CHAPTER 4

Nutrient cycling in grazed pastures

José C.B. Dubeux Jr. [1] **and Lynn E. Sollenberger**[2]
[1]North Florida Research and Education Center, Institute of Food and Agriculture Sciences, University of Florida, Marianna, FL, United States
[2]Agronomy Department, University of Florida, Gainesville, FL, United States

Definition and importance of nutrient cycling

What are nutrients and nutrient cycling? Nutrients are elements essential for plant and livestock growth. They are found naturally in "nutrient pools" that can include soil minerals, soil organic matter (SOM), plant and animal tissue, senescent plant material, animal excreta, and the atmosphere. Nutrients do not remain in a single pool indefinitely; instead, they cycle among pools, undergoing biochemical processes that change their chemical structure and biological availability (Fig. 4.1).

Consider the nutrient cycle for nitrogen. If we start with nitrogen as a component of soil, it can be taken up by living organisms, including soil biota, plants, and livestock. For example, plants take up nitrates from the soil and transform them into amino acids and proteins. After livestock consumes forages, rumen microorganisms ferment plant proteins and other plant compounds, such as carbohydrates, to form volatile fatty acids, ammonia, and other by-products of fermentation. Protein that escapes ruminal fermentation can be digested in the abomasum and absorbed in the small intestine to become part of the animal tissue or of an animal product such as milk. Alternatively, protein can pass through the digestive tract undigested and returned to the soil via excreta. Livestock also eliminates excess N via urinary excretion. Nitrogen in livestock excreta has several fates. Soil microorganisms decompose proteins in dung with the resulting mineralized N taking different pathways, including immobilization by soil microbes, plant uptake, volatilization, denitrification, leaching, and runoff. Urinary N is mainly in an inorganic form and does not require microbial activity to be plant available. Its chemical form allows it to function much like a fertilizer nutrient source, but it also suffers greater losses to the environment, especially in warm climate regions, via ammonia volatilization. These nitrogen pathways and transformations are an example of a nutrient cycle in a grassland ecosystem, where nutrients move among different pools while undergoing chemical changes (Fig. 4.2). While this example addresses N cycling, all other nutrients pass through similar processes, with unique biochemical reactions for each nutrient.

Management Strategies for Sustainable Cattle Production in Southern Pastures
DOI: https://doi.org/10.1016/B978-0-12-814474-9.00004-9

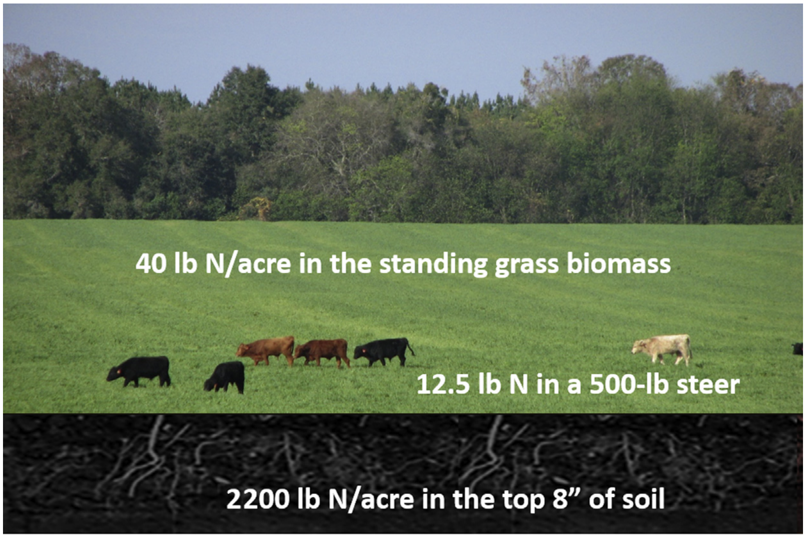

Figure 4.1 Relative N pools in a grassland ecosystem. Assuming (1) herbage mass of 2000 lb DM/acre and 2% N; (2) 2.5% N in steer body mass; (3) 2% soil organic matter (SOM), 57% C in the SOM, C:N ratio of 12:1. *Photo credit: Jose Dubeux.*

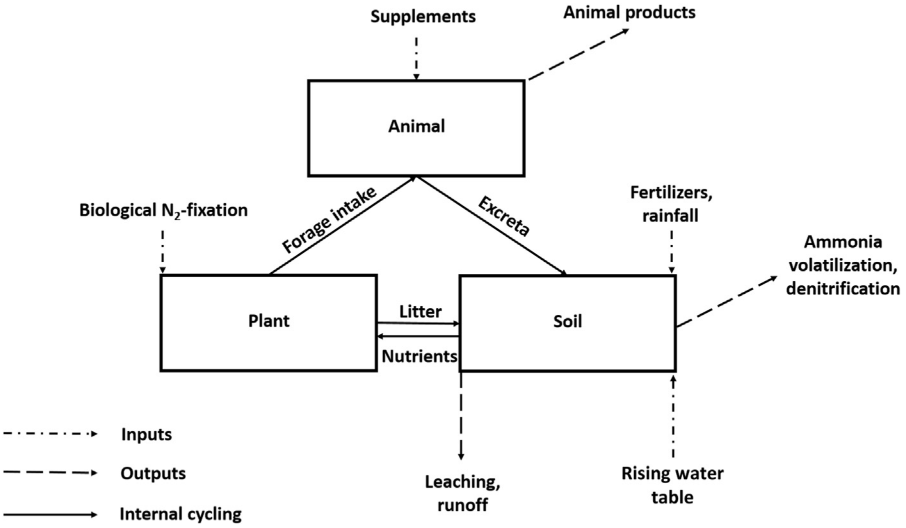

Figure 4.2 Nitrogen cycling in grassland ecosystems.

Nutrient cycling is essential in grassland ecosystems because it replenishes soil nutrients and sustains plant growth. The faster these nutrients cycle and the smaller the losses, the more efficient the process of nutrient cycling. In this chapter, we will explore ways to enhance the efficiency of nutrient cycling in grazed grassland ecosystems.

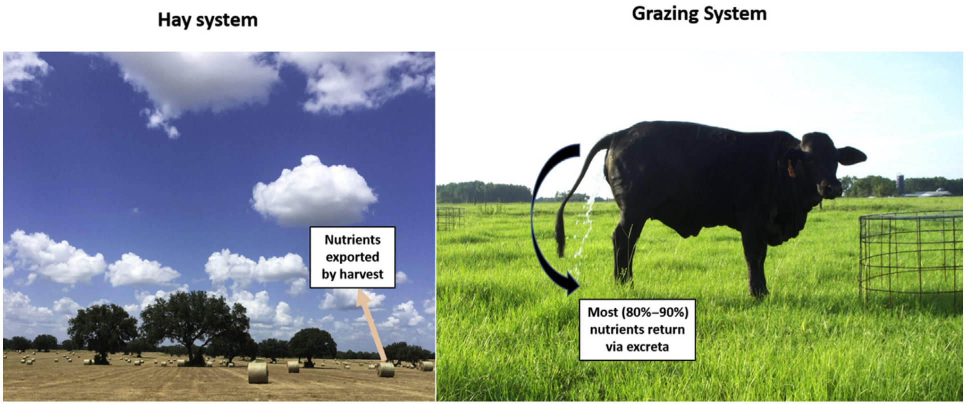

Figure 4.3 Contrasting nutrient cycling in hay versus grazing systems. *Photo credit: Jose Dubeux.*

Nutrient budgets for grazed pastures

> ***Where animals go, nutrients flow.***
>
> **D.M. Ball, G.D. Lacefield, V.G. Allen, C.S. Hoveland, and J.H. Bouton (2014)**

Nutrient budgets in the grassland ecosystems are important to define fertilization requirements when the nutrient balance is negative, and strategies to reduce nutrient losses to the environment when the balance is positive. Nutrient budgets include inputs, outputs, and transformations that nutrients undergo across ecosystem nutrient pools. The balance between inputs, outputs, and transformations will affect the sustainability of the system in the long term. Positive nutrient balances are typical in confined animal feeding operations (CAFO). Negative nutrient balances are common in low-input systems with limited use of fertilizers, or in systems where nutrients are exported via harvested forages (e.g., hay production). Grazing animals return most of the nutrients they eat back to the pasture via excreta (Fig. 4.3), but the return is not uniform and is concentrated around shade, water, and feeding points.

Inputs

Fertilizers

Fertilizers are an important source of nutrients for grazed pastures. Deficiencies of macro and/or micronutrients often limit the growth of forages, especially in highly weathered soils. Forages are not all the same, with some species requiring greater soil fertility than others. Alfalfa (*Medicago sativa* L.) is an example of a species with a large nutrient requirement, while other species, such as bahiagrass (*Paspalum notatum* Flügge) and bermudagrass [*Cynodon dactylon* (L.) Pers.], are able to persist and produce in low-input systems. In some regions or production systems, nutrient inputs to grazed pastures via fertilizer are limited because of economic constraints. One of the approaches to overcome this limitation is to use forage crops adapted to low soil fertility. In contrast to these nutrient-scarce environments, grazing systems using excessive fertilization and pastures associated with CAFO often have a surplus of nutrients with a positive nutrient balance. This may lead to environmental contamination because of nutrient losses.

Legumes are an alternative to N fertilizer to increase the amount of N in grazed pastures. Forage legumes are able to overcome soil N limitations by associating with soil microorganisms to transform atmospheric N_2 into N compounds that plants can use. However, biological N_2-fixation (BNF) requires other essential nutrients that are often deficient in soils, such as P, K, S, B, Mo, and in some cases, Fe. Thus, even in grass–legume mixtures, fertilization is necessary to obtain the full benefit from BNF.

Biological N_2-fixation

BNF is an important N input in terrestrial ecosystems. Forage legumes associate with soil bacteria to convert atmospheric N_2 to ammonia [1]. Some grasses associate with BNF microorganisms (diazotrophs) that are able to fix atmospheric N_2 [2], but the amount fixed is highly variable and is usually much less than BNF from legumes. These N inputs from legume BNF bring a variety of benefits to grasslands and land-managers, and these include reduced cost due to less N fertilizer, enhanced nutrient cycling, greater pasture productivity, and improved forage nutritive value.

In the Southeastern United States there are many forage legume options, including the perennial legumes rhizoma perennial peanut (*Arachis glabrata* Benth.); short-lived perennials such as alfalfa, red clover (*Trifolium pratense* L.), white clover (*Trifolium repens* L.), and pigeon pea (*Cajanus cajan* L.); warm-season annuals such as cowpea (*Vigna unguiculata* L.), sunn hemp (*Crotalaria juncea* L.) and aeschynomene (*Aeschynomene americana* L.); and cool-season annuals such as crimson (*Trifolium incarnatum* L.), and ball (*Trifolium nigrescens* L.) clovers. Poor persistence of perennial forage legumes in mixed grass–legume pastures is often a problem, although grazing-tolerant types of some species have been identified [3]. Managing annual legumes to reseed can be a challenge, but it is possible with proper timing and intensity of grazing [4].

Amount of fixed N in grass–legume mixtures depends on the proportion of legume in the mixture, overall legume forage production, N concentration of the legume, and proportion of N that is derived from the atmosphere versus that from the soil. Typically, it is necessary to have at least 30% legume in the total forage mass to measure significant contributions of BNF [5].

Atmospheric deposition

Nutrient deposition from the atmosphere is also an input to the pasture nutrient budget. Annual atmospheric N deposition is typically lower than 10–15 lb N/acre.

Although this amount might be considered low for cultivated forage crops and pastures, it is significant for rangelands and extensive livestock systems. Nitrogen is the main nutrient deposited. The average deposition has been increasing since the mid-1990s and could more than double by 2050 [6]; however, other nutrients including sulfur are also deposited [7].

Feeds and supplements

Supplements fed to grazing animals are another nutrient input to grazed pastures. Supplementation, in this case, encompasses mineral mixtures, creep feeding, or supplementation to adult livestock using concentrates or roughages (e.g., hay or baleage). Supplementation amount, type of supplement, and supplement chemical composition are the main factors of importance for this source of nutrients in the overall pasture nutrient budget. To avoid large deposition of nutrients from livestock excreta around supplement or mineral feeding stations on pastures, it is important to move feeders and periodically distribute hay bales to different locations.

Outputs and losses

Nutrients can exit the grassland ecosystem in different ways, including exportation via animal products such as beef, milk, and wool, or through losses via different processes, including ammonia volatilization, denitrification, leaching, and runoff. Maximizing exportation via animal products with reduced nutrient losses is the goal of the land manager.

Nutrient losses

Ammonia volatilization

Ammonia volatilization is a major pathway of N loss and is more important in warm-climate regions and during periods when rainfall is plentiful. Ammonia volatilization is affected by several environmental factors, and the amount of volatilization is difficult to predict. Conditions that favor ammonia volatilization include large amounts of plant litter residue, warm temperatures ($>55°F$), a drying soil surface (water vapor loss from surface), neutral or alkaline soil pH, and soil with a low cation exchange capacity [8]. Based on these conditions, urine spots from grazing animals are “hotspots” for ammonia volatilization. The moisture from the urine coupled with the urea present in the urine and the high pH favor the ammonia volatilization process. Losses from urine patches vary with environmental factors, and in some cases can be as high as 25% of the N returned in a particular spot [9].

Denitrification

Denitrification is the chemical reduction of soil nitrates or nitrites by denitrifying bacteria leading to gaseous N losses. When oxygen is limited, some bacteria use nitrate to support respiration. Thus, denitrification occurs in anaerobic conditions with the presence of denitrifying microorganisms, soluble C compounds, and oxidized forms of N (e.g., nitrates or nitrites). In addition to N losses, denitrification end-products, such as nitrous oxide (N_2O), are powerful greenhouse gases. N_2O has a global warming potential 298 times greater than carbon dioxide for a 100-year timescale [10].

Based on the conditions for denitrification to occur, management strategies that enhance uniformity of nutrient spatial distribution across the pasture will reduce N losses via this pathway. When selecting sites for locating grazing systems with greater N inputs, poorly drained soils should be avoided. These poorly drained areas may be used for more extensive systems, that is, with reduced fertilization and off-farm nutrient inputs, and/or to establish natural reserves. Preventing nitrification can potentially reduce denitrification losses. Some plants produce nitrification inhibitors and release them into the area around the roots (i.e., rhizosphere), reducing nitrate formation, and thereby reducing denitrification losses [11].

Leaching

Leaching occurs when nutrients move with water beyond the root zone. Plants are no longer able to take up these nutrients and they move into the groundwater. This problem is important because nutrients are valuable, but it is particularly critical because of potential environmental contamination of groundwater, lakes, and streams. Excessive nutrient concentration impairs the use of water for humans and promotes algea growth (i.e., eutrophication), which can result in reduction of oxygen levels in the water and thereby affect fish and other aquatic organisms.

Movement of water beyond the root zone occurs when water input from rainfall or irrigation is greater than the soil water storage capacity for the soil layers where most roots are located. Nutrient concentration in the water will also drive nutrient leaching. Soil texture affects soil water storage capacity, with clay soils storing more water than sandy soils. Management practices that strengthen and develop the root system while establishing conditions for deeper rooting will reduce leaching and nutrient losses. One important example of such practices is the proper adjustment of stocking rate. Plants that are overgrazed have less root mass and shallower roots; thus, they are not well-suited for efficient nutrient uptake. Avoiding pasture fertilization when the soil is already wet and additional rainfall is predicted will also reduce nutrient leaching.

Runoff

Runoff is the water discharged into surface water bodies. When rainfall is greater than soil infiltration rate, surface runoff occurs. Factors affecting runoff include rainfall intensity, slope, soil water storage capacity, and infiltration rate [12]. Nutrients contained in the runoff water will be lost from the system and deposited elsewhere. When added to lakes and streams, these nutrients can cause eutrophication, especially when soil fertility is high, as typically found around CAFO. Reducing soil nutrient concentration in these areas is essential, and manure management is very important.

Animal products

Nutrient output via animal products is one of the major goals of livestock production; therefore, we do not consider it a nutrient loss. However, as the nutrients move out of the natural cycle in the grassland ecosystem, this output must be considered in the overall nutrient budget. Nutrient export via animal products varies with the animal physiological status (e.g., lactation, growth), level of production, and the type and composition of the product exported. In general, ruminants return most (80%–90%) of the nutrients they consume to the system in excreta [13], but a small portion is retained in the animal body and another portion is exported via products such as milk and wool.

Transformations

In addition to inputs and outputs, there are transformations that may occur, which render nutrients unavailable for certain periods of time. For example, very low or very high pH can result in the formation of insoluble compounds. These nutrients might return to the nutrient cycle, but whenever they are unavailable, nutrient use-efficiency in the overall system is reduced.

Nutrient immobilization

Soil microbes use nutrients from the soil to grow, and they compete for nutrients directly with plants. When microbes outcompete plants for nutrients and retain these nutrients, this is referred to as immobilization, and the nutrients become unavailable for plant uptake. Certain conditions increase nutrient immobilization by soil microbes, for example, the presence of a large amount of dead plant material (i.e., plant litter) that is low in N and has a high C:N ratio. Litter C:N ratio of C_4 grasses might reach 50–100:1 while the C:N ratio of average soil microbes is 8:1. Therefore more N (and other nutrients) is needed in order for microbes to grow [14]. These nutrients come from the soil solution, which is the same pool from which plants are taking up nutrients. Immobilization is not permanent because soil microbes will die and decay over time, with nutrients being released and returned to the soil. A strategy to improve litter quality, minimize nitrogen immobilization, and enhance the efficiency of nutrient cycling is that of integrating legumes into livestock systems [15]. Another approach is to apply nutrients via fertilizer to reduce nutrient immobilization.

Nutrient movement across soil layers

Nutrients can move vertically in either direction across soil layers and will become available or unavailable for plants. Some nutrients are readily soluble in water and move by mass flow of water across soil pore space. This is the main mechanism of nutrient transport over longer distances. Therefore, factors affecting the movement of water in the soil profile will also affect the movement of nutrients. Leaching is the main downward movement of water, and it was explained in a previous section. Upward nutrient movement might occur in soils with a high water table during periods of high rainfall, with nutrients that were formerly lower in the soil profile rising to surface soil layers [16].

Nutrient availability

Nutrients undergo chemical changes in the soil profile by converting from available to unavailable forms. Phosphorus has complex chemistry in the soil. Plants take up P as phosphates and orthophosphate. Phosphorus also forms insoluble complexes with Fe and Al that make it unavailable for plant uptake. Soil pH is a major driver of these chemical transformations, which are reversible upon pH change. Other nutrients may bind to soil colloids (e.g., 2:1 layered clay) and become temporarily unavailable for plant uptake. These chemical changes are different than soil microbial immobilization described previously. Liming is an important agronomic practice to correct soil pH, and to increase nutrient availability because it can change the chemical form in which a nutrient appears in the soil.

Excreta and plant litter: links between above- and below-ground

Once nutrients are taken up by grassland plants, they have two pathways of return to soil: litter or excreta. Forages grazed by cattle will result in nutrients returning via excreta. Ungrazed, senescent forages will return via litter. The proportion of nutrient returned through either pathway depends on the grazing pressure. Increasing stocking rate and grazing pressure results in greater nutrient flow via excreta. Low stocking rates and reduced grazing pressure shifts the return from excreta to litter deposition. In both pathways, there are advantages and disadvantages. We will discuss them in the following sections.

Nutrient return through excreta

Dung

Most of the nutrients ingested by cattle (often 80% or more) return through excreta [17]. Nutrient partitioning to dung and urine varies with several factors which include animal developmental stage, forage chemical composition, and production level. In general, most of the P and Ca (nearly 100%) and the majority of Mg (70%–90%) return via dung. Other nutrients such as Na (30%–40%) and K (10%–30%) return in

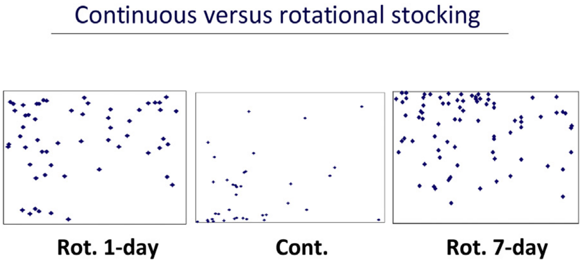

Figure 4.4 Dung spatial distribution as affected by stocking method [32]. *Rot. 1-day*, rotational stocking with a 1-day residence period; *Rot. 7-day*, rotational stocking with a 7-day residence period; *Cont.*, continuous stocking.

lower proportion through dung, with the majority excreted via urine. Nitrogen and S proportion depends on their concentration in the diet. Greater N and S concentrations in the diet increase their proportion in the urine [18].

Uneven spatial distribution of dung often occurs in grazing systems. Cattle spend more time under the shade and around mineral troughs and water sources [13]. These are considered nutrient "hotspots" because of their greater concentration of soil nutrients that derive from animal excreta. Stocking methods and managing the location of shade and water can improve the spatial distribution of nutrient return from dung. Rotational stocking with short grazing periods and high stocking rate often results in more uniform dung distribution [19]. Moving shade and mineral-feeding troughs, and if possible, the water troughs, are management practices that can improve dung spatial distribution (Fig. 4.4).

Urine

Urine is an important pathway of nutrient return to pastures. A single urine deposit by beef cattle grazing pasture may provide the equivalent of 180 lb N/acre and even larger amounts of K to the small area affected [20]. Bahiagrass forage accumulation in urine-affected areas increased 31%–58% on pastures fertilized with 53 lb N/acre per year [21]. Increases in forage accumulation were still measurable 84 days after the urine deposit, and extended up to 1 ft. beyond the edge of the actual urine application [21].

Because nutrients from urine are concentrated in relatively small areas, amounts can far exceed what plants can take up. As a result, losses occur. Nitrogen losses from urine occur mainly via ammonia volatilization, especially in warm-climate regions during the rainy season. Nitrogen losses via denitrification are also likely to occur [22]. Potassium is another important essential macronutrient that returns mainly via urine. Potassium can be lost via leaching, especially in soils with lower cation exchange capacity (e.g., sandy soils) that lack the ability to hold nutrient cations. In general, recommendations for more uniform dung spatial distribution will also be effective for urine distribution.

Forages with high N concentration, such as N-fertilized cool-season grasses, will result in a greater proportion of N returning via urine [23]. Forages with low N concentration results in a greater proportion excreted via feces [24]. One possible alternative to reduce urinary-N losses when animals consume N-rich forages is feeding low-protein, high-energy supplements, with the potential to reduce N excretion in the urine by 50% [25].

Nutrient return through plant litter

Litter quality

Above- and below-ground litter are important pathways of nutrient return to the soil. Amount of litter return will vary with grazing pressure, with greater litter deposition occurring when grazing pressure is less. Nutrient return will be a function of the amount of litter deposited, litter chemical composition, and decay rates. Several factors play a role in litter quality, including plant species, soil fertility, maturity stage, and fertilization.

Litter quality can be defined as the chemical composition and nature of chemical compounds affecting the litter decomposition process. Plants have different compounds, and some of them are more readily available for decomposition, including sugars, proteins, amino acids, and lipids. Other compounds are more resistant to decay, such as lignin, polyphenols, and structural carbohydrates. The combination of these compounds and their ratios have been used to qualify the ability of litter to decay. One of the most common indexes of litter quality is the C:N ratio. Compounds with greater C:N ratio (>30) immobilize nutrients and decay slowly, while compounds with lower C:N ratio decompose faster. Litter C:N ratio is a reliable indicator to assess potential decomposition for recently deposited residues. Long-term decomposition responses may be better explained by other indexes, such as lignin:N or lignin:ADIN (acid detergent insoluble N; considered nearly unavailable) ratio. One possible way to improve litter quality is to add plant species with greater N concentration, such as forage legumes. Because C concentration does not vary widely in plants, increasing N concentration will reduce C:N ratio leading to faster decay rates [15]. Nitrogen fertilization generally reduces litter C:N ratio and may lead to faster decay rates [26,27].

Litter decomposition and nutrient release

Litter decomposition supplies nutrients to the soil solution, which renders them available for plant and soil microbial uptake. In addition to litter quality, other factors affect decomposition including moisture, temperature, soil nutrient availability, and particle size. Faster decay rates may result in more efficient nutrient cycling; thus, more plant biomass is produced per unit of nutrient. This is particularly true when losses after decomposition are limited. Litter decay rates vary, but typically 40%–60% of warm-season grass litter decays per year [27]. Combining litter deposition, nutrient

Poor-quality litter

Assuming:

- 4,000 lb DM/acre of litter deposition
- 1% N in litter
- C:N ratio of 42
- 1/3 microbial C use efficiency and C:N ratio of 8:1 in microbial biomass

We would have:

- 40 lb N/acre deposited via litter
- 1680 lb C/acre
- We would need 70 lb N/acre to decompose the litter
- As a result, we would have a **negative balance** of 30 lb N/acre, which would come from N immobilization

- **Result:** reduced plant growth and pasture degradation

Good-quality litter

Assuming:

- 4,000 lb DM/acre of litter deposition
- 2% N in litter
- C:N ratio of 21
- 1/3 microbial C use efficiency and C:N ratio of 8:1 in microbial biomass

We would have:

- 80 lb N/acre deposited via litter
- 1680 lb C/acre
- We would need 70 lb N/acre to decompose the litter
- The N provided would give a **positive balance**, enough to decompose the litter input with a surplus of 10 lb N/acre

- **Result:** improved plant growth and pasture productivity

Figure 4.5 Effects of litter quality on nutrient cycling and pasture productivity.

concentration, and decay rates allow for the estimation of litter nutrient release [28]. It is important to account for both above- and below-ground litter when estimating litter nutrient contribution, but understanding processes involving below-ground litter presents significant challenges.

Nutrient release from decomposing litter is important, but in some cases, the timing of nutrient release may not match crop nutrient demand. In semiarid regions, litter deposited during the dry season accumulates until the beginning of the following rainy season because limited moisture during the dry season prohibits decomposition. Likewise, regions with cold temperatures during the winter have reduced litter decomposition. As a result, a flush of decomposition occurs at the beginning of the rainy, warm season with a surplus of nutrients. Often, during this time of the year the forages are in the early stages of regrowth after the prolonged dry (or cold) season. Many times the shortage of forage during this period forces land managers to stock pastures to take advantage of this fresh regrowth. This will result in nutrient losses via excreta and reduced regrowth due to overgrazing. From a nutrient management perspective, an efficient practice is to allow the forages more time to regrow by utilizing efficiently the nutrient surplus from litter that occurs at the beginning of the season (Fig. 4.5).

Excreta, plant litter, and soil organic matter

Excreta and plant litter supply C to support the formation of SOM. Initial decomposition of dung and litter will release more soluble C compounds, while more stable (i.e., recalcitrant) compounds remain. Soil microbes that use the labile (more soluble) compounds in the initial phase of decomposition will also decay over time and form stable compounds by binding with clay particles [29]. At the end of this decomposition process, a matrix composed of stable microbial products and persistent (hard-to-decay) compounds will be the building blocks of the SOM. Soils with greater SOM are able to supply more nutrients over time. This results in greater net primary productivity, which will translate into greater stocking rates and livestock productivity, with less nutrient inputs from fertilizers. Therefore, the ultimate goal is to manage SOM in such a way that it increases or at least is maintained.

SOM concentration is a function of residue deposition and decomposition. Greater residue inputs with reduced decomposition will result in greater SOM. The first step to increase residue deposition is to increase plant productivity. This will result in greater litter and excreta return to the soil. This can be achieved through diversification of plant species and plant functional groups, fertilization, irrigation, and combinations of these practices. Maintaining existing SOM is affected by land disturbance. Minimum tillage or no-tillage reduces SOM decomposition compared with soil-disturbing techniques such as plowing, disking, or tilling the soil.

Stocking rate and stocking method: how they affect nutrient cycling

Stocking rate and stocking method affect the pathway of nutrient return and its spatial distribution. Because these grazing practices can be controlled by land managers, they are powerful tools for affecting nutrient cycling in grasslands.

Stocking rate

Shifting between litter and excreta

Stocking rate directly affects the proportion of forage harvested by livestock, which in turn, affects the proportion of nutrients returning to the pasture as plant litter or animal excreta. The proportion in excreta increases with increasing stocking rate. Nutrients returned in plant litter are more evenly distributed across the pasture surface compared with those returned via excreta. Nutrient losses are less when they are returned via litter compared with urine or dung. Therefore, overgrazing might lead to increasing nutrient losses, especially N. This is of concern in low-input C_4 (i.e., warm season) grass-based pastures because it can result in loss of productivity and pasture sustainability over time [14]. Litter accumulation in undergrazed pastures is also not desirable, especially with poor-quality litter. Accumulation of poor quality litter is associated with nutrient immobilization, and thereby reduces soil nutrient availability for plant growth. Excess litter will also reduce tillering by the plants because it limits the amount of light reaching the base of the canopy. Adjustment of stocking rate is the most powerful grazing management tool to balance nutrient return between litter and excreta which is a condition that favors the pasture's ability to persist and produce over time.

Impacts on soil characteristics and nutrient cycling

Stocking rate may also affect soil characteristics which include physical and chemical properties. Cattle hooves exert pressure on soil and may cause soil compaction [30]. Therefore, it is expected that high stocking rates may lead to greater soil compaction, particularly in soils containing considerable amounts of clay. This effect, however, occurs mainly in the shallower soil layers and does not affect deeper layers. Within shallower layers, roots play a major role in stabilizing the soil, thereby increasing SOM and soil aggregates. A strong and developed root system, therefore, counteracts the compaction exerted by cattle hooves and reduces the extent of the problem. Litter cover on the soil surface also helps to reduce hoof pressure and soil compaction.

It is important to differentiate between high stocking rate and overgrazing. Productive pastures may support high stocking rates without signs of overgrazing (i.e., they maintain adequate soil cover, proper canopy height, developed root system), and with no significant soil compaction. Conversely, degraded pastures with reduced herbage mass and soil cover and a limited root system will suffer severely from high stocking rate, and soil compaction is more likely to occur.

Stocking rate will also affect soil nutrient spatial distribution and nutrient losses as it will shift the balance between litter and excreta, as explained previously. Stocking rate exerts a major effect on the root system, especially in overgrazing conditions. Overgrazing leads to a depleted root system, reducing nutrient uptake as a result. Therefore, overgrazing will not only increase nutrient losses by shifting the balance toward excreta return, but it will also reduce the plant's ability to take up nutrients because of a weakened root system.

Stocking method

Nutrient spatial distribution

Stocking method is a defined procedure or technique to manipulate animals in space and time to achieve specific objectives [31]. Continuous and rotational stocking are the most commonly discussed methods in the literature, however, there are variations of rotational stocking which differ in how animals are manipulated. One important feature of rotational stocking is the ability to congregate animals in smaller areas for shorter periods of time. This may lead to improved excreta spatial distribution compared with continuous stocking [19]. Camping sites are areas where cattle repeatedly lounge, and they usually have a greater density of excreta deposition [19]. Moving animals daily or within 1–3-day periods reduces the number of days they camp at the same site and can improve nutrient distribution. Other features related to stocking methods, such as positions of shade and water, will be discussed next.

Shade and water

Cattle spend proportionally more time in shaded areas of the pasture and near water sources which transfers nutrients from other pasture areas to these "hotspots" [19]. This will increase soil nutrient concentrations near shade and water points [33], and may result in greater nutrient losses to the environment. Because rotationally stocked pastures are subdivided into smaller paddock units, livestock are forced to utilize different camping sites across the pasture which results in better spatial distribution of nutrient deposition. One possible alternative to improve nutrient distribution in a continuous stocking system is to have portable shades, watering points, and mineral and feeding stations.

Management practices to improve the efficiency of nutrient cycling

Soil testing and fertilization

Nutrient cycling efficiency can be defined as the amount of desired product (or environmental service) delivered per unit of nutrient cycled in the system. Therefore, the faster nutrients cycle and the smaller the losses, the more efficient the overall nutrient cycling. The balance of all essential nutrients for plant and livestock growth is essential to maximize the use of all nutrients. The first step is to take a representative soil sample. Based on previous information, it is important to sample separately the soil near shade, water, and camping sites, since they will overestimate the status of soil fertility in the pasture. Soil test results will indicate liming requirements as well as needs for macro and micronutrients. Fertilization is often essential to balance soil nutrients. Grass—legume mixtures may need the addition of lime, P, K, and other macronutrients. Nitrogen application to mixtures can be reduced when considering the ability of forage legumes to associate with N-fixing bacteria. Once soil nutrients are adequate, it is important to supplement livestock with minerals, since some elements that are essential for livestock may not be present in sufficient quantities in the plants they consume [34].

Pasture design (e.g., shape, water, and shade placement)

Pasture design may improve nutrient distribution. Major features of design include location of shade and water, and managing animals to utilize different camping sites. Silvopasture systems can enhance nutrient spatial distribution since shade is available across the pasture. Smaller paddocks with short grazing periods using rotational stocking also tend to improve nutrient spatial distribution [19]. Another feature of paddock design is to reduce the number of neighboring paddocks with resident

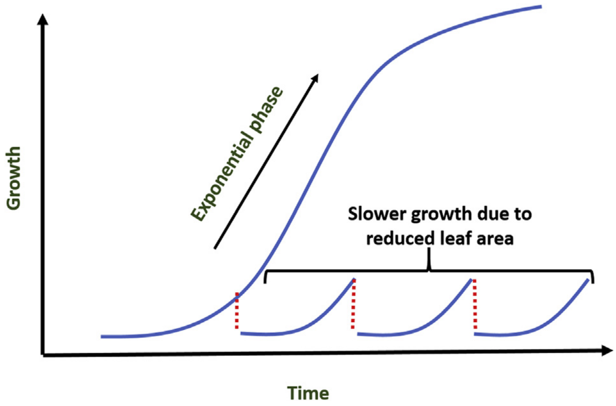

Figure 4.6 Growth curve of forage crops.

livestock. This limits the amount of fence line shared between 2 paddocks, which in turn limits congregation of livestock near a fence line [19].

Grazing management

Grazing management strategies include the adjustment of stocking rate, stocking method, and whatever other method is available to manage defoliation. Grazing frequency, intensity, and timing are the major aspects of defoliation affecting plant regrowth. Maximizing plant growth, forage quality, and harvesting the forage efficiently with grazing animals are the ultimate goals of the grazing manager. It is also important to reach economic goals and to apply sustainable management practices. Sometimes greater plant or animal productivity may not be the best option to maximize economic and environmental benefits.

Rotational stocking often results in greater herbage accumulation [35], because these plant canopies have greater leaf percentage and younger average leafage than those in continuously stocked pastures. As a result, forage in rotationally stocked pastures spend a greater proportion of time in the linear phase of the forage growth curve (Fig. 4.6). Greater nutrient use efficiency is the result of more products and services being delivered per nutrient unit. However, it is important to optimize both herbage accumulation and forage nutritive value. This is a challenging task since forages often increase herbage accumulation with longer rest periods between grazing events, but forage nutritive value declines as plants mature.

Conclusions

Nutrient cycling is an important process contributing to grassland persistence and productivity. Efficient nutrient cycling will produce more forage with less nutrients; thus, economic and environmental benefits are enhanced. Management practices that affect the efficiency of nutrient cycling include adjustment of stocking rate, choice of stocking method, manipulating forage species diversity, and distribution of shade structures, supplement feeding stations, water troughs, and fertilization.

Reducing nutrient losses and improving nutrient turnover are key aspects to enhancing overall nutrient cycling. Several management practices can contribute to achieving these objectives, but the adjustment of stocking rate is the single most important tool in order to balance nutrient return between litter and excreta. Improving litter quality by integrating forage legumes, especially in warm-climate C_4-based grasslands, is also an efficient way to improve nutrient cycling and potential economic returns.

References

[1] E.S. Jensen, M.B. Peoples, R.M. Boddey, P.M. Gresshoff, H. Hauggaard-Nielsen, B.J.R. Alves, et al., Legumes for mitigation of climate change and the provision of feedstock for biofuels and biorefineries. A review, Agron. Sustain. Dev. 32 (2012) 329−364.

[2] R.M. Boddey, J. Dobereiner, Nitrogen fixation associated with grasses and cereals: recent progress and perspectives for the future, Fert. Res. 42 (1995) 241−250.

[3] E.M. Shepard, L.E. Sollenberger, M.M. Kohmann, L.S. da Silva, J.C.B. Dubeux, J.M.B. Vendramini, Phenotypic plasticity and other forage responses to grazing management of Ecoturf rhizoma peanut, Crop Sci. 58 (2018) 2164−2173.

[4] C.J. Chaparro, L.E. Sollenberger, S.B. Linda, Grazing management effects on aeschynomene seed production, Crop Sci. 31 (1991) 197−201.

[5] A. Lüscher, I. Mueller-Harvey, J.F. Soussana, R.M. Rees, J.L. Peyraud, Potential of legume-based grassland-livestock systems in Europe: a review, Grass Forage Sci. 69 (2014) 206−228.

[6] G.K. Phoenix, W.K. Hicks, S. Cinderby, J.C.I. Kuylenstierna, W.D. Stock, F.J. Dentener, et al., Atmospheric nitrogen deposition in world biodiversity hotspots: the need for a greater global perspective in assessing N deposition impacts, Global Change Biol. 12 (2006) 470−476.

[7] V. Wasiuta, M.J. Lafrenière, A.L. Norman, Atmospheric deposition of sulfur and inorganic nitrogen in the Southern Canadian Rocky Mountains from seasonal snowpacks and bulk summer precipitation, J. Hydrol. 523 (2015) 563−573.

[8] C.P. Jantalia, A.D. Halvorson, R.F. Follett, B.J.R. Alves, J.C. Polidoro, S. Urquiaga, Nitrogen source effects on ammonia volatilization as measured with semi-static chambers, Agron. J. 104 (2012) 1595−1603.

[9] R.R. Sherlock, K.M. Goh, Dynamics of ammonia volatilization from simulated urine patches and aqueous urea applied to pasture. I. Field experiments, Fert. Res. 5 (1984) 181−195.

[10] H. Tian, G. Chen, C. Lu, X. Xu, W. Ren, B. Zhang, et al., Global methane and nitrous oxide emissions from terrestrial ecosystems due to multiple environmental changes, Ecosyst. Health Sustain. 1 (2015) 1−20.

[11] G.V. Subbarao, K. Nakahara, M.P. Hurtado, H. Ono, D.E. Moreta, A.F. Salcedo, et al., Evidence for biological nitrification inhibition in *Brachiaria* pastures, Proc. Natl. Acad. Sci. U.S.A. 106 (2009) 17302−17307.

[12] C. Hahn, V. Prasuhn, C. Stamm, R. Schulin, Phosphorus losses in runoff from manured grassland of different soil P status at two rainfall intensities, Agric. Ecosyst. Environ. 153 (2012) 65−74.

[13] J.C.B. Dubeux Jr., L.E. Sollenberger, B.W. Mathews, J.M. Scholberg, H.Q. Santos, Nutrient cycling in warm-climate grasslands, Crop Sci. 47 (2007) 915−928.

[14] R.M. Boddey, R. Macedo, R.M. Tarré, E. Ferreira, O.C. de Oliveira, C. de, et al., Nitrogen cycling in *Brachiaria* pastures: the key to understanding the process of pasture decline, Agric. Ecosyst. Environ. 103 (2004) 389−403.

[15] H.M.S. Silva, J.C.B. Dubeux Jr., M.V.F. dos Santos, M.A. Lira, M.A. Lira Jr., J.P. Muir, Signal grass litter decomposition rate increases with inclusion of calopo, Crop Sci. 52 (2012) 1416−1423.

[16] A.K. Obour, M.L. Silveira, J.M.B. Vendramini, L.E. Sollenberger, G.A. O'Connor, Fluctuating water table effect on phosphorus release and availability from a Florida Spodosol, Nutr. Cycl. Agroecosyst. 91 (2011) 207–217.

[17] C.A. Rotz, F. Taube, M.P. Russelle, J. Oenema, M.A. Sanderson, M. Wachendorf, Whole-farm perspectives of nutrient flows in grassland agriculture, Crop Sci. 45 (2005) 2139–2159.

[18] B.W. Mathews, L.E. Sollenberger, J.P. Tritschler II, Grazing systems and spatial distribution of nutrients in pastures: soil considerations, in: R.E. Joost, C.A. Roberts (Eds.), Nutrient Cycling in Forage Systems, PPI/FAR, Columbia, MO, 1996, pp. 213–229.

[19] J.C.B. Dubeux Jr., L.E. Sollenberger, J.M.B. Vendramini, S.M. Interrante, M.A. Lira Jr., Stocking method, animal behavior, and soil nutrient redistribution: how are they linked? Crop Sci. 54 (2014) 2341–2350.

[20] R. White-Leech, K. Liu, L.E. Sollenberger, K.R. Woodard, S.M. Interrante, Excreta deposition on grassland. I. Forage harvested, nutritive value, and nitrogen recovery, Crop Sci. 53 (2013) 688–695.

[21] R. White-Leech, K. Liu, L.E. Sollenberger, K.R. Woodard, S.M. Interrante, Excreta deposition on grassland. II. Spatial pattern and duration of forage responses, Crop Sci. 53 (2013) 696–703.

[22] C.A.M. Klein, R.S.P. van Logtestijn, Denitrification and N_2O emission from urine-affected grassland soil, Plant Soil 163 (1994) 235–242.

[23] D.C. Whitehead, The role of nitrogen in grassland productivity, Commonwealth Agricultural Bureau, Farnham Royal, Bucks, 1970.

[24] S.P. Braz, D. do Nascimento Jr., R.B. Cantarutti, A.J. Regazzi, C.E. Martins, D.M. da Fonseca, et al., Quantitative aspects of nutrient recycling in the feces of bovines grazing a pasture of *Brachiaria decumbens* in the Zona da Mata region of Minas Gerais, R. Bras. Zootec. 31 (2002) 858–865.

[25] H. Valk, M.E.J. Hobbelink, Supplementation of grazing dairy cows to reduce environmental pollution, in: Proceedings of the 14th General Meeting of the European Grassland Federation, Lahti, Finland, June 8–11, 1992, pp. 400–405.

[26] J.C.B. Dubeux Jr., L.E. Sollenberger, S.M. Interrante, J.M.B. Vendramini, R.L. Stewart Jr., Litter decomposition and mineralization in bahiagrass pastures managed at different intensities, Crop Sci. 46 (2006) 1305–1310.

[27] H.M.S.D. Silva, J.C.B. Dubeux Jr., M.L. Silveira, E.V. de Freitas, M.V.F. dos Santos, Stocking rate and nitrogen fertilization affect root decomposition of elephantgrass, Agron. J. 107 (2015) 1331–1338.

[28] M.M. Kohmann, L.E. Sollenberger, J.C.B. Dubeux Jr., M.L. Silveira, L.S.B. Moreno, L.S. da Silva, et al., Nitrogen fertilization and proportion of legume affect litter decomposition and nutrient return in grass pastures, Crop Sci. 58 (2018) 2138–2148.

[29] M.F. Cotrufo, M.D. Wallenstein, C.M. Boot, K. Denef, E. Paul, The microbial efficiency-matrix stabilization (MEMS) framework integrates plant litter decomposition with soil organic matter stabilization: do labile plant inputs form stable soil organic matter? Global Change Biol. 19 (2013) 988–995.

[30] A.P. Silva, S. Imhoff, M. Corsi, Evaluation of soil compaction in an irrigated short-duration grazing system, Soil Tillage Res. 70 (2003) 83–90.

[31] V.G. Allen, C. Batello, E.J. Berretta, J. Hodgson, M. Kothmann, X. Li, et al., An international terminology for grazing lands and grazing animals, Grass Forage Sci. 66 (2011) 2–28.

[32] J.C.B. Dubeux, Jr., Management Strategies to Improve Nutrient Cycling in Grazed Pensacola Bahiagrass Pastures (PhD dissertation), Agronomy Department, University of Florida – IFAS. 204 p., 2005. Available from: <http://etd.fcla.edu/UF/UFE0011202/dubeux_j.pdf>.

[33] J.C.B. Dubeux Jr., R.L. Stewart, L.E. Sollenberger, J.M.B. Vendramini, S.M. Interrante, Spatial heterogeneity of herbage response to management intensity in continuously stocked Pensacola bahiagrass pastures, Agron. J. 98 (2006) 1453–1459.

[34] B.W. Mathews, S.C. Miyasaka, J.P. Tritschler, Mineral nutrition of C_4 forage grasses, in: L.E. Moser, B.L. Burson, L.E. Sollenberger (Eds.), Warm-Season (C_4) Grasses. ASA-CSSA-SSSA (Agronomy series, 45), ASA-CSSA-SSSA, Madison-WI, 2004, pp. 217–266.

[35] R.L. Stewart Jr., J.C.B. Dubeux Jr., L.E. Sollenberger, J.M.B. Vendramini, S.M. Interrante, Stocking method affects plant responses of Pensacola bahiagrass pastures, Forage Grazinglands (2005). Available from: https://doi.org/10.1094/FG-2005-1028-01-RS. 2005.3.