to 26. Dubeux Jr et al. (2006e) reported plant litter deposition of 4540 kg OM ha^{-1} during a 168-d grazing season of ‘Pensacola’ bahiagrass. Thomas & Asakawa (1993) measured from 2830 to 11 800 kg DM ha^{-1} of litter deposited from May to December in creeping signalgrass [*Brachiaria humidicola* (Rendle) Schweick.] and gambagrass (*Andropogon gayanus* Kunth) pastures.

According to Myers et al. (1994), litter influences the net balance between mineralization and immobilization, which is particularly important for N, P, and S availability. Typically, there is a positive correlation between litter decomposition and nutrient concentration (Taylor et al., 1989). Fresh litter may contain insufficient nutrients to support microbial use of the C contained within the litter (Staaf & Berg, 1981). Litter decomposition of tropical grass pastures is limited by high C:N ratio, lignin:N ratio, and acid detergent insoluble N (ADIN) concentration. Under these circumstances, nutrient immobilization occurs to a great extent and is considered one of the major causes of pasture decline (Robbins et al., 1989) in tropical ecosystems. Cantarutti (1996) observed that during the

first week of incubation of soil samples with litter of creeping signalgrass [*Brachiaria humidicola* (Rendle) Schweick], 600 to 800 g kg⁻¹ of all soil mineral N was immobilized and 300 to 500 g kg⁻¹ remained immobilized after 150 days. In Brazil, most of the planted pastures are pure grass stands of *Brachiaria* genus, and to a lesser extent *Panicum* or *Andropogon* genera (Boddey et al., 2004). Therefore, accumulation of low quality litter may be one of the causes of extensive pasture degradation in Brazil. Dubeux Jr et al. (2006c) investigated the effects of stocking rates and N fertilization levels on litter decomposition and mineralization of bahiagrass pastures. Litter decomposition was greater for higher stocking rates and N fertilization levels increasing from 0.0016 to 0.0030 g g⁻¹d⁻¹. The net mineralization after 128 days of incubation was ~ 250 g kg⁻¹ of the total N. Increasing stocking rates and N fertilization levels resulted in faster litter turnover and greater nutrient release. Liu et al. (2011b) observed that increasing post-graze stubble height from 8 to 16 cm did not affect litter decomposition in Tifton 85 pastures; however, increasing N fertilization levels from 50 to 250 kg ha⁻¹ yr⁻¹ increased litter decomposition.

According to Wedin & Ruselle (2007), low tissue N concentration of senescent leaves and roots leads to microbial N immobilization and reduces net N mineralization and subsequent N availability to plants. Low N availability can, therefore, reduce forage production, nutritive value, and pasture persistence.

Use of warm-season legumes as a means to improve litter quality

Warm-season grasses produce litter of low quality, which may lead to immobilization and nutrient deficiency in low-input pasture systems. An alternative to minimize the negative effects of microbe-induced nutrient deficiency is to improve litter quality and subsequently promote a more efficient nutrient cycling in pastures. Mixed grass-legume pastures (Cantarutti et al., 2002) or pasture fertilization (Dubeux Jr et al., 2006e) are two options to improve litter quality. Economic aspects of pasture fertilization in tropical developing countries have not been favorable in the last years (Martha et al., 2004); therefore, the inclusion of forage legumes in pure grass pasture remains the best option to improve litter quality in these regions (Cantarutti et al., 2002, Dubeux Jr et al., 2006a, Lira et al., 2006).

Biological N fixation requires other elements, including P, Fe, S, and Mo. In highly weathered and low-pH soils, these elements, although present, may be immobilized in a variety of geochemical forms (Wedin & Ruselle, 2007). Three conditions are necessary for maximizing N₂ fixation in mixed swards: i. high forage yield, ii. high proportion of legumes in the mixture (> 50%), and iii. high reliance of the legume on N₂ fixation (> 70% of plant N; Boller & Nosberger, 1987). Maintenance of sufficient legume populations has been difficult in many mixed pastures due to selective grazing, inadequate soil fertility, and stand decline caused by pest infestation.

Nitrogen is transferred from legumes through exudation and leakage of N from roots and nodules, senescence and degradation of nodules and roots, direct transfer from legume

roots to non-legume roots through connections made by arbuscular mycorrhizal fungal hyphae, movement of N from legume herbage to the soil by leaching or decomposition of surface litter, and re-deposition of consumed N by livestock. However, the predominant pathways are the decomposition of above and below-ground plant residues and return of N via animal excreta.

Recent stories of grass-legume pastures in warm-climates include *Desmodium ovalifolium* (Prain) Wall. ex Merr. (Cantarutti et al., 2002), *Arachis pintoi* Krapov. & W.C. Greg. (Valentim & Andrade, 2005a), *Pueraria phaseoloides* (Roxb.) Benth (Valentim & Andrade, 2005b), and *Calopogonium mucunoides* Desv. (calopo; Zimmer & Seiffert, 1983) cultivated in association with different *Brachiaria* species. Silva et al. (2012) evaluated signalgrass [*Brachiaria decumbens* (Stapf) R.D. Webster] litter chemical composition and decomposition with the inclusion of 0, 50, and 100% of calopo litter. Pure signalgrass litter C:N values were ~ 5% greater than pure calopo, while the inclusion of 50% calopo reduced grass C:N ratios by ~ 63%. Net annual N mineralization rates were 270 and 380 g kg⁻¹ yr⁻¹ for pure grass and 50% calopo, respectively.

Nutrient Cycling via Excreta

Large herbivores play a dominant role in nutrient cycling in pastures via excreta. The proportion of ingested nutrients retained in body tissue and exportation in animal products is low relative to that which is excreted. In general, 70 to 90% of the nutrients return to the soil via excreta deposition (Whitehead, 2000); however, nutrient return through excreta is not uniform. Cattle tend to congregate in small areas of the pasture, usually near shade, watering and bedding sites (Mathews et al., 1996; Haynes & Williams, 1993). In addition, topography and other site conditions can exert differential effects on grazing and excretion behavior, leading to zonal heterogeneity in nutrient distribution (Jewell et al., 2007). Cattle usually prefer flat zones as bedding sites and visit inclined zones only for grazing. Thus, a greater proportion of excreta return occurs on the bedding areas, reducing soil fertility in other pasture areas relative to nutrient concentration in the resting sites. Schnyder et al. (2010) studied N and P transfers by cattle in two grazing periods and their relationship in an unfertilized pasture with a history of > 50 years grazing. Nutrients accumulated in the flat crest topography zone and were depleted in the steeper areas. Nutrient ingestion was less and excretion greater in the accumulation areas, revealing that both components of graze-driven net transfers of nutrients promoted the localized accumulation of nutrients.

Partitioning of nutrients between feces and urine also reduces the uniformity of nutrient return through excreta. Cattle grazing a given patch consume forage containing different nutrients; however, the return does not occur uniformly. Phosphorus, Mg, and Ca return mainly in feces while K and Na return mainly via urine (Mathews et al., 1996). Because dung and urine events often do not occur at the same site, nutrient return is not uniform.

Nutrient bioavailability is greater in excreta than plant litter (Mathews et al., 1996), leading to a faster uptake by plants. The

negative aspect of this is nutrient loss, which is also greater when it returns via excreta, particularly N and to a lesser extent P (Boddey et al., 2004). Increasing stocking rate often leads to a greater proportion of nutrient return via excreta compared to litter (Thomas, 1992). Boddey et al. (2004) concluded that pasture decline is hastened by increasing stocking rates without increasing pasture primary productivity (i.e., increase in grazing pressure).

Grazing management exerts a major influence on herbage nutrient returns, altering the proportion of nutrients returned via excreta and litter (Thomas, 1992). Stocking method is one management option to improve nutrient distribution. Rotational stocking with short grazing periods (1 vs. 4 days) may provide the high stocking density necessary to enhance uniformity of excretal return while reducing steep nutrient gradients near shade and watering sites (Peterson & Gerrish, 1996). Dubeux Jr et al. (2006d) compared dung distribution of heifers under two rotational stocking strategies (7 and 1 day grazing periods) and continuous stocking on Pensacola bahiagrass pastures. Rotational stocking with a 1 day grazing period promoted more uniform dung distribution compared to rotational stocking with 7 day grazing periods and continuous stocking, which followed a negative binomial distribution. Contrary to the Dubeux Jr et al. (2006d) study, Mathews et al. (1994) suggested that stocking method had little effect on short-term (2-year) soil nutrient distribution, especially when grazing occurred during months when temperatures were high. These contrasting results may be due to the fact that Mathews et al. (1994) moved water troughs and portable artificial shade along the fence line in both continuously and rotational stocked pastures, reducing potential nutrient concentration near those sites, while Dubeux Jr (2006d) did not move shade and watering points under continuous stocking, a practice more common among land owners. Dubeux Jr et al. (2009) observed that surface-soil N, P, and Mg concentrations were greater in continuously stocked bahiagrass pastures with greater stocking rates and N fertilization levels. Russelle (1997) suggested that moving shade and watering points improves nutrient distribution, but this may not be practical in extensively-managed pasture systems.

Animal aspects that influence solar radiation tolerance may be tools in warm climates to enhance nutrient distribution. Cattle breed and coat-color may interact with environmental conditions and thereby affect pasture utilization and nutrient redistribution patterns (Sollenberger et al., 2002). Brahman cattle, for example, spend less time under shade than non-Brahman cattle (Blackshaw & Blackshaw, 1994) and Holstein cows with predominantly black coats spent 20 min d⁻¹ more time under shade in Florida, USA, compared to predominantly white-coated cows (Macon, 1999). Because there is a correlation between time spent in a particular pasture area and the number of excretions (White et al., 2001), the more time cattle spend under the shade, the greater the nutrient concentration in that area (i.e., less uniformity of distribution). Dubeux Jr et al. (2009) observed that from 0 to 8 cm soil depth, P and K concentrations were greater 16 m radii from the shade and water (21 vs. 10 mg kg⁻¹ and 103 vs. 52 mg kg⁻¹ for P and K, respectively) than in the remaining area of the pasture.

The greater concentrations of nutrients were associated with greater proportional time spent at these points that resulted in greater return via excreta by cattle. Increasing air temperature and temperature-humidity index increased time spent under the shade and affected patterns of excreta return.

During & Weeda (1973) applied cattle manure with low and high P concentrations to pastures in simulated piles of 0.05 m² in ground coverage. Manure piles affected herbage accumulation in a zone 5-fold larger than the area physically covered by the pile. In a 0.25 m² area surrounding a manure pile, herbage accumulation and P content increased 14 and 23%, respectively. Possible causes of these effects were the nutrient movement from the pile washed by rain events and lateral spread of roots, rhizomes, and stolons. Grazing animals avoid fouled herbage if they have the choice, and this behavior may lead to creating heterogeneous herbage mass and nutritive value in the pasture. Teixeira et al. (2012) tested the effects of dung piles on herbage mass, rejection by livestock, and chemical composition on signalgrass pastures grazed at three stocking rates (1.9, 3.2, and 4.2 AU ha⁻¹). Herbage mass increased near the dung pad by 40% compared to the surrounding areas but was not affected by stocking rate. Herbage rejection was greater near the dung pad and rejection was greater at lower stocking rate. Plants distant from the dung pad had lower P concentrations. White (2008) collected urine and feces from heifers grazing bahiagrass pastures fertilized with 60 or 120 kg granular N ha⁻¹ and applied the urine or feces in pastures at the equivalent rates of 0, 60, or 120 kg N ha⁻¹ 1, 2, or 3 times over 7 months. There was a frequency × excreta type interaction for herbage responses. The interaction occurred because dung application had no effect on most herbage responses, whereas responses to urine were consistently significant. In urine-treated plots, herbage accumulation increased from ~2600 kg ha⁻¹ at zero application to ~4600 kg ha⁻¹ with three applications, while over the same application frequency herbage N concentration increased from 13.3 to 16.2 g kg⁻¹. In urine-treated plots, herbage response generally was greatest near the center of the urine deposit and decreased as distance from the center of the excreta application increased. In dung-treated plots, physical interference by dung resulted in decreased herbage accumulation in the area under the dung deposit and dung had no effect on any response outside the area physically covered by the dung.

Soil mesofauna may also improve nutrient cycling efficiency. Dung beetles (*Scarabaeidae* family) and earthworms (*Lumbricidae* family) increase the rate of mineralization, and reduce NH₃ volatilization by incorporating feces into the soil, as well as control denitrification through elimination of anaerobic zones within fecal deposits (Mathews et al., 1996; Mathews et al., 2001).

Summary and Conclusions

Unfavorable economic return of inorganic fertilization and depleted soil fertility in tropical and subtropical regions of the world has resulted in decreased warm-season grass pasture productivity, persistence, and long-term sustainability. As a result, producers often reduce stocking rates and animal

productivity in response to poor pasture performance which may negatively affect the profitability of livestock operations. Significant research has been conducted in the last decade with the goal of creating and promoting the use of viable and practical technologies that can be integrated into forage-based livestock production systems. Stocking method, grazing intensity, strategic fertilization, and overseeding warm-season legumes are management practices that can potentially promote nutrient cycling in warm-season grass pastures. Future long-term studies are necessary to quantify the benefits of these management practices to reduce degradation and recover degraded grasslands in tropical and subtropical regions.

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