CHAPTER 5

Managing grazing in forage—livestock systems

Lynn E. Sollenberger[1], Glen E. Aiken[2] and Marcelo O. Wallau[1]
[1]Agronomy Department, University of Florida, Gainesville, FL, United States
[2]Center Director, UF-IFAS North Florida Research and Education Center — Quincy, Quincy, FL, United States

> ***The success of any forage-animal system depends on the grazier, a person with equal interest and expertise in managing the interplay of soils, plants, and animals.***
> **Roy E. Blaser (1986)**

Definition and importance of grazing management

Grasslands cover more than 40% of Earth's ice-free terrestrial surface [1]. Forage is the most consumed livestock feed in the world [2], and land grazed by livestock is the largest single land-use type [3]. Although grazing management is an important tool for grassland ecosystem maintenance and regulation, grazing has also been implicated in grassland degradation [4]. When considered together, these factors support an effort to optimize grazing management in forage—livestock production systems [5].

What is grazing management? Grazing management is simply "the manipulation of grazing in pursuit of a specific objective or set of objectives" [6]. Objectives may include optimizing forage production, efficient utilization of forage produced, maintaining pasture persistence, achieving specific goals for animal production and economic return, sustaining natural resources, and delivery of ecosystem services [5]. Achieving such a wide range of objectives is a formidable challenge for those implementing grazing management practices. However, the potential reward is great because when pasturelands are managed sustainably, they maintain the resource base of the ecosystem while providing human food in an economically viable manner that enhances the quality of life for both producers and consumers [7].

Grazing management tools

We have already described grazing management as manipulation of grazing. But what specifically are the components of grazing management that can be manipulated in

Management Strategies for Sustainable Cattle Production in Southern Pastures
DOI: https://doi.org/10.1016/B978-0-12-814474-9.00005-0

order to achieve our objectives? These components, or grazing management tools, include grazing intensity, grazing frequency, which is related to stocking method, and timing of grazing.

Grazing intensity relates to the severity of grazing. Measures of grazing intensity can be animal-based, like stocking rate (animal units or lb of animal liveweight per acre), or pasture-based, like quantity of forage or plant height. These descriptions of grazing intensity are limited to an extent because they refer only to one component of the system, i.e., either the plant or the animal, and do not integrate both components. For example, one animal unit per acre may be a high grazing intensity for pastures of relatively low productivity, but it is likely a low grazing intensity for a very productive pasture. Thus, there is value in describing grazing intensity as forage allowance (amount of forage per unit of animal liveweight) or grazing pressure (relationship between animal liveweight and amount of forage), which contain both pasture- and animal-based aspects [6,8].

Stocking method is another grazing management component or tool. Stocking method is the manner in which animals are allocated to pastures during the grazing season, and choice of stocking method affects grazing frequency. Many stocking methods have been described [6], but typically they are either continuous stocking or some form of rotational stocking.

The last grazing management tool we will discuss is the timing of grazing. It relates to the plant growth stage or season of the year when grazing occurs. This tool is important because a particular management practice may be effective at certain times of the year or under certain conditions but not others [9]. These three tools, grazing intensity, stocking method, and timing of grazing are the focus of the sections that follow.

Grazing intensity (stocking rate)—where it all begins

In determining the appropriate pasture stocking rate, a useful starting point is to consider the carrying capacity of the pasture. In a specific grazing system, carrying capacity is the maximum stocking rate that will achieve a target level of animal performance without deterioration of the grazing land [6]. Carrying capacity is a useful concept when based on adequate historical data and experience, but it is site-specific and varies from season to season and year to year. There also are multifunctional uses of grazing lands, and carrying capacity can differ depending on the function that is of greatest priority.

The selection of grazing intensity (e.g., forage allowance, stocking rate, and pasture height) is more important than any other grazing management decision [10]. Grazing intensity plays a major role in determining subsequent forage plant productivity and persistence [5], animal performance and profitability of the grazing operation [11], and environmental impact and delivery of ecosystem services [12]. Understanding the relationship of grazing intensity (subsequently used interchangeably with the term stocking rate) to pasture and animal performance is crucial for the long-term success of the forage–livestock enterprise.

Factors that affect choice of stocking rate

There are a number of factors to consider when choosing the stocking rate. As a starting point pasture carrying capacity (affected by plant species, species and class of animals, soil characteristics, climate, etc.) should be assessed based on the particular land-use objective. It is also important to think about stocking rate within two contexts, the entire farm or ranch versus an individual pasture. We revisit this issue several times throughout the chapter, so let us highlight a few important distinctions. In the absence of weather extremes or major changes in overall farm/ranch management, many producers maintain approximately the same number of animals per unit land area on their entire farm or ranch over periods of years. In contrast, stocking rate of individual pastures may change annually, due to variable weather conditions, or even several times per year in order to match stocking rate with seasonal differences in forage production. Entire farm or ranch stocking rate decisions must consider climate (i.e., long-term averages of weather) effects on seasonality of forage production on their property. If entire-farm stocking rate is based on forage production during the season when it is greatest, the amount of conserved or purchased feeds required during the season of forage shortfall increases dramatically. Costs of these supplementary feeds negatively affect farm profitability. Thus, entire-farm stocking rate decisions must take into account the amount of forage produced during the season of shortfall (cold or dry season) and the availability and cost of conserved forage or purchased feeds relative to the price received for the animal product.

Other factors that influence the choice of stocking rate are the species and class of animal on the farm and the producer's goal for animal production (e.g., weight gain or milk production). Additionally, stocking rate is an important determinant of overall pasture persistence, and in pastures with a mixture of several forages the stocking rate can affect the survival of these species differently. Choice of stocking rate in pastures also affects the likelihood of soil erosion, amount of sediment and nutrient runoff to surface water and nutrient leaching to groundwater, soil organic matter levels, and quality of wildlife habitat. More detail about stocking rate effects on these factors follows.

Impact of stocking rate on the forage–livestock system

Animal performance

Starting with an overgrazed condition (i.e., high stocking rate), as stocking rate decreases (i.e., herbage allowance increases) individual animal performance increases (Fig. 5.1). This occurs initially because forage quantity becomes less limiting and

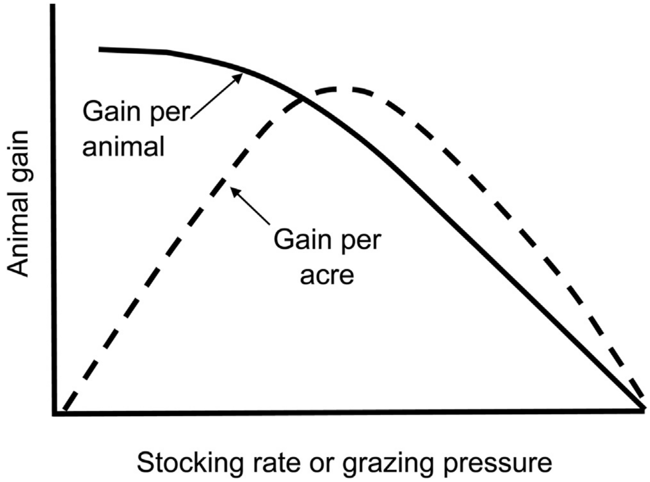

Figure 5.1 The relationship of gain per animal and gain per acre with stocking rate or grazing pressure. *Adapted from G.O. Mott, J.E. Moore, Evaluating forage production. in: R.F Barnes et al. (Eds.), Forages: The Science of Grassland Agriculture, Iowa State University Press, Ames, IA, 1985, pp. 97–110 [78].*

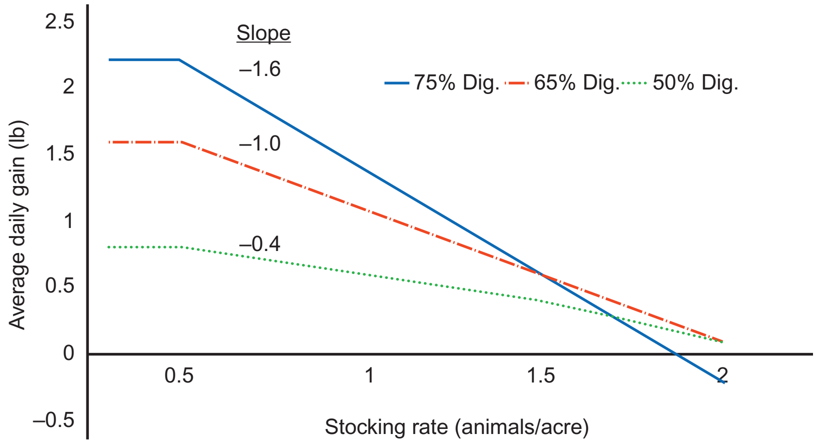

Figure 5.2 The expected relationship of grazing livestock average daily gain with stocking rate for forages of different digestibility. Note that slope of the linear portion of the curve typically is more negative as forage digestibility increases. *Based on concepts described by L.E. Sollenberger, E.S. Vanzant, Interrelationships among forage nutritive value and quantity and individual animal performance. Crop Sci. 51 (2011) 420–432 [13].*

eventually because of greater opportunity for diet selection by the animal. The rate of the increase (i.e., slope) in individual animal performance with decreasing stocking rate is related to forage nutritive value; and the greater the nutritive value of the forage the faster animal performance increases as stocking rate is reduced (Fig. 5.2) [13]. Total animal production per unit area of pasture responds differently than individual animal production (Fig. 5.1). Starting from an overstocked condition, as stocking rate decreases production per acre increases. This continues up to some maximum, after which further decreases in stocking rate cause a decline in production per acre because the forage is underutilized (Fig. 5.1).

It is important to understand that both individual animal performance and animal production per acre cannot be maximized using the same stocking rate. Maximum individual animal production will nearly always occur at a lower stocking rate than maximum production per acre (Fig. 5.1). In light of this, what is the best choice? This depends on a number of factors, in particular, the product that is being marketed. For example, a producer who sells breeding stock, which is priced based on their individual weight gain on pasture, will want to use a relatively lower stocking rate to maximize individual animal performance. In contrast, a producer who grazes stocker cattle on a fixed area of pastureland and is paid based on total amount of weight that the entire group of stockers gains, will want to choose a stocking rate that maximizes gain per acre, knowing that they are sacrificing some individual animal gain.

Plant productivity, nutritive value, and persistence

Increasing stocking rate or grazing to shorter canopy heights decreases pasture forage mass [14,15] and forage allowance [16,17], leading to decreasing individual animal performance with increasing stocking rate (Fig. 5.1). The effect on forage plant productivity (referred to as forage accumulation) is less clear cut. In a review of published research, nearly half of the studies showed that greater forage accumulation occurred as grazing intensity decreased. However, forage accumulation was not affected by grazing intensity in one quarter of studies, and actually increased with increasing grazing intensity in one quarter of studies [5]. Forage species that showed greater forage accumulation as grazing intensity increased were typically grazing-tolerant plants, for example, tall fescue [*Lolium arundinaceum* (Schreb.) Darbysh.] [18], a perennial ryegrass (*Lolium perenne* L.) white clover (*Trifolium repens* L.) mixture [19], and a decumbent type of rhizoma peanut (*Arachis glabrata* Benth.) adapted to close grazing [20]. In contrast, forage accumulation decreased with increased grazing intensity for forages including stargrass (*Cynodon nlemfuenis* Vanderyst) [21], bermudagrass [*Cynodon dactylon* (L.) Pers.] [22], and orchardgrass (*Dactylis glomerata* L.) [23]. For orchardgrass, this response was attributed to its upright growth habit and lack of tolerance for heavy grazing. Thus, we can conclude that for most forage species, forage accumulation decreases as grazing intensity increases; but this expected outcome may be different for some forages that are particularly grazing tolerant, or can adapt their growth habit to heavy grazing.

About two-thirds of published experiments show that nutritive value of the forage presented to the animal generally increases with increasing grazing intensity [5],

Table 5.1 Stargrass forage crude protein, in vitro digestibility, and neutral detergent fiber when grazed by weanling bulls that were rotationally stocked at three stocking rates during 300 days/year in each of 2 years.

Stocking rate (head/acre)	Crude protein (%)	In vitro digestion (%)	Neutral detergent fiber (%)
1	13.4	58.6	77.4
2	14.0	59.3	76.2
3	15.1	59.9	74.9
Polynomial contrast	Linear	Linear	Linear

Data from A. Hernández Garay, L.E. Sollenberger, D.C. McDonald, G.J. Ruegsegger, R.S. Kalmbacher, P. Mislevy, Nitrogen fertilization and stocking rate affect stargrass pasture and cattle performance, Crop Sci. 44 (2004) 1348–1354 [21].

although greater grazing intensity does reduce the opportunity for diet selection by the animal. A good example of this is the effect of stocking rate on stargrass nutritive value (Table 5.1) [21]. Crude protein and digestibility of stargrass forage increased, and neutral detergent fiber concentration decreased as stocking rate became greater. Why did this happen? When pastures are continuously stocked and grazed closely (i.e., high stocking rate) for an extended period, there is a relatively small amount of forage present for animals to consume. As a result, the animals visit and revisit specific pasture locations more frequently. Frequent visits mean less mature forage which results in greater forage nutritive value. Under rotational stocking the situation is somewhat different because the manager, and not the grazing animal, controls the frequency of grazing. In this case when stocking rate is high, the forage is grazed closely by the time the cows are moved to the next paddock. This closely grazed forage often regrows more slowly. The rate at which it matures is also slower; thus, the forage in the heavily grazed pasture is greater in nutritive value when the animals return to that paddock the next time. Note that this discussion relates to the nutritive value of the forage present in the pasture, not necessarily to the diet consumed by the animal. At low stocking rates, there is greater opportunity for diet selection by the animal, and this can result in the nutritive value of the diet being considerably greater than that of the forage present.

> ***Management of forages must be associated with the morphology of species in order to maintain production and persistence.***
>
> **Roy E. Blaser (1986)**

Long-term pasture survival is a goal for most pasture-based livestock systems because pasture establishment is a major input cost. How is persistence affected by grazing intensity? Stocking rate is an important determinant of pasture survival, so it is critical to avoid overgrazing that can lead to subsequent loss of stand. Forages differ in their level of grazing tolerance, so it is important to know how the plant species present in a particular pasture respond to grazing in order to determine the most appropriate stocking rate. Generally, plants that have rhizomes or stolons and a more decumbent growth habit can tolerate greater stocking rates than upright-growing legumes or bunch grasses. However, each plant within a population has some ability to adapt to stress from defoliation by changing the way it orients and positions its stems and leaves, an attribute termed phenotypic plasticity [24]. Phenotypic plasticity includes changes in size, structure, and spatial positioning of stems and leaves in response to defoliation [20,25]. Phenotypic plasticity is related to grazing tolerance, and the degree to which it occurs varies among forage species [26], even among cultivars within the same species [27]. Plants that exhibit phenotypic plasticity may shorten the length of internodes or change the angle of stem growth resulting in a shorter canopy that is arranged in a way that leaves and growing points are less easily accessed by grazing animals. Even for plants capable of these adaptations, phenotypic plasticity has limits, and if defoliation is too severe it may exceed the ability of the plant to adjust, and plant death may occur [28].

Ecosystem services

Ecosystem services are benefits an ecosystem provides to society including effects on soil, water, and atmosphere. Delivery of ecosystem services by pastureland is affected by grazing intensity. Excessive stocking rate leads to increased soil erosion, soil compaction, and a decline in soil quality [5]. Pastures grazed too closely are associated with greater amounts of soil sediment and nutrients flowing into surface water and negatively affecting water quality [29]. For example, three stocking rates (0.6, 0.8, and 1.2 animal units/acre) were studied in Texas rangeland composed of several mid-grass and short-grass species and forbs, and highest stocking rate led to the greatest amount of sediment loss (nearly 1340 lb/acre) and lesser rates of water infiltration into soil [30]. Likewise, the amount of phosphorus in runoff was approximately three times greater for a smooth bromegrass (*Bromus inermis* Leyss.) pasture grazed to a 2- versus a 4-in. stubble under rotational stocking [31]. Overgrazed pastures have diminished root or rhizome mass [32] which can increase the likelihood of soil erosion, limit nutrient uptake, and increase nutrient leaching to groundwater.

Organic matter is a critical component of soil because it increases water-holding capacity, supply of nutrients, and nutrient cation (e.g., potassium and magnesium) retention. Organic matter accumulation in soil is favored by greater amounts of below-ground plant biomass, aboveground senescent material, and deposition of animal excreta. After 20 years of management, grazed bermudagrass pastures had 23% greater soil organic carbon (top 8 in. of soil) than fields that were hayed [33], but the effect of grazing on soil carbon and soil organic matter accumulation depends on the intensity of grazing. For example, 'Coastal' bermudagrass was either unharvested, hayed monthly, or grazed at low or high stocking rates during 12 years [34].

The annual rate of increase in soil organic carbon (depth of 0–35 in.) was approximately twice as great for the low stocking rate as for unharvested areas and the high stocking rate, and approximately five times as great for the low stocking rate as for hayed areas [34]. In another study with bermudagrass, a low stocking rate resulted in greater increases in soil carbon and nitrogen than a high stocking rate [35]. The soil carbon response to grazing intensity is climate dependent. In drier regions, low or moderate grazing intensities increased soil carbon under grasslands, but soil carbon decreased with greater intensities [36]. Adoption of sustainable management practices, including reducing stocking rate to an optimum level, contributed to the restoration of soil carbon levels in Canadian prairie grasslands over the past 70–80 years [37].

An important ecosystem service of pastureland is providing wildlife habitat and food supply. High grazing intensity is blamed for a reduction in abundance of pastureland birds due to loss of preferred habitat for nesting, destruction of nests due to trampling, and a reduction in invertebrate food sources [38]. Field vole abundance in pastureland is important because of their role as a food source for other wildlife species, and vole abundance was greater in plots with low versus high stocking rate of sheep plus cattle [39]. Low stocking rate favored voles because of greater food resources and greater cover to protect from avian predators. Not all species are favored by low stocking rate, however. Lightly grazed pastures were less preferred by brown hares (*Lepus europaeus*) compared with moderately grazed ones because grazing reduced herbage height and density, allowing hares to see approaching predators [40]. The spur-thighed tortoise (*Testudo graeca*) also selected areas with intermediate annual grass cover and rejected areas with low and high cover [41]. Thus, high stocking rates are rarely favorable to wildlife, but moderate grazing may improve habitat for some species versus a nongrazed condition.

Pollinators benefit 35% of global crop-based food production [42], and insects, particularly bees, are the primary pollinators of most agricultural crops. Populations of wild and domesticated pollinators are declining, and this is considered a threat to global food security [43]. Grazing intensity affects pollinator populations, and managing grazing intensity to avoid overgrazing and to increase the number of flowering plants (e.g., many legumes) is beneficial for both cattle and pollinators [44].

Should stocking rate be constant or variable throughout the year?

There have been many arguments about this question. Two conflicting points of view can be summarized as follows. Advocates for use of a variable stocking rate, where stocking rate changes throughout the growing season, argue that strong seasonality of forage production requires adjustment of animal numbers on pasture to avoid under- or over-grazing. Advocates for use of a constant (or fixed) stocking rate, that is, one that does not change seasonally, argue that producers cannot simply buy or sell animals throughout the year to account for variation in seasonal forage production.

As is the case with many arguments, there are strengths and weaknesses in both positions. Part of the difference in perspective relates to the issue discussed earlier of total farm versus individual pasture stocking rates. Individual pasture stocking rates can be varied by moving animals from one pasture on a ranch to another more productive pasture on the same ranch to better utilize the forage currently present. Similarly, during a time of rapid forage growth a producer may increase stocking rate on a pasture simply by closing off to livestock a portion of the pasture and subsequently cutting hay from the fenced area or allowing forage to stockpile. These are both examples of varying stocking rates of individual pastures but keeping total farm stocking rate constant.

Another issue that adds confusion to this discussion is different perspectives regarding what constitutes variable stocking. As noted earlier, advocates of a fixed stocking rate argue that producers cannot adjust their total farm stocking rate by regularly buying or selling cattle when forage production indicates that they need to raise or lower stocking rate. This is a valid point, but it fails to take into account the true definition of stocking rate. Stocking rate is determined by a number of animals *and* amount of land area. The amount of land area refers to *all* land that is used to produce feed for the animals on that farm or ranch. When feed grown off the farm or ranch is purchased, the producer has effectively reduced their stocking rate because they have increased the amount of land used to feed the same number of livestock. Of course there are some farms or ranches that bring in no feed from elsewhere, but that is relatively rare. Thus, the argument of fixed versus variable stocking rate may not be terribly relevant to the production environment because most farms and ranches vary stocking rate by some means, even if it is only by buying feed from off the property.

Stocking methods (frequency)—fine-tuning the system

Stocking method is "a defined procedure or technique to manipulate animals in space and time to achieve a specific objective" [6]. Producer and popular press conversations about grazing management often focus on stocking method more than grazing intensity. It is important to recognize that errors in selection of grazing intensity cannot be fully compensated by the choice of stocking method. Thus, grazing intensity is the most important grazing management decision, and the choice of stocking method is used to fine tune grazing management to improve sustainability of the grazing system [5].

We need to distinguish between the terms stocking method and grazing system because they are often used interchangeably despite having different meanings.

Grazing system is "a defined, integrated combination of soil, plant, animal, social and economic features, stocking method(s), and management objectives designed to achieve specific results or goals" [6]. Looking at the definitions, we can see that the stocking method is one of many components of the overarching grazing system.

In this discussion we will consider stocking method to be the manner in which animals are stocked or are given access to pastures and paddocks (pasture subdivisions, if present) during the grazing season. Note that the choice of stocking method is independent from the choice of grazing intensity, with a particular stocking method potentially being used across a wide range of intensities. Many stocking methods have been described [6], but each is derived from continuous or some form of rotational stocking. Continuous stocking is "a method of grazing livestock on a specific unit of land where animals have unrestricted and uninterrupted access throughout the time when grazing is allowed" [6]. In contrast, rotational stocking "utilizes recurring periods of grazing and rest among three or more paddocks in a grazing management unit throughout the time when grazing is allowed" [6].

Factors affecting choice of stocking method

> ***With continuous stocking, pastures should be stocked so the sod residue maintains an adequate leaf area to generate new growth.***
>
> **Roy E. Blaser (1986)**

Long-term pasture persistence is an important objective in most grazing systems, and some species may require rotational stocking to persist, or they may perform better under rotational than continuous stocking [45]. Alternatively, if pastures are planted to bahiagrass, Kentucky bluegrass (*Poa pratensis* L.), or endophyte-infected tall fescue, species that persist well under continuous stocking if stocking rate is not excessive, the producer may not wish to assume the additional cost of fencing and waterlines to facilitate rotational stocking. Another reason to consider rotational stocking is the potential to increase pasture carrying capacity because of less spot grazing and faster average forage accumulation rate on rotationally than continuously stocked pastures [5]. Moving animals from paddock to paddock under rotational stocking can increase uniformity of distribution of animal excreta and increase the efficiency of nutrient cycling relative to continuous stocking [46,47]. Rotational stocking also makes it easier to utilize techniques like first-second grazer and forward creep grazing. Both allow first access to new paddocks to animals with greatest nutrient requirements, and they are designed to more closely match the nutrient requirements of the animal with the nutritive value of the forage in the portion of the canopy that is grazed. In addition to less capital outlay, advantages for continuous stocking include greater opportunity for diet selection (if the pasture is not over-stocked), less variation in day-to-day forage intake and digestibility, fewer decisions required of management (e.g., when to begin and end grazing on a new paddock), and somewhat less labor.

Impact of stocking method on the forage–livestock system

The relative advantages of different stocking methods are often a subject of vigorous debate, not all of which is based on data and experimentation [10]. In this section we will attempt to clarify the effects of various stocking methods based on a consensus of published research.

Animal performance

The ways that we describe animal performance include individual animal production (e.g., liveweight gain or milk production per day) and production per acre (e.g., live-weight gain or milk produced per acre of pasture), where production per acre is determined by individual animal performance and the number of animals grazing the pasture (i.e., average stocking rate or carrying capacity). Therefore, in order to determine if stocking methods affect animal performance differently, we need to consider their effects on individual animal production, average pasture stocking rate, and animal production per acre.

When looking at many published studies, about two-thirds of the comparisons of continuous and rotational stocking show no difference in daily individual animal production [5]. About one quarter of published studies show an advantage of continuous over rotational stocking, and only slightly more than 10% show an advantage of rotational over continuous stocking. This is surprising for some, particularly for those whose image of a continuously stocked pasture is one that is overgrazed. If that image is what you see, keep in mind that an overgrazed pasture occurs because grazing intensity (i.e., stocking rate) is too high, not because of the stocking method used. In order to draw accurate conclusions about the effect of stocking method, we must consider only those comparisons of stocking methods where grazing intensity was the same. That was the approach in the summary described earlier, so we conclude from the literature that in the majority of situations there will not be a measurable difference in individual animal production between rotational and continuous stocking methods.

Why is this the case? Does it make sense biologically? Let us think about it. Individual animal performance is affected by both quantity of forage and forage nutritive value (i.e., chemical composition and digestibility), however, if forage quantity is not limiting then nutritive value explains a large proportion of the individual animal performance response. The following studies provide support of this statement. When cattle were grazing pearl millet and quantity was not limiting, forage in vitro digestibility explained 74% of the variation in individual animal performance [48]. In an experiment with bermudagrass pastures, the proportion of the variation in individual animal performance explained by nutritive value was 56% when quantity was not limiting [49]. We can conclude from these studies that forage nutritive value explains from about one-half to three-quarters of the variation in individual animal performance if the amount of forage is not limiting. It follows then that if stocking method affects individual animal performance, it will be because stocking method affects forage nutritive value. So the question is, does stocking method affect forage nutritive value? What does the published literature tell us? This will be discussed more thoroughly later, but over 70% of papers reviewed regarding this question showed no effect of stocking method on nutritive value. Thus, it stands to reason that nearly the same percentage of papers found no effect of stocking method on individual animal performance.

Does stocking method affect the average stocking rate or carrying capacity of the pasture? In the review of previous studies, 85% reported an advantage in forage quantity or carrying capacity for rotationally versus continuously stocked pastures [5]. The average increase for rotational versus continuous stocking was 30%, meaning that if there is a *well-managed* pasture that is continuously stocked, and the manager switches to well-managed rotational stocking, we expect that stocking rate could be increased approximately 30%. There are several possible reasons for this. One is more uniform forage utilization across the pasture, improving the efficiency of grazing [50]. Rotational stocking generally increases utilization by 5%−15% in research studies, but this number may be greater in larger pastures that are common on farms [51].

Lastly, we want to know if stocking method affects animal production per acre. We already know production per acre is a function of two factors, individual animal production and average stocking rate. And we know that in most cases stocking method does not affect individual animal performance, however, rotationally stocked pastures can often support a 30% greater stocking rate than continuously stocked pastures. Based on experiments in which stocking rate was adjusted occasionally based on the amount of forage in the pasture, there was no difference in gain per acre due to stocking method 50% of the time, but rotationally stocked pastures had greater gain per acre than continuously stocked pastures 45% of the time.

So, what do we know about how the choice of stocking method affects animal production? Generally, individual animal production (daily gain or daily milk production) will not differ between continuous and rotational stocking. However, average stocking rate can be greater on rotationally than continuously stocked pastures most of the time, and this results in greater animal gain per acre on rotationally stocked pastures in approximately half of the situations where it has been used.

Plant productivity, nutritive value, and persistence

It has been established that rotational stocking often allows greater average stocking rates (i.e., carrying capacity) than continuous stocking. In order for this to happen, rotationally stocked pastures must have either greater forage accumulation rate, more efficient utilization of existing forage mass, or both. More efficient utilization of existing forage was already confirmed to occur, and it likely contributes part of the forage quantity advantage observed for rotational stocking. What about greater forage accumulation rate? Does that occur, and if so, how?

Several observations are of interest in considering these questions. Canopy photosynthesis was greater in continuously (leaf area index = 1) than rotationally stocked (leaf area index = 0.5) perennial ryegrass pastures immediately following defoliation [52]. However, this soon reversed because the leaf area index and percentage of young leaves increased more rapidly in rotational pastures. As a result, long-term canopy photosynthesis rates of rotationally stocked pastures exceeded those of continuously stocked pastures even when defoliation was severe and regrowth periods were relatively short. Therefore, we can conclude that a greater average leaf area index and a younger average leaf age in rotationally stocked pastures contribute to their forage quantity advantage over continuously stocked pastures.

Before leaving this topic we should also consider that greater uniformity of grazing may contribute to greater average forage accumulation rate in addition to affecting efficiency of utilization. An example is the patch grazing that often occurs in continuously stocked pastures. The plants in these patches are grazed closely and frequently which causes plant growth to slow because leaf area is consistently limited. Rotational stocking allows the manager, instead of the grazing animal, to control the length of the regrowth period. As a result, even moderately overgrazed pastures may have time to recover and move into a more rapid growth phase if the regrowth period is long enough (Fig. 5.3). This means that especially when stocking rates are high or during times of feed deficit, rotational stocking should better control the average leaf area, leading to faster growth rates than continuous stocking. Of course, if stocking rates are extremely high, rotational stocking will not be able to compensate for this poor management.

There is limited information regarding the effect of stocking method on forage nutritive value. As noted earlier, most studies evaluating this response have found no measurable difference. Logically, we might conclude that if differences exist, they would be more likely to favor continuous stocking [53]. Let us think about that for a moment. Forage nutritive value is primarily affected by maturity, and nutritive value of the diet is affected by the opportunity for selection. If forage quantity is not limiting, greater nutritive value for continuous than rotational stocking could be associated with greater opportunity for selection and the tendency of animals to make frequent visits to the same grazing stations, which would result in the consumption of less mature forage [54].

The persistence (i.e., long-term survival) of some forage species is strongly favored by rotational stocking [45] while for others either rotational or continuous stocking can be used so long as grazing intensity is not too great. One of the challenges in

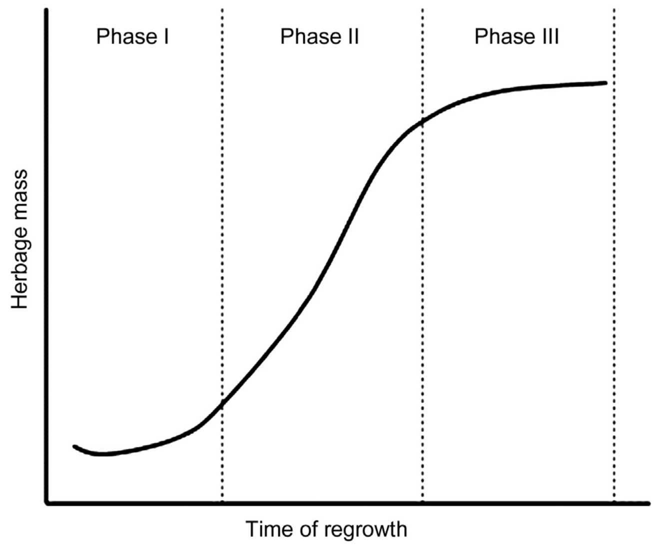

Figure 5.3 Accumulation of forage during a regrowth period follows this general pattern. The pasture starts at low forage mass (Phase I: Low accumulation rate), increases to intermediate forage mass (Phase II: High accumulation rate), and then to high forage mass (Phase III: Little or no net accumulation due to balance between new growth and death of aging plant tissue). *Adapted from G.R. Saul, D.F. Chapman, Grazing methods, productivity and sustainability for sheep and beef pastures in temperate Australia. Wool Technol. Sheep Breed. 50 (2002) 449–464 [51].*

assessing whether stocking method will eventually affect animal performance is most grazing experiments are too short to measure long-term survival. One example of this is a study comparing two cultivars of the legume rhizoma peanut under continuous stocking [55]. One cultivar was upright growing; the other was lower growing. During the first 2 years, the percentage of both cultivars in the pasture was greater than 80%, and there was no difference in average daily gain of grazing cattle. In year 3, the proportion of the more upright-growing plant decreased to 66%, and animal gain was greater for the lower growing plant that composed 87% of the pasture mass. Thus, some changes in persistence take time to occur, and conclusions about best management practices may not be obvious in the first year or two of an experiment.

Ecosystem services

Rotational stocking may provide environmental benefits, but limited research has been conducted to evaluate the effects of rotational versus continuous stocking. The majority of a relatively small number of studies indicate that rotational stocking is less detrimental to water quality, hydrology, and stream morphology than is continuous stocking [5]. Mean total phosphorus in runoff was 34% greater with continuous stocking to maintain a 2-in. canopy height than with rotational stocking leaving a 2-in. postgrazing stubble [31]. During the regrowth period, plants on the rotationally stocked pasture grew much taller than 2 in. This resulted in greater average forage coverage of the soil; therefore, the impact of raindrops on soil was reduced, and water runoff decreased from rotationally versus continuously stocked pastures. A review of the literature showed that average vegetation cover was greater using rotational than continuous stocking, which implied that choice of rotational stocking may have long-term positive implications for water quality [56]. Winter-feeding areas on pastures in Ohio have been associated with greater runoff, sediment, and phosphorus loads as compared with nonuse areas, and losses of total *N* were approximately twice as great with continuous as with rotational stocking [57]. In Minnesota, suspended sediment was greater in the stream and more streambank soil was exposed for continuously compared with rotationally stocked sites [58]; whereas in Wisconsin, lower amounts of streambank erosion and suspended sediment in stream water occurred where intensive rotational stocking was practiced, compared with continuous stocking [59]. Responses to stocking method are not always consistent, as monthly water runoff was greater with continuous than rotational stocking 75% of the time in Ohio [60], but in Georgia, there was no difference in annual surface runoff volume between pastures treated with broiler litter that was continuously or rotationally stocked year-round [61].

Uneven spatial distribution of nutrients occurs in grazing systems because cattle deposit more dung and urine where they spend more time, that is, under the shade and around mineral troughs and water sources [62]. Rotational stocking with short grazing periods and high stocking density often results in more uniform dung distribution [47]. However, this benefit of rotational stocking is likely to be less pronounced in warm climates or during hot weather in temperate climates. Under these conditions, animals spend more time under shade or near watering points, and the majority of dung and urine is deposited there regardless of stocking method [45].

Stocking method has had limited or no effect on wildlife responses [5]. Several examples follow. In southwestern Wisconsin, there were no differences between rotational and continuous stocking in population size of several grassland bird species [63]. Instead, bird density was related to vegetation structure with greater density found on nongrazed buffer strips with deeper plant litter. Loss of nests due to cattle trampling was directly proportional to stocking rate in Texas, and stocking method had little effect [64]. In Wisconsin stocking method had no effect on either the number of individuals or number of small mammal species present in continuously or rotationally stocked riparian areas [65]. Relative to populations of pollinators, the most important consideration is likely choice of a stocking method that maximizes persistence of legumes or flower-rich species. Thus, if persistence of these key forage species is better under rotational than continuous stocking, then benefits to pollinators would likely follow.

Overall, the literature suggests a role for rotational stocking in enhancing the uniformity of nutrient deposition in pastures and protecting water quantity and quality. The choice of stocking method, however, is likely to be less important from an environmental perspective than maintaining an appropriate stocking rate.

Number of paddocks and stocking density in rotational stocking

Number of paddocks in rotationally stocked pastures

If the decision to rotationally stock a pasture has been made, how many paddocks (pasture divisions) should be used? More paddocks cost more money in infrastructures like fencing and water lines, so costs must be balanced against potential benefits. What do previous studies tell us about potential benefits of increasing number of paddocks on pasture productivity and nutritive value? Relative to forage production, approximately half of studies cited in a recent review [5] reported advantages in forage quantity by increasing number of paddocks, and about half reported no effect. So, relative to forage production, the number of studies is small and inconclusive. Relative to forage nutritive value, six of eight relevant studies representing a wide range of forage species reported no difference in forage nutritive value due to a number of paddocks, that is, length of the grazing period on each paddock. Of the other two studies, one favored more paddocks and one favored fewer paddocks. Thus, based on the currently available research for rotationally stocked pastures, there is not a consistent advantage of a large number of paddocks versus a smaller, more typical number in terms of pasture productivity or nutritive value.

Stocking density and "Mob Grazing"

Stocking density is defined as the relationship between the number of animals and the specific unit area of land being grazed at any one time [6]. It is an instantaneous measurement of the animal-to-land area relationship in contrast with stocking rate which is the same relationship, but over an extended period of time. Under continuous stocking, stocking density is the same as stocking rate. On rotationally stocked pastures they are different. For example, if over a summer grazing season there are five animals grazing a 5-acre pasture that is divided into five 1-acre paddocks, the stocking rate is one animal per acre, but the stocking density at any instant is five animals per acre.

An understanding of stocking density is important because currently, some people advocate using rotational stocking with a very high stocking density. This stocking method can be referred to as mob stocking, which is a method of stocking at a high grazing pressure for a short time to remove forage rapidly [6]. By definition, mob stocking is simply rotational stocking with pastures divided into a large number of paddocks. In recent years, a variation of this long-defined method has emerged. Its proponents have used the term "mob grazing" to describe it. It is a form of high-density rotational stocking, but in addition, it uses long rest intervals (often 60 days or more) between grazing events. It is useful to note that the formal definition of mob stocking does not carry any reference to the length of the rest interval between grazing events; thus, it should not be confused with the informal term "mob grazing." Although "mob grazing" is practiced in various forms by growers, and the method is not specifically defined, it has been described as concentrating grazing livestock into small paddocks to achieve stocking densities of 200,000 lb or greater of animal liveweight per acre, moving animals through multiple paddocks per day, and grazing a paddock only once (or at least infrequently) per grazing season [66]. Practitioners of "mob grazing" claim numerous benefits including increased forage production and species diversity, improved distribution of livestock grazing, and superior soil function [67]. Some have suggested that achieving 60% trampling of the standing forage mass is the optimum level for increasing soil organic matter and nutrient concentration [68]. Data are currently lacking to substantiate these claims.

In perhaps the most comprehensive replicated research assessment of "mob grazing," a Nebraska sandhills meadow was grazed during 60–80 days in each of 5 years [66,69]. The grassland was dominated by cool-season grasses but also included various sedges, forbs, legumes, and warm-season grasses. Treatments were (1) a 120-paddock rotation with a stocking density of 200,000 lb of animal liveweight per acre in which each paddock was grazed once per grazing season and (2) a 4-paddock rotation with two grazing events per paddock each grazing season. Stocking rate was the same on both treatments (three animal unit months per acre). Over 5 years, daily gain of yearling steers averaged 1.49 lb/day for the 4-paddock system and 0.39 lb/day for the 120-paddock system (Fig. 5.4), and forage production was not different between the two treatments. Greater gains were attributed to greater forage nutritive value for the 4-paddock system that was grazed twice during the grazing season instead of once for the "mob grazing" system. Relative to the use of the 120-paddock system, it was concluded that the lack of increased aboveground production and the large reduction in animal performance do "not justify the increased cost in both labor and implementation of this grazing strategy" [69].

In Virginia, pastures dominated by tall fescue, orchardgrass, and Kentucky bluegrass were overseeded with white and red clovers (*Trifolium pratense* L.) [70]. Stocking rate was one animal unit (1000 lb) per 2 acres on pastures that were stocked continuously, rotationally (28–30 day rest periods; 3–4 day residence periods), or using "mob grazing" (64-day rest periods; 1-day residence periods; stocking density of 40,000 lb/acre). Cows on the "mob grazing" treatment weighed least at breeding and had the lowest body condition scores, while calves on the same treatment had the lowest weaning weights. One notable advantage of "mob grazing" was lesser congregation of cattle near water and loafing areas; this likely would result in more even distribution of nutrients from dung and urine across the pasture. The author "found little evidence to

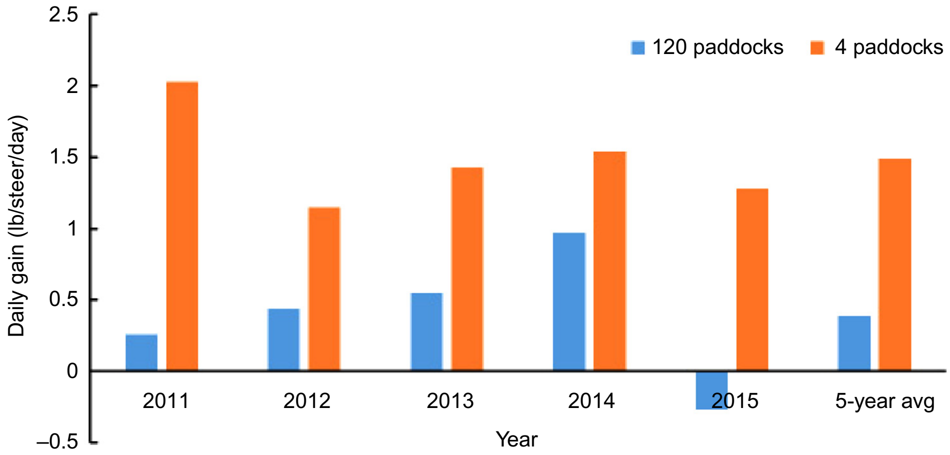

Figure 5.4 Average daily gain of yearling steers grazing Nebraska Sandhills meadow during 60–80 days in each of 5 years and the average of those 5 years. The grazing treatments were a 120-paddock rotation with a stocking density of 200,000 lb of animal liveweight per acre (each paddock grazed once per grazing season) and a 4-paddock rotation with two grazing events per paddock each grazing season. Stocking rate was three animal unit months per acre on both treatments. *Data from M.D. Redden, Grazing method effects on forage production, utilization, and animal performance on Nebraska Sandhills meadow (MS Thesis), University of Nebraska-Lincoln, 2014 [66] and T. Lindsey, Grazing method effects on forage production, utilization, animal performance and animal activity on Nebraska Sandhills meadow (MS Thesis), University of Nebraska-Lincoln, 2016 [69].*

support broad adoption of mob grazing in Virginia over standard rotational grazing practices," and he stated that "mob grazing appears to be better suited to specific, short-term management tasks (e.g., vegetation control) rather than year-round grazing" [70].

Testimonial versus data-driven decision-making

Bransby [71] stated "few topics in agriculture have been addressed with such charismatic language and such abandonment of scientific evidence and logic" as discussions of rotational and continuous stocking. Advocates of rotational stocking have often exaggerated its potential benefits or compared results from well-managed rotationally stocked pastures with continuously stocked pastures that were grossly overstocked or in general, poorly managed. Currently, so-called "mob grazing" is an example where advocates of practice rely largely on anecdotal evidence with little or no conclusive data to support their perspectives. Data from independent research is the best source of unbiased and reliable information from which sound decisions can be made. Researchers, however, must appreciate that their work needs to be relevant to production settings, and conducting experiments across sufficient time periods and spatial scales (pasture size) is important [72].

Timing of grazing

The third grazing management tool to be considered is timing of grazing. Timing can have significant impacts on plants and plant communities because implementing a particular management practice may be beneficial under some conditions but not others. For example, the extent to which plant reserves have been restored prior to the onset of winter or to a dry season can be greatly influenced by timing of defoliation prior to the period of stress. Appropriate timing of defoliation may also be affected by plant growth stage. For example, stand losses of smooth bromegrass (*Bromus inermis* Leyss.) and timothy (*Phleum pratense* L.) growing with alfalfa (*Medicago sativa* L.) have resulted when defoliation occurred during the critical period between grass stem elongation and inflorescence emergence [73]. Similarly, defoliation that removes the apical growing point of switchgrass (*Panicum virgatum* L.) often reduces tiller density, and if not followed by a long regrowth period, may compromise stand persistence [74].

Termination of grazing relative to the timing of flowering and seed set affects annual or short-lived perennial species that rely on natural reseeding for stand regeneration. In northeastern Texas, most cultivars of annual ryegrass (*Lolium multiflorum* Lam.) grazed until late April produced satisfactory volunteer stands the following autumn [75], but later grazing decreased volunteer annual ryegrass seedling density. Similarly, seed yield of the summer-annual legume aeschynomene (*Aeschynomene americana* L.) was greatly reduced if autumn grazing continued after first flower [76].

The timing of grazing may also take into account the diurnal variation in forage nutritive value. Nutritive value and animal preference can be greater in the afternoon compared with the morning because of the accumulation of nonstructural carbohydrates during the day associated with active photosynthesis [77]. In rotational—stocking systems where animals are rotated to a new paddock daily (e.g., lactating dairy cows), there may be advantages to moving them in the afternoon/early evening so that the larger meal that usually follows transition to a new grazing area is composed of forage of the greatest possible nutritive value [9]. This relationship requires further testing to be confirmed.

Role of producer preferences and operation characteristics in choice of grazing management

Choice of grazing management is definitely a decision where one size does not fit all. Intensification of management may well be profitable in some operations but not others. For example, a blanket recommendation of rotational stocking, and particularly rotational stocking with a large number of paddocks, may not be realistic economically nor fit the personality or situation of individual producers. Some producers are excited about management details, measuring everything they can, and keeping detailed, exacting records. Others may rather be fishing. It behooves scientists and extension specialists to account for this range in producer interests in developing research programs and outreach activities. Knowing the abilities, interests, and goals of individual producers is a very important first step in developing a relevant management program.

Conclusions

Because land grazed by livestock is the largest single land-use type, and forage is the most consumed livestock feed in the world, the global implications of grazing management are highly significant. Grazing management is the manipulation of grazing in pursuit of a specific objective or set of objectives, and the tools that we can use to manipulate grazing include grazing intensity, stocking method, and timing of grazing. Of these, grazing intensity (e.g., stocking rate or pasture height) is the most important and has overriding effects on forage production, pasture persistence, animal performance, and environmental impact of pasture-based livestock systems. Stocking method, i.e., the choice of rotational or continuous stocking, is important but less impactful than grazing intensity. In some situations there are measurable benefits of rotational stocking on pasture productivity, persistence of grazing-sensitive species, and sustaining plant cover to minimize runoff of water, sediment, and nutrients. In other situations, the species present, the cost of infrastructure, or the goals of the producer may favor continuous stocking. Within the community of grazing management practitioners, proponents of one approach or another may rely too heavily on anecdotes and too lightly on data. Before adopting a new grazing management approach, there is value in requesting data that support the recommendations being made. It is equally important that the source of the data be an independent organization without conflict of interest, and that the experiments be conducted on a time and size scale that provides relevant results to producers.

References

[1] D.B. Hewins, M.P. Lyseng, D.F. Schoderbek, M. Alexander, W.D. Willms, C.N. Carlyle, et al., Grazing and climate effects on soil organic carbon concentration and particle-size association in northern grasslands, Scientific Rep. 8 (2018). Available from: https://doi.org/10.1038/s41598-018-19785-1.

[2] M. Peters, M. Herrero, M. Fisher, K-H. Erb, I. Rao, G.V. Subbarao, et al., Challenges and opportunities for improving eco-efficiency of tropical forage-based systems to mitigate greenhouse gas emissions, Proceedings of the 22nd International Grassland Congress, 2013, pp. 1251–1260.

[3] E.F. Lambin, P. Meyfroidt, Global land use change, economic globalization, and the looming land scarcity, PNAS 108 (2011) 3465–3472.

[4] D.R. Kemp, D.L. Michalk, Towards sustainable grassland and livestock management, J. Agric. Sci. 145 (2007) 543–564.

[5] L.E. Sollenberger, C.T. Agouridis, E.S. Vanzant, A.J. Franzluebbers, L.B. Owens, Prescribed grazing on pasturelands, in: C.J. Nelson (Ed.), Conservation Outcomes from Pastureland and Hayland Practices: Assessment, Recommendations, and Knowledge Gaps, Allen Press, Lawrence, KS, 2012, pp. 111–204.

[6] 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.

[7] B.A. Stewart, R. Lal, S.A. El-Swaify, Sustaining the resource base of an expanding world agriculture, in: R. Lal, F.J. Pierce (Eds.), Soil Management for Sustainability, Soil Water Conserv. Soc. Ankeny, IA, 1991, pp. 125—144.

[8] L.E. Sollenberger, J.E. Moore, V.G. Allen, C.G.S. Pedreira, Reporting forage allowance in grazing experiments, Crop Sci. 45 (2005) 896—900.

[9] L.E. Sollenberger, and Y.C. Newman. Grazing management. In R.F Barnes et al. (ed.) Forages — The Science of Grassland Agriculture (sixth ed.), Blackwell Publishing, Ames, IA, 2007, pp. 651—659.

[10] F.M. Rouquette, Jr., Grazing systems research and impact of stocking strategies on pasture-animal production efficiencies, Crop Sci. 55 (2015) 2513—2530.

[11] F.M. Rouquette Jr., E. van Santen, G.R. Smith, Long-term forage and cow—calf relationships for bermudagrass overseeded with arrowleaf clover or annual ryegrass managed at different stocking rates, Crop Sci. 58 (2018) 1426—1439.

[12] L.E. Sollenberger, M.M. Kohmann, J.C.B. Dubeux, Jr., M.L. Silveira Grassland management affects delivery of regulating and supporting ecosystem services. Crop Sci. 59 (2019) 441—459.

[13] L.E. Sollenberger, E.S. Vanzant, Interrelationships among forage nutritive value and quantity and individual animal performance, Crop Sci. 51 (2011) 420—432.

[14] Y.C. Newman, L.E. Sollenberger, W.E. Kunkle, C.G. Chambliss, Canopy height and nitrogen supplementation effects on performance of heifers grazing limpograss, Agron. J. 94 (2002) 1375—1380.

[15] J.C. Burns, D.S. Fisher, 'Coastal' and 'Tifton 44' bermudagrass availability on animal and pasture productivity, Agron. J 100 (2008) 1280—1288.

[16] G.E. Aiken, W.D. Pitman, C.G. Chambliss, K.M. Portier, Responses of yearling steers to different stocking rates on a subtropical grass-legume pasture, J. Anim. Sci. 9 (1991) 3348—3356.

[17] U. Inyang, J.M.B. Vendramini, L.E. Sollenberger, B. Sellers, A. Adesogan, L. Paiva, et al., Effects of stocking rate on animal performance and herbage responses of Mulato and bahiagrass pastures, Crop Sci. 50 (2010) 1079—1085.

[18] J.C. Burns, D.S. Chamblee, F.G. Giesbrecht, Defoliation intensity effect on season-long dry matter distribution and nutritive value of tall fescue, Crop Sci. 42 (2002) 1274—1284.

[19] K.A. Macdonald, J.W. Penno, J.A.S. Lancaster, J.R. Roche, Effect of stocking rate on pasture production, milk production, and reproduction of dairy cows in pasture-based systems, J. Dairy Sci. 91 (2008) 2151—2163.

[20] 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.

[21] A. Hernández Garay, L.E. Sollenberger, D.C. McDonald, G.J. Ruegsegger, R.S. Kalmbacher, P. Mislevy, Nitrogen fertilization and stocking rate affect stargrass pasture and cattle performance, Crop Sci. 44 (2004) 1348—1354.

[22] C.G.S. Pedreira, L.E. Sollenberger, P. Mislevy, Productivity and nutritive value of 'Florakirk' bermudagrass as affected by grazing management, Agron. J 91 (1999) 796—801.

[23] M. Carlassare, H.D. Karsten, Species contribution to seasonal productivity of a mixed pasture under two sward grazing height regimes, Agron. J. 94 (2002) 840—850.

[24] C.J. Nelson, Shoot morphological plasticity of grasses: leaf growth vs. tillering, in: G. Lemaire, et al. (Eds.), Grassland Ecophysiology and Grazing Ecology, CABI Pub, New York, 2000, pp. 101—126.

[25] H. Huber, S. Lukács, M.A. Watson, Spatial structure of stoloniferous herbs: an interplay between structural blueprint, ontogeny and phenotypic plasticity, Plant Ecol. 141 (1999) 107—115.

[26] D. Gibson, J.J. Casal, V.A. Deregibus, The effect of plant density on shoot and leaf lamina angles in *Lolium multiflorum* and *Paspalum dilatatum*, Ann. Bot. 70 (1992) 69—73.

[27] M.K. Mullenix, L.E. Sollenberger, M.O. Wallau, D.L. Rowland, A.R. Blount, J.M.B. Vendramini, et al., Sward structure, light interception, and rhizome-root responses of rhizoma peanut cultivars and germplasm to grazing management, Crop Sci. 56 (2016) 899—906.

[28] C. Matthew, S.G. Assuero, C.K. Black, N.R. Sackville Hamilton, Tiller dynamics of grazed swards, in: G. Lemaire, et al. (Eds.), Grassland Ecophysiology and Grazing Ecology, CABI Pub, New York, 2000, pp. 127−150.
[29] J.S. Schepers, B.L. Hackes, D.D. Francis, Chemical water quality of runoff from grazing land in Nebraska II. Contributing factors, J. Environ. Qual. 11 (1982) 355−359.
[30] S.D. Warren, W.H. Blackburn, C.A. Taylor Jr., Soil hydrologic response to number of pastures and stocking density under intensive rotation grazing, J. Range Manage. 39 (1986) 500−504.
[31] M.M. Haan, J.R. Russell, W.J. Powers, J.L. Kovar, J.L. Benning, Grazing management effects on sediment and phosphorus in surface runoff, Rangeland Ecol. Manag. 59 (2006) 607−615.
[32] J.A. Ortega-S, L.E. Sollenberger, J.M. Bennett, J.A. Cornell, Rhizome characteristics and canopy light interception of grazed rhizoma peanut pastures, Agron. J. 84 (1992) 804−809.
[33] A.J. Franzluebbers, J.A. Stuedemann, H.H. Schomberg, S.R. Wilkinson, Soil organic C and N pools under long-term pasture management in the Southern Piedmont USA, Soil Biol. Biochem. 32 (2000) 469−478.
[34] A.J. Franzluebbers, J.A. Stuedemann, Soil-profile organic carbon and total nitrogen during 12 years of pasture management in the Southern Piedmont USA, Agric. Ecosys. Environ. 129 (2009) 28−36.
[35] A.L. Wright, F.M. Hons, F.M. Rouquette Jr., Long-term management impacts on soil carbon and nitrogen dynamics of grazed bermudagrass pastures, Soil Biol. Biochem. 36 (2004) 1809−1816.
[36] M.A. Abdalla, A. Hastings, D.R. Chadwick, D.L. Jones, C.D. Evans, M.B. Jones, et al., Critical review of the impacts of grazing intensity on soil organic carbon storage and other soil quality indicators in extensively managed grasslands, Agric. Ecosyst. Environ. 253 (2018) 62−81.
[37] S.J. Pogue, R. Kröbel, H.H. Janzen, K.A. Beauchemin, G. Legesse, D.M. de Souza, et al., Beef production and ecosystem services in Canada's prairie provinces: a review, Agric. Syst. 166 (2018) 152−172.
[38] R.J. Fuller, S.J. Gough, Changes in sheep numbers in Britain: implications for bird populations, Biol. Conserv. 91 (1999) 73−89.
[39] D.M. Evans, S.M. Redpath, D.A. Elston, S.A. Evans, R.J. Mitchell, P. Dennis, To graze or not to graze? Sheep, voles, forestry and nature conservation in the British uplands, J. Appl. Ecol. 43 (2006) 499−505.
[40] I.E. Karmiris, A.S. Nastis, Intensity of livestock grazing in relation to habitat use by brown hares (*Lepus europaeus*), J. Zool. 271 (2007) 193−197.
[41] J.D. Anadón, A. Giménez, I. Pérez, M. Martínez, A. Esteve, Habitat selection by the spur-thighed tortoise *Testudo graeca* in a multisuccessional landscape: implications for habitat management, Biodivers. Conserv. 15 (2006) 2287−2299.
[42] A.M. Klein, B.E. Vaissiere, J.H. Cane, I. Steffan-Dewenter, S.A. Cunningham, C. Kremen, et al., Importance of pollinators in changing landscapes for world crops, Proc. Royal Soc. B 274 (2007) 303−313.
[43] S.G. Potts, J.C. Biesmeijer, C. Kremen, P. Neumann, O. Schweiger, W.E. Kunin, Global pollinator declines: trends, impacts and drivers, Trends Ecol. Evol. 25 (2010) 345−353.
[44] P. Batáry, A. Báldi, M. Sárospataki, F. Kohler, J. Verhulst, E. Knop, et al., Effect of conservation management on bees and insect-pollinated grassland plant communities in three European countries, Agric. Ecosyst. Environ. 136 (2010) 35−39.
[45] B.W. Mathews, L.E. Sollenberger, W.E. Kunkle, J.E. Moore, A.C. Hammond, Dairy heifer and bermudagrass pasture responses to rotational and continuous stocking, J. Dairy Sci. 77 (1994) 244−252.
[46] J.R. Gerrish, J.R. Brown, P.R. Peterson, Impact of grazing cattle on distribution of soil mineral, American Forage and Grassland Council Proc, Des Moines, IA, March 29−31, 1993, American Forage and Grassland Council, Georgetown, TX, 1993, pp. 66−70.
[47] 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.
[48] M.M. McCartor, F.M. Rouquette Jr., Grazing pressures and animal performance from pearl millet, Agron. J. 69 (1977) 983−987.

[49] R.L. Duble, J.A. Lancaster, E.C. Holt, Forage characteristics limiting animal performance on warm-season perennial grasses, Agron. J. 63 (1971) 795—798.

[50] M.K. Barnes, B.E. Norton, M. Maeno, J.C. Malechek, Paddock size and stocking density affect spatial heterogeneity of grazing, Rangel. Ecol. Manage. 61 (2008) 380—388.

[51] G.R. Saul, D.F. Chapman, Grazing methods, productivity and sustainability for sheep and beef pastures in temperate Australia, Wool Technol. Sheep Breed. 50 (2002) 449—464.

[52] A.J. Parsons, I.R. Johnson, J.H.H. Williams, Leaf age structure and canopy photosynthesis in rotationally and continuously grazed swards, Grass Forage Sci. 43 (1988) 1—14.

[53] L.E. Sollenberger, Y.C. Newman, Grazing management, in: R.F. Barnes, et al. (Eds.), Forages - The Science of Grassland Agriculture, Blackwell Publishing, Ames, IA, 2007, pp. 651—659.

[54] J.F. Vallentine, Grazing Management, second ed., Academic Press, San Diego, California, 2001.

[55] A. Hernández Garay, L.E. Sollenberger, C.R. Staples, C.G.S. Pedreira, Florigraze and Arbrook rhizoma peanut as pasture for growing Holstein heifers, Crop Sci. 44 (2004) 1355—1360.

[56] J.M. Earl, C.E. Jones, The need for a new approach to grazing management: is cell grazing the answer? Rangel. J. 18 (1996) 327—350.

[57] L.B. Owens, M.J. Shipitalo, Surface and subsurface phosphorus losses from fertilized pasture systems in Ohio, J. Environ. Qual. 35 (2006) 1101—1109.

[58] L.A. Sovell, B. Vondracek, J.A. Frost, K.G. Mumford, Impacts of rotational grazing and riparian buffers on physiochemical and biological characteristics of southeastern Minnesota, USA, streams, Environ. Manage. 26 (2000) 629—641.

[59] J. Lyons, B.M. Weigel, L.K. Paine, D.J. Undersander, Influence of intensive rotational grazing on bank erosion, fish habitat quality, and fish communities in southwestern Wisconsin trout streams, J. Soil Water Conserv. 55 (2000) 271—276.

[60] L.B. Owens, M.J. Shipitalo, Runoff quality evaluations of continuous and rotational over-wintering systems for beef cows, Agric. Ecosys. Environ. 129 (2009) 482—490.

[61] H.A. Kuykendall, M.L. Cabrera, C.S. Hoveland, M.A. McCann, L.T. West, Stocking method effects on nutrient runoff from pastures fertilized with broiler litter, J. Environ. Qual. 28 (1999) 1886—1890.

[62] 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.

[63] R.B. Renfrew, C.A. Ribic, Grassland birds associated with agricultural riparian practices in southwestern Wisconsin, J. Range Manage. 54 (2001) 546—552.

[64] B.H. Koerth, W.M. Webb, F.C. Bryant, F.S. Guthery, Cattle trampling of simulated ground nests under short duration and continuous grazing, J. Range Manage. 36 (1983) 385—386.

[65] E.W. Chapman, C.A. Ribic, The impact of buffer strips and stream-side grazing on small mammals in southwestern Wisconsin, Agric. Ecosys. Environ. 88 (2002) 49—59.

[66] M.D. Redden, Grazing method effects on forage production, utilization, and animal performance on Nebraska Sandhills meadow (MS Thesis), University of Nebraska-Lincoln, 2014.

[67] T. Gompert, The power of stock density, in: Proc. Nebraska Grazing Conference. Kearney, NE, 2010, 14—17. https://www.unl.app.box.com/s/rcujr19pvretjfgr3gpo5bjmt4eadv9b.

[68] P.R. Peterson, J.R. Gerrish, Grazing management affects manure distribution by beef cattle, in: Proc. Am. Forage Grassland Council, Lexington, 1995, pp. 170—174.

[69] T. Lindsey, Grazing method effects on forage production, utilization, animal performance and animal activity on Nebraska Sandhills meadow (MS Thesis), University of Nebraska-Lincoln, 2016.

[70] B. Tracy, Summary of mob grazing in Virginia, in: Proc. 2017 Northeast Pasture Consortium Annual Conference and Meeting. Hagerstown, MD, 2017, 1—7 pp.

[71] D.I. Bransby, Biological implications of rotational and continuous grazing: a case for continuous grazing, pp. 10—14, in: Proc. Am. Forage Grassl. Conf. Columbia, MO, Apr 1—4, 1991, Am. Forage Grassl. Counc. Georgetown, TX.

[72] L.E. Sollenberger, Challenges, opportunities, and applications of grazing research, Crop Sci. 6 (2015) 2540—2549.

[73] M.D. Casler, I.T. Carlson, Smooth bromegrass, in: R.F. Barnes, et al. (Eds.), Forages: An Introduction to Grassland Agriculture, Iowa State Univ. Press, Ames, 1995, pp. 313—324.

[74] B. Anderson, A.G. Matches, C.J. Nelson, Carbohydrate reserves and tillering of switchgrass following clipping, Agron. J. 81 (1989) 13−16.
[75] G.W. Evers, L.R. Nelson, Grazing termination date influence on annual ryegrass seed production and reseeding in the southeastern USA, Crop Sci. 40 (2000) 1724−1728.
[76] C.J. Chaparro, L.E. Sollenberger, S.B. Linda, Grazing management effects on aeschynomene seed production, Crop Sci. 31 (1991) 197−201.
[77] D.S. Fisher, H.F. Mayland, J.C. Burns, Variation in ruminant preference for alfalfa hays cut at sunup and sundown, Crop Sci. 42 (2002) 231−237.
[78] G.O. Mott, J.E. Moore, Evaluating forage production, in: R.F. Barnes, et al. (Eds.), Forages: The Science of Grassland Agriculture, Iowa State University Press, Ames, IA, 1985, pp. 97−110.