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CHAPTER

3

Prescribed Grazing on Pasturelands

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Sustainable grasslands enhance environmental quality and the resource base of the ecosystem while providing human food needs”

Prescribed Grazing on Pasturelands

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INTRODUCTION

Prescribed grazing is defined by the Natural Resources Conservation Service (NRCS) as “managing the harvest of vegetation with grazing and/or browsing animals” (NRCS, 2007). The principles of grazing management center round the temporal and spatial distribution of various kinds and number of livestock (Heitschmidt, 1988). Within the context of this chapter, management of grazing or browsing will be characterized in terms of intensity, method, and season (timing), and as a function of the type and class of livestock and their distribution on the landscape.

The choice to use a particular level of any of these management strategies should be objective driven. Objectives may include achieving canopy conditions and forage productivity that result in optimal levels of animal performance (Hodgson, 1990), but can be expanded to include the concept of sustainability and provision of ecosystem services. Sustainable grasslands enhance environmental quality and the resource base of the ecosystem while providing human food needs in a manner that is economically viable and that enhances the quality of life for both producers and consumers (Stewart et al., 1991). Achieving such a wide range of objectives is a challenge for those implementing and practicing prescribed grazing.

The NRCS has developed conservation practice standards to provide guidance for applying conservation technology on the land and to set the minimum acceptable level for application of the technology. The Prescribed Grazing Practice Standard (code 528; see Appendix I) is intended for application to all lands where grazing or browsing animals are managed. An assessment

of prescribed grazing purposes on rangeland has been completed (Briske et al., 2011), so this chapter is focused on the same purposes for pastureland. The five specific purposes outlined in the Prescribed Grazing Practice Standard for pastureland and the criteria by which they were assessed are summarized in Table 3.1.

The goal of this literature synthesis was to determine if the prescribed practices do, in fact, meet the purposes and criteria. Therefore, the assessment is organized around the five purposes (as main headings) or desired outcomes from imposing prescribed grazing “management strategies.” Management strategies include grazing intensity, stocking method, timing of grazing (i.e., season of grazing and deferral from grazing), type and class of livestock, and livestock distribution on the landscape.

A comprehensive search and review of the refereed literature was conducted for each management strategy to describe its effect on the grazing system and to determine if implementation of the strategy will achieve the short- and long-term purposes of the practice standard. Knowledge gaps in the literature were identified, and the potential use of management to correct undesirable trends or restore desired grassland condition was explored. The focus was U.S. literature, but in cases where U.S. data were unavailable or limited, international research and well-designed, nonrefereed papers were used.

PURPOSE 1: IMPROVE OR MAINTAIN DESIRED SPECIES COMPOSITION AND VIGOR OF PLANT COMMUNITIES

GRAZING INTENSITY

Measures of grazing intensity are animal or pasture based. Stocking rate (animal units ha⁻¹)



Rotational stocking used on a “Florakirk” bermudagrass pasture in Florida. Photo by Lynn Sollenberger, University of Florida.

TABLE 3.1. Purposes of the Prescribed Grazing Practice Standard, criteria for assessing achievement of the purposes, and a summary of which grazing strategies were documented in the literature to affect these criteria.

Purposes of the practice standard	Criteria for assessing achievement of the purpose	Level of research support (in parentheses) ¹ of prescribed grazing strategies for each criterion
Improve or maintain desired species composition and vigor of plant communities	<ul style="list-style-type: none"> · By providing grazed plants sufficient recovery time to meet objectives · By improving or maintaining vigor of plant communities, especially key species · By enhancing diversity of plants and optimizing delivery of nutrients to animals · By combining it with other pest management practices to promote community resistance to invasive weed species and enhance desired species 	<ul style="list-style-type: none"> · Stocking method (SS); season of grazing (SS) · Grazing intensity (SS); stocking method (MS); season of grazing (MS); type and class of livestock (MS) · Grazing intensity (SS); stocking method (WS); distribution of livestock (MS) · Grazing intensity (SS); stocking method (MS); season of grazing (MS)
Improve or maintain quantity and quality of forage for grazing and browsing animals' health and productivity	<ul style="list-style-type: none"> · By reducing animal stress and death from toxic or poisonous plants · By improving and maintaining plant health and productivity · By basing management on target levels of forage utilization or stubble height as a tool to help insure goals are met · By locating of feeding, watering, and handling facilities to improve animal distribution 	<ul style="list-style-type: none"> · None documented · Grazing intensity (SS); stocking method (MS); season of grazing (SS); type and class of livestock (MS) · Grazing intensity (SS) · Distribution of livestock in the landscape (MS)
Improve or maintain surface and/or subsurface water quality and quantity, and riparian and watershed function	<ul style="list-style-type: none"> · By improving or maintaining riparian and watershed function · By minimizing deposition or flow of animal wastes into water bodies · By minimizing animal effects on stream bank stability · By providing adequate litter, ground cover, and plant density to maintain or improve infiltration capacity of the vegetation · By providing ground cover and plant density to maintain or improve filtering capacity of the vegetation · By minimizing concentrated livestock areas, trailing and trampling to reduce soil compaction, excess runoff, and erosion 	<ul style="list-style-type: none"> · Grazing intensity (SS); stocking method (MS); season of grazing (SS); distribution of livestock (MS) · Grazing intensity (SS); stocking method (WS); season of grazing (WS); distribution of livestock (SS) · Grazing intensity (WS); stocking method (MS); season of grazing (MS); distribution of livestock (SS) · Grazing intensity (SS); stocking method (MS); season of grazing (MS) · Grazing intensity (SS); stocking method (MS); season of grazing (MS) · Grazing intensity (SS); stocking method (MS); season of grazing (MS)

is the most common animal-based measure of grazing intensity. Pasture- or sward-based measures include forage mass, canopy height, and canopy light interception. Forage allowance and grazing pressure include both a pasture and animal measure. These terms have been defined by the Forage and Grazing Terminology Committee (Allen et al., 2011).

It is suggested that the choice of grazing intensity is more important than any other single grazing management decision (Jones and Jones, 1997; Sollenberger and Newman, 2007) because of its prominent role in determining forage plant growth and persistence (Chacon and Stobbs, 1976), forage mass and allowance (Burns et al., 2002; Hernández Garay et al.,

TABLE 3.1. continued.

Purposes of the practice standard	Criteria for assessing achievement of the purpose	Level of research support (in parentheses) ¹ of prescribed grazing strategies for each criterion
Reduce accelerated soil erosion, and maintain or improve soil condition	<ul style="list-style-type: none"> · By reducing accelerated soil erosion · By minimizing concentrated livestock areas to enhance nutrient distribution and improve ground cover · By improving carbon sequestration in biomass and soils · By application of soil nutrients according to soil test to improve or maintain plant vigor 	<ul style="list-style-type: none"> · Grazing intensity (MS) · Grazing intensity (MS); stocking method (MS) · Grazing intensity (MS) · Grazing intensity (MS)
Improve or maintain the quantity and quality of food and/or cover available for wildlife	<ul style="list-style-type: none"> · By maintaining adequate riparian community structure and function to sustain associated riparian, wetland, flood plain, and stream species · By providing for development and maintenance of the plant structure, density, and diversity needed for desired fish and wildlife species · By improving the use of the land for wildlife and recreation · By avoiding any adverse effects on endangered, threatened, and candidate species and their habitats 	<ul style="list-style-type: none"> · Grazing intensity (SS); season of grazing (SS); distribution of livestock (MS) · Grazing intensity (SS); season of grazing (SS); type and class of livestock (MS); distribution of livestock (MS) · Grazing intensity (SS); season of grazing (MS); distribution of livestock (MS) · Grazing intensity (MS); season of grazing (MS); distribution of livestock (MS)

¹The five grazing strategies were grazing intensity, stocking method, season and deferral of grazing, type and class of livestock, and distribution of livestock in the landscape. SS indicates strongly supported; MS, moderately supported; and WS, weakly supported; for grazing strategies not shown there was no support in the literature that this strategy affected the criterion in question.

2004a), animal performance (Humphreys, 1991; Newman et al., 2002b), size of nutrient pools and fluxes between pools (Thomas, 1992; Dubeux et al., 2006), soil chemical and physical characteristics (Kelly, 1985; Dubeux et al., 2009), water quality (Van Poollen and Lacey, 1979), and profitability of the grazing operation. Understanding the relationships of grazing intensity with pasture, animal, and soil responses is crucial for the long-term success of the forage-livestock enterprise (Walker, 1995). In this section the focus is on plant responses to grazing intensity.

Forage Quantity

A total of 67 papers contained relevant data, and 48 reported forage mass, forage accumulation, or forage allowance responses to grazing intensity. Treatment variables were primarily stocking rate or sward height.

Forage Mass. Forage mass (kg ha^{-1}) is the instantaneous measure of the total dry weight of forage per unit land area above a defined

reference level (e.g., stubble height; Allen et al., 2011). Forage mass was measured in 31 of the 48 studies in which a measure of quantity was taken. In 29 of 31 (94%) studies, forage mass decreased, in most cases linearly, with increasing grazing intensity (Fig. 3.1). For example, forage mass of continuously stocked limpgrass (scientific names for species are in Appendix III) pastures in Florida (Newman et al., 2002b), “Coastal” and “Tifton 44” bermudagrass pastures in North Carolina (Burns and Fisher, 2008), and mixed black oat and annual ryegrass pastures in Brazil (Aguinaga et al., 2008) increased linearly with increasing sward height. Pre-graze forage mass of stargrass in rotationally stocked pastures in Jamaica decreased linearly as stocking rate increased (Hernández Garay et al., 2004a). In one of the two studies in which forage mass was unaffected by grazing intensity, the range of stocking rates was low and the pastures were understocked (Valencia et al., 2001).

Forage Accumulation Rate. Forage accumulation rate is the increase in forage mass

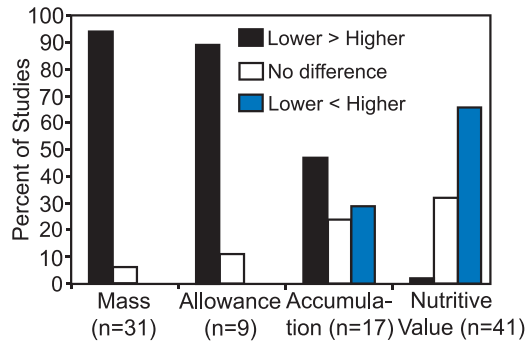


FIGURE 3.1. Percent of studies showing responses to higher and lower grazing intensity for experiments that reported data based on measures of forage mass, forage allowance, forage accumulation, and forage nutritive value. Number of experiments for each data set is indicated in parentheses. “Higher” and “lower” indicate grazing intensity (i.e., higher or lower stocking rate).

per unit area over a specified period of time. This response was measured in 17 of the 48 studies that reported forage quantity responses to grazing intensity. The forage accumulation response was less consistent than forage mass (Fig. 3.1). In nearly half of the studies (47%), forage accumulation was favored by lower grazing intensity, but it was not affected by grazing intensity in four studies (24%) and was increased by increasing grazing intensity in five studies (28%).

Species showing greater forage accumulation in response to increasing grazing intensity typically were ones considered to be grazing tolerant including tall fescue in North Carolina (Burns et al., 2002), perennial ryegrass–white clover in New Zealand (Macdonald et al., 2008), and “Mulato” brachiariagrass in Florida (Inyang et al., 2010). In contrast, forage accumulation decreased with increased grazing intensity for less grazing tolerant warm-season forages, including stargrass in Florida and Jamaica (Mislevy et al., 1989; Alcordo et al., 1991; Hernández Garay et al., 2004a), rhizoma peanut in Florida (Ortega et al., 1992b), and bermudagrass in Florida (Pedreira et al., 1999). Forage accumulation also decreased with increasing grazing intensity for temperate forage mixtures based on orchardgrass, including those with Kentucky bluegrass, quackgrass, red clover, alfalfa, and white clover in Pennsylvania (Carlassare and Karsten, 2002),

and ladino clover in California (Hull et al., 1961, 1965). This response is attributed to the upright growth habit of orchardgrass, which causes it to be relatively intolerant of greater grazing intensity (Carlassare and Karsten, 2002).

Species responses were not always consistent, as black oat–annual ryegrass (Aguinaga et al., 2008), Kentucky bluegrass and white clover (Bryan and Prigge, 1994), stargrass (Adjei et al., 1980), and bermudagrass (Roth et al., 1990) were part of the group for which accumulation did not respond to grazing intensity. Also, in the study with rhizoma peanut, the effect of grazing intensity was more pronounced with short than long rest periods between grazings showing an interaction with grazing frequency (Ortega et al., 1992b). These reports provide clear evidence that the effect of grazing intensity on forage accumulation cannot be predicted in isolation; it depends on forage species, grazing frequency, and the environment.

Forage Allowance. Forage allowance is defined as the relationship between forage mass and animal liveweight per unit area at any one time (Sollenberger et al., 2005; Allen et al., 2011). Forage allowance was measured as a response in only nine of 48 studies (Adjei et al., 1980; Conrad et al., 1981; Guerrero et al., 1984; Aiken et al., 1991; Valencia et al., 2001; Fike et al., 2003; Newman et al., 2002b; Hernández Garay et al., 2004a; Inyang et al., 2010) and was a treatment variable in one (Roth et al., 1990). Forage allowance decreased with increasing grazing intensity in eight of nine studies (89%; Fig. 3.1). The single exception occurred when pastures were stocked too lightly to distinguish treatments (Valencia et al., 2001).

Decreasing forage allowance by increasing grazing intensity is expected due to the near universal observation of decreasing forage mass (the numerator in calculation of forage allowance) and increasing number of animal units (the denominator) with increasing grazing intensity. The nature of the response was most often curvilinear (in five of six studies where more than two levels of grazing intensity were investigated, or where the nature of the response was reported) with the rate

of change decreasing with increasing grazing intensity. For example, on stargrass pastures stocked with 200-kg bulls at 2.5, 5.0, and 7.5 head ha⁻¹ the forage allowance was 7.6, 2.7, and 1.2 kg forage kg⁻¹ animal liveweight, respectively (Hernández Garay et al., 2004a). This curvilinear relationship is mathematically consistent with linear decreases in forage mass as a function of increasing grazing intensity.

Forage Nutritive Value

Nutritive value is defined as the chemical composition, digestibility, and nature of digested products of forage (Sollenberger and Cherney, 1995). Forty-one of 67 grazing intensity papers reported nutritive value responses, mainly crude protein (CP), *in vitro* digestion, neutral detergent fiber (NDF), acid detergent fiber (ADF), and lignin. In a few papers, the traditional definition of nutritive value was broadened to include plant part composition and forage bulk density. A limitation of much of the nutritive value literature is that sampling strategies often fail to collect forage that represents the portion of the canopy in which the animals are grazing.

The nutritive value response to increasing grazing intensity was not as consistent as the forage quantity response, yet nearly all studies (40 of 41; 98%) reported either no effect (13 of 41; 32%) or a positive effect (27 of 41; 66%) on nutritive value (Fig. 3.1). Only one (2%) reported a negative effect (Ackerman et al., 2001). In three of the 13 studies showing no effect, the authors cited the relatively narrow range of stocking rates imposed as a reason for lack of response (Valencia et al., 2001; Arthington et al., 2007; Scaglia et al., 2008).

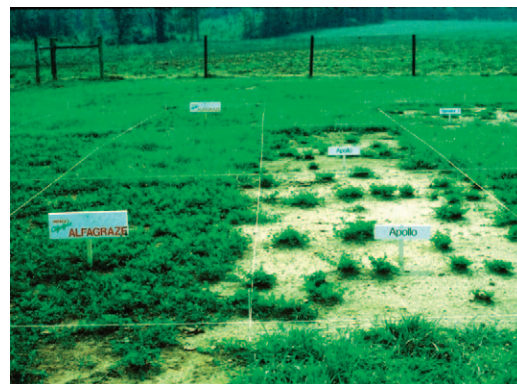
Positive effects of increasing grazing intensity on nutritive value occurred in West Virginia where Kentucky bluegrass–white clover pastures were continuously stocked (Bryan and Prigge, 1994), in an orchardgrass–ladino clover association in California that was rotationally stocked (Hull et al., 1965), with alfalfa in Michigan (Schlegel et al., 2000a), and with a perennial ryegrass–white clover mixture in New Zealand (Macdonald et al., 2008). For C₄ grasses, *in vitro* digestion increased with increasing stocking rate for both Coastal and “Callie” bermudagrass pastures in Texas (Guerrero et al., 1984), for “Tanzania”

guineagrass in Brazil (do Canto et al., 2008), and for digitgrass in tropical Australia (Jones and LeFeuvre, 2006).

The increase in forage nutritive value with greater grazing intensity may seem counterintuitive because there is less forage mass and grazing occurs at lower strata in the canopy. Nutritive value generally decreases from top to bottom of a canopy, particularly for C₄ grasses (Fisher et al., 1991; Holderbaum et al., 1992). However, when canopies are grazed intensively over an extended period of time the leaf proportion of the forage mass is greater and age of regrowth is younger because of shorter intervals between animal visits to individual patches (Roth et al., 1990; Pedreira et al., 1999; Newman et al., 2002a, 2002b; Hernández Garay et al., 2004a; Dubeux et al., 2006).

The positive response of forage nutritive value to increasing grazing intensity may result in limited measureable effects on animal performance because of the associated decrease in forage quantity. For example, digitgrass nutritive value increased with increasing stocking rate in Australia (Jones and Lefeuvre, 2006), but nutritive value was negatively correlated with cattle average daily gain. In the same study, the relationship of forage mass and daily gain was positive (Jones and Lefeuvre, 2006). Other studies have shown that the greater nutritive value associated with higher grazing intensity cannot overcome a quantity limitation (McCartor and Rouquette, 1977; Guerrero et al., 1984; Hernández Garay et al., 2004a).

In a comprehensive review of the grazing literature, forage nutritive value was found to



Grazing tolerant “Alfagraze” (left) and intolerant “Apollo” alfalfa stands following 3 yr of frequent, intense grazing. Photo by Joe Bouton, University of Georgia and Noble Foundation.



Grazed pastures generally have greater species richness than areas that are not grazed. Photo by Carmen Agouridis, University of Kentucky.

1) set the upper limit for average daily gain, 2) determine the slope of the regression of daily gain on stocking rate, and 3) establish the forage mass at which daily gain plateaus (Sollenberger and Vanzant, 2011). In contrast, forage quantity determined the proportion of potential daily gain that was achieved and was the primary driver for direction of the daily gain response (negative) to increasing stocking rate. Thus, choosing which grazing intensity to use must account for the overriding importance of forage mass and forage allowance in affecting animal response.

Forage Botanical Composition and Species Persistence

Grazing intensity affects pasture productivity and nutritive value and may impact species composition of the sward and persistence of desired species. Twenty-nine of the 67 grazing intensity papers reviewed described botanical composition or persistence-related responses

to grazing intensity. In most cases grazing intensity interacted strongly with other factors, which are explored in this section.

Grazing Intensity by Frequency Interaction.

The importance of grazing intensity by frequency interaction in sward persistence is well established (Sollenberger and Newman, 2007). For example, sainfoin survival was not affected by stubble height when defoliated at seed-shatter stage, but if defoliated more frequently, at bud or flower stage, and grazed to a low stubble height (5 cm), stands were greatly reduced (Mowrey and Matches, 1991).

Weed invasion into rotationally stocked, mixed pastures of the legume Siratro and the grass setaria was greater and legume contribution less when pastures were grazed every 3 wk than every 6 or 9 wk at a range of stocking rates (Jones, 1979). Longer regrowth intervals lessened the impact of high stocking rate on

the legume. In Florida a rhizoma peanut–common bermudagrass mixture (90% peanut at initiation) was stocked rotationally to leave a range of residual forage mass (Ortega et al., 1992a, 1992b). Peanut percentage in the stand after 2 yr was lower with short rest periods, especially when residual forage mass was low, but legume persistence was better with a 42-d rest period. Changes in rhizome mass also reflected the intensity by frequency interaction.

Grazing Intensity by Cultivar Interaction.

Several papers highlight the interaction between cultivar and grazing intensity on persistence. “Alfagraze” and “Apollo” alfalfa were stocked continuously at three levels of forage mass in central Georgia (Bates et al., 1996). After 3 yr of grazing, Alfagraze had 59 plants m^{-2} for both the greatest and least forage mass, while less grazing-tolerant Apollo maintained 36 plants at the greatest mass but only 16 plants m^{-2} at the lowest forage mass.

In Florida, at high stocking rate, “Bigalta” limpograss was rapidly invaded by common bermudagrass while “Floralta” persisted at both stocking rates (Pitman et al., 1994). Stubble height had varying effects on persistence of three stargrasses in Florida (Mislevy et al., 1989). Weeds contributed less than 10% of forage mass if stubble height was 15 cm or greater for all three cultivars tested, but if stubble height was < 15 cm, weed percentage was 12 to 25% for “Florico” but averaged 6% for “Florona” and “Ona.” These data show that prescribed grazing intensity is a function of forage species and also dependent to a large degree on the cultivar.

Multispecies Pastures. When multiple forage species are present, the complexity of selecting the optimal grazing intensity increases, particularly when growth characteristics of the species vary widely. For example, when limpograss-dominated grass pastures in Florida were stocked continuously to a range of canopy heights, the bunchgrass weed vaseygrass was essentially removed by grazing to 20 cm (Newman et al., 2003). In contrast, percentage of the stoloniferous weed common bermudagrass increased markedly with the 20-cm height, but remained low when a 40-cm height was maintained.

In grass-legume pastures, legumes often are considered to be less persistent under high stocking rates than grasses; however, the species present in the sward has a major effect on the response. Mixtures of the stoloniferous creeping signalgrass, with either ovalifolium or tropical kudzu, were continuously stocked with 2 or 3 steers ha^{-1} (Cantarutti et al., 2002). Average legume percentage was 30 and 10 for the low and high stocking rates, respectively. Higher stocking rate favored the aggressive, relatively decumbent grass.

The opposite was observed when a palisadegrass–pinto peanut pasture in Costa Rica was stocked continuously at 600 and 1200 kg liveweight ha^{-1} (Hernandez et al., 1995). During 3 yr of grazing, pinto peanut contributed 34% of dry matter on offer at the high but only 6% at the low stocking rate. This was due to its prostrate, stoloniferous growth habit that conveyed greater tolerance of high stocking rates than the upright-growing palisadegrass.

In California the percentage of white clover increased as stocking rate increased reflecting greater tolerance of close grazing than orchardgrass. Similarly, the greatest percentage of white clover in a mixed pasture in Ireland occurred at the highest stocking rate (Conway, 1968). In Pennsylvania, when a complex mixture was stocked rotationally for 2 yr with grazing initiation/termination at heights of 20/5 cm or 27/7 cm, forage accumulation of red clover, alfalfa, and orchardgrass was greater for tall than short pastures whereas Kentucky bluegrass accumulation was greater for short than tall (Carlassare and Karsten, 2002). This can be attributed, in part, to tillering response to stocking rate; greater stocking rate decreased tiller density for upright-growing orchardgrass and increased tiller density for prostrate-growing Kentucky bluegrass (Fales et al., 1995).

Plant Adaptations to Grazing Intensity. Each plant within a population has some ability to adapt to stress by changing its morphology, an attribute termed phenotypic plasticity (Nelson, 2000). Phenotypic plasticity is reversible and includes changes in size, structure, and spatial positioning of organs (Huber et al., 1999) such that optimization of canopy leaf area at lower defoliation height may be achieved through



When multiple forage species are present, the complexity of selecting the optimal grazing intensity increases”



...conservation planning activities should prioritize prescription of the appropriate stocking rate or sward height.”

a decrease in mean tiller size and an increase in tiller density (Matthew et al., 2000). For example, tiller density of caucasian bluestem was more than double at a high than a low grazing intensity while tiller mass was 10 times greater for low than for high grazing intensity (Christiansen and Svejcar, 1988). Phenotypic plasticity has limits, and if defoliation is too severe, the leaf area, substrate supply, and tiller production decrease, which in turn reduces tiller survival and weakens the stand (Matthew et al., 2000).

Phenotypic plasticity varies among species (Gibson et al., 1992) and can be related to grazing tolerance. When two C_4 bunchgrasses were defoliated frequently and severely, buffelgrass produced more horizontal tillers and achieved a 10-fold greater leaf area below defoliation height than did red oatgrass, which retained its upright tillering orientation (Hodgkinson et al., 1989). Thus, phenotypic plasticity of buffelgrass contributed to its greater grazing tolerance than red oatgrass.

Below-ground responses also impact plant persistence. Root length and root mass of caucasian bluestem pastures were about 30% less after 1 yr and 45% less after 2 yr for high versus low grazing intensity (Christiansen and Svejcar, 1988). Root-rhizome mass of rhizoma peanut was 80% less and ground cover was 38% less after 4 yr of defoliation to 2.5 cm compared with 10 cm (Mislevy et al., 2007). Root mass of stargrass was reduced 3 to 10 times by stubble height of 5 cm vs. 15 cm, and stem base carbohydrate reserves were reduced by 15 to 22 g kg^{-1} (Alcordero et al., 1991). In Texas root carbohydrate reserves of sanfoin were lower following high vs. medium or low grazing intensity (Mowrey and Matches, 1991).

Species Richness Response to Grazing Intensity. There is limited information in the U.S. literature on this subject. In Israel species richness of annual legumes was lowest in non-grazed sites and increased gradually with increasing grazing intensity; however, extremely high grazing intensity reduced mean legume richness (Noy-Meir and Kaplan, 2002). The 24 species with a positive response to grazing intensity had low, decumbent, or prostrate growth habits. Intermediate response species were more upright types, but the most negative

effect of grazing intensity was associated with twining species. Greater species richness of grazed vs. non-grazed pastureland was also reported in several studies in Iowa (Barker et al., 2002; Guretzky et al., 2004, 2005, 2007).

Summary and Recommendations: Grazing Intensity

Review of the grazing intensity literature affirms its often-stated characterization as the most important grazing management decision for pastureland. Because of the major effect of grazing intensity on productivity, nutritive value, botanical composition, and persistence of pasturelands, conservation planning activities should prioritize prescription of the appropriate stocking rate or sward height. If conservation planning fails to identify, achieve, and maintain the proper grazing intensity, then choice of stocking method, season of grazing and deferment, or any other grazing strategy will not be able to overcome this failure.

Several shortcomings were identified in the grazing intensity literature. A major shortcoming is inconsistency in forage terminology. Pastureland scientists and advisers should adopt a standard terminology, preferably based on that already developed by the Forage and Grazing Terminology Committee (Allen et al., 2011). Forage mass, forage accumulation, and forage allowance are preferred terms. Others such as yield and forage available are vague, confusing, and ill-advised for reporting quantity measures on pastureland. The term *forage quality* is widely misused and should be reserved for measures of animal performance or intake. The term *nutritive value* is correctly used when chemical composition and digestibility of the plant tissue have been quantified.

A recurring methodological weakness in the nutritive value literature is that sampling procedures may not effectively represent the portion of the sward canopy the animals are grazing. Thus, estimates of diet nutritive value may be flawed, and in some cases the comparisons among treatments biased.

Most literature reports on botanical composition and persistence are 2-yr studies, which for many species and environments is insufficient to develop or even predict the

long-term balance of species composition and expression of phenotypic plasticity in response to the grazing management. Although short grant funding cycles, limited length of graduate student research projects, and high costs of grazing research are contributors, they cannot be excuses. Short-term studies contribute to inadequate and often misleading knowledge that may not represent long-term botanical composition and persistence responses.

STOCKING METHOD

Stocking method is “a defined procedure or technique to manipulate animals in space and time to achieve a specific objective” (Allen et al., 2011). It is important to distinguish *stocking method* from *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” (Allen et al., 2011). As defined, stocking method is but one component of the overarching grazing system.

For this assessment, stocking method refers to the manner in which animals are stocked or have access to pastures and paddocks (pasture subdivisions, if present) during the grazing season. Choice of *stocking method* is separate from *grazing intensity*; a particular stocking method may include a wide range of grazing intensities that are based on stocking rates or forage height or mass. Many stocking methods have been described (Vallentine, 2001; Allen et al., 2011), but each is derived from continuous or some form of rotational stocking. Under continuous stocking, animals have unlimited and uninterrupted access to the grazing area throughout the period when grazing is allowed (Allen et al., 2011). Rotational stocking utilizes recurring periods of grazing and rest among paddocks in a grazing management unit. Often the objective of rotational stocking is to achieve efficient and more uniform defoliation of the pasture and to optimize pasture productivity and persistence.

Plant-related advantages of rotational over continuous stocking purportedly include increased pasture carrying capacity, improved plant persistence (Matches and Burns, 1995), and more uniform use of an

extensive pasture area (Hart et al., 1993). Whether these advantages are supported by the scientific literature has been a topic of much debate and has generated considerable disagreement among scientists and graziers. For example, Bransby (1991) stated “few topics in agriculture have been addressed with such charismatic language and such abandonment of scientific evidence and logic” as have discussions regarding rotational and continuous stocking.

Data from 57 papers were used to determine the effect of stocking method on measures of forage quantity, nutritive value, botanical composition, and persistence. Achieving meaningful comparisons of plant responses under continuous and rotational stocking is complex. Sampling methods used to quantify these responses vary widely in the literature, and in some cases the sampling method may provide biased comparisons of stocking methods.

Forage Quantity

Many reports suggest rotational stocking allows greater average stocking rates (i.e., carrying capacity) than continuous stocking (Blaser et al., 1986), inferring that rotationally stocked pastures have greater forage accumulation rate and/or more efficient utilization of existing forage mass than continuously stocked pastures. Unfortunately, few stocking method studies have measured



Whether these advantages are supported by the scientific literature has been a topic of much debate”

Cattle use their tongue to select and gather leaf of the woody legume leucaena before biting. Photo by Lynn Sollenberger, University of Florida.





Greater average stocking rate for rotationally vs. continuously stocked pastures was reported on bermudagrass (and several other species).”

these independent responses, so in most cases indirect measures of pasture productivity, e.g., average stocking rate or animal days of grazing, are the only quantity-related responses available for making comparisons among methods.

There were 27 papers reviewed that included both rotational and continuous stocking treatments and reported responses related to quantity of forage. Of these, 23 (85%) reported an advantage in forage quantity response for rotationally vs. continuously stocked pastures. From the 23 studies cited that showed greater forage quantity-related responses on rotationally than continuously stocked pastures, 16 were described sufficiently that the magnitude of the difference could be determined (Table 3.2). For these, the advantage for rotational stocking ranged from 9% to 68%, with an average of 30%.

Indirect Measures of Forage Quantity.

Average stocking rate is the most common indirect measure of forage quantity. Greater average stocking rate for rotationally vs. continuously stocked pastures was reported on bermudagrass in Florida (Mathews et al., 1994b), wheat–annual ryegrass in Arkansas (Aiken, 1998), alfalfa–grass mixtures in Illinois (Bertelsen et al., 1993), orchardgrass–legume mixtures in Virginia (Bryant et al., 1961), “Plains” old world bluestem in Oklahoma (Volesky et al., 1994), switchgrass and big bluestem in Iowa (George et al., 1996), orchardgrass–perennial ryegrass–tall fescue–white clover mixtures in California (Hull et al., 1967), and bermudagrass in Arkansas (Tharel, 1989). Plains old world bluestem pastures in Oklahoma had a 34% higher stocking rate using frontal stocking (cattle move a sliding fence to access new forage, a back fence restricts regrowth) than for continuous stocking (Volesky, 1994). He suggested frontal stocking increases tillering, keeps the canopy near optimum leaf area index (LAI), provides a greater proportion of young tissue, and removes more old tissue.

Forage Mass, Accumulation Rate, and Canopy Photosynthesis. Greater forage mass was reported on rotationally than on continuously stocked bermudagrass–tall fescue

pastures in Georgia (Hoveland et al., 1997). In Florida average forage accumulation rate of “Pensacola” bahiagrass over three growing seasons was greater for rotationally than continuously stocked pastures (Stewart et al., 2005). With phalaris–subterranean clover mixtures in Australia, rotational stocking supported greater forage accumulation and stocking rates of ewes than did continuous stocking (Chapman et al., 2003).

Canopy photosynthesis of perennial ryegrass in the United Kingdom was greater in continuously stocked swards (LAI = 1) immediately following defoliation of the rotationally stocked treatment (to LAI of 0.5), but this soon reversed because percentage of young leaves increased more rapidly in rotational swards (Parsons et al., 1988). These authors found that long-term rates of canopy photosynthesis of rotationally stocked perennial ryegrass pastures exceeded those of continuously stocked pastures even when defoliation was severe and regrowth periods were relatively short.

Efficiency of Utilization of Forage Mass.

Greater forage quantity-related responses in rotationally than continuously stocked pastures may be due to greater efficiency of utilization of forage mass. Norton (2003) hypothesized that livestock are more evenly distributed and encounter more forage in smaller paddocks or at higher stocking densities, like those used with rotational stocking. This was supported by a Utah study of mixed-grass pastures using the same stocking rate, but different paddock sizes (Barnes et al., 2008). In most cases, paddocks ≤ 4 ha were grazed more evenly than larger paddocks and had a lower proportion of nonutilized area. Similarly, Heitschmidt (1988) concluded, “Because intensively managed rotational type grazing systems facilitate livestock distribution by increasing livestock density, spatial variation in grazing pressure index is reduced. This in turn improves the efficiency of harvest of all forage that is available within a given unit or pasture.”

Rotational stocking generally increases utilization by 5% to 15% over continuous stocking on small pastures in research

TABLE 3.2. Proportional advantage of rotational (R) vs. continuous (C) stocking for quantity-related responses.

Reference	Species	Location	Treatments	Response compared	Advantage of rotational vs. continuous
Aiken, 1998	Wheat-ryegrass	Booneville, AR	C vs. 3 and 11-paddock R	Average stocking rate	34% (2190 [R] vs. 1640 [C] kg liveweight ha ⁻¹)
Bertelsen et al., 1993	Alfalfa	Baylis, IL	C vs. 6 and 11-paddock R	Average stocking rate	42%; (4.31 [R] vs. 3.03 [C] heifers ha ⁻¹)
Bryant et al., 1961	Temperate grass-legume mixtures	Blacksburg, VA	C vs. 10-paddock R	Average stocking rate	30, 19, and 22% (avg. of 24%) for 3 mixtures
Chapman et al., 2003	Phalaris-sub clover	Victoria, Australia	C vs. 4-paddock R	Average stocking rate	9%; supported higher SR (14.9 vs. 13.7 ewes ha ⁻¹)
Davis and Pratt, 1956	Alfalfa-white clover-bromegrass	Wooster, OH	C vs. 6-paddock R	Total digestible nutrients ha ⁻¹	42% (3240 vs. 2280 kg TDN ha ⁻¹)
Hoveland et al., 1997	Common bermudagrass-tall fescue	Eatonton, GA	C vs. 12-paddock R	Hay fed and avg. stocking rate	31% less hay and 38% greater stocking rate
Hull et al., 1967	Temperate grass-legume mixture	Davis, CA	C vs. 6-paddock R	Seasonal carrying capacity	17% on average across treatments (1137 vs. 967 animal days ha ⁻¹)
Mathews et al., 1994b	Bermudagrass	Gainesville, FL	C vs. 15-paddock R	Seasonal carrying capacity	16%; average SR of R was 3525 vs. 3035 kg liveweight ha ⁻¹ d ⁻¹ for C in 2 yr
Popp et al., 1997b	Alfalfa-meadow bromegrass	Manitoba, CN	C vs. 10-paddock R	Seasonal carrying capacity (steer days ha ⁻¹)	10%; 213 vs 193 steer days ha ⁻¹ (4-yr avg.)
Stewart et al., 2005	Bahiagrass	Gainesville, FL	C vs. 4 different R treatments	Herbage accumulation rate	68%; 69 vs. 41 kg ha ⁻¹ d ⁻¹
Tharel, 1989	Bermudagrass	Arkansas	C vs. R	Seasonal carrying capacity	34%; grazing days was 1150 ha ⁻¹ for R vs. 860 for C
Volesky, 1994	Old world bluestem	El Reno, OK	C vs. frontal R	Seasonal carrying capacity (stocking rate)	34%
Volesky et al., 1994	Old world bluestem	El Reno, OK	C vs. 2-paddock R and frontal R	Seasonal carrying capacity (steer days)	24%; 540 for frontal vs. 436 steer days ha ⁻¹ for C
Overall					Range 9–68%; average 30%

studies, but improved utilization from use of rotational stocking may be greater in 50- to 100-ha pastures that are common on farms (Saul and Chapman, 2002). Teague and Dowhower (2003), from a Texas rangeland perspective, state that patch-selective grazing means that the effective stocking rate is much greater than intended on heavily used patches, resulting in deterioration in these patches. They suggest that the effect may be more pronounced on larger, heterogeneous areas but indicate that most research has been conducted on small, homogeneous experimental units.

The concepts of potentially greater forage accumulation and improved utilization of forage mass under rotational stocking were integrated by Saul and Chapman (2002), who suggested the greater homogeneity of utilization of rotationally stocked pastures is partially responsible for greater forage accumulation. They reasoned that amount of post-grazing residual mass and length of regrowth interval are affected by both stocking methods. In continuous stocking, they are affected at the individual bite scale and are largely under the control of the animal, but in rotational they are affected at the paddock scale and are under



Rotational stocking generally allows manager control over postgrazing residual and, particularly, regrowth interval”

the control of the manager. Rotational stocking generally allows manager control over post-grazing residual and, particularly, regrowth interval, whereas continuous stocking does not, beyond what can be achieved through adjusting stocking rate.

An extreme example is the patch-grazing phenomenon commonly seen in continuously stocked pastures. The post-grazing residual is too short and regrowth interval inadequate in the heavily grazed patches. Rotational stocking allows better control over at least one of the critical variables, the length of the regrowth period. Even if the pasture is grazed below the optimum height or mass, it can be allowed time to recover and move into what the authors term Phase II of plant growth (Fig. 3.2). This difference leads to the conclusion that, especially at high stocking rates or during times of feed deficit, rotational stocking should lead to better control of average leaf area, faster growth rates, and greater forage accumulation.

Number of Paddocks per Pasture. Eleven papers reviewed studied the effect of length of stocking period within one cycle of rotational stocking (i.e., a function of number of paddocks) on forage accumulation or average stocking rate. The literature is not consistent, as five of 11 papers reported advantages in forage quantity by increasing number of paddocks and decreasing the duration of the grazing period,

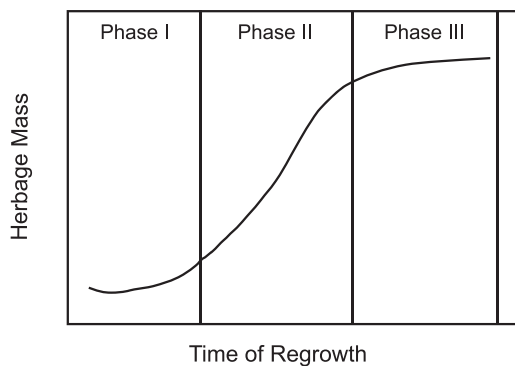


FIGURE 3.2. Accumulation of forage mass during a regrowth period follows a sigmoid curve as the canopy develops from low mass (Phase 1: low accumulation rate) to intermediate mass (Phase 2: high accumulation rate) to high mass (Phase 3: little or no net accumulation due to balance between new growth and senescence). Adapted from Saul and Chapman (2002).

five reported no effect, and one reported a disadvantage of greater paddock number. Four of the five studies reporting no effect used a fixed stocking rate, with forage mass the measure of production. There was no common thread in forage species among studies as they included alfalfa (Schlegel et al., 2000b), cool-season forage mixtures (Bertelsen et al., 1993; Phillip et al., 2001), bahiagrass (Stewart et al., 2005), and bermudagrass (Aiken, 1998).

Studies showing a quantity advantage for rotational stocking with a greater versus a smaller number of paddocks used a variable stocking rate approach and equalized post-graze forage mass or stubble height. The average advantage in stocking rate or animal days of grazing ha^{-1} was 28% for pastures with a greater number of paddocks and represented a wide range of forage species including orchardgrass (33% advantage; Holmes et al., 1952), bermudagrass (18%; Mathews et al., 1994b), a complex cool-season mixture (26%; Kuusela and Khalili, 2002), and old world bluestem (34%; Volesky, 1994; Volesky et al., 1994). The small number of studies from which the average advantage was derived suggests that conclusions should be drawn cautiously until additional research has been conducted.

Forage Nutritive Value

Forage nutritive value may be greater on continuously than rotationally stocked pastures if forage quantity is not limiting at that stocking rate (Sollenberger and Newman, 2007). The increase is associated with greater opportunity for selection and the tendency of animals to make frequent visits to the same grazing stations, resulting in consumption of less mature forage (Valentine, 2001).

The literature comparing forage nutritive value responses of continuously and rotationally stocked pastures is difficult to interpret, in part because of inadequate experimental methodology. Many reports fail to account for the large differences in nutritive value that occur during the course of a grazing period in rotationally stocked pastures. Samples from continuously stocked pastures have been compared with those from rotationally stocked pastures taken at a single point in time, most often at the beginning of a grazing period.

TABLE 3.3. Chemical composition of forage and extrusa from rotationally (6 and 11 paddocks per pasture) and continuously stocked pastures. Rotationally stocked pastures were sampled pre- and post-graze, and extrusa was collected at the beginning and end of grazing periods. Continuously stocked pastures were sampled on the same dates as rotational treatments. Data are adapted from Bertelsen et al. (1993).¹

Chemical constituent	Stocking method	Pasture samples		Extrusa samples	
		Pre-graze	Post-graze	Beginning	End
		g kg ⁻¹			
NDF	Continuous	680 a	692 a	584 a	571 b
	6-paddock	577 b	668 a	453 b	641 a
	11-paddock	581 b	687 a	380 c	656 a
	SE	16	10	19	19
ADF	Continuous	427 a	437 a	348 a	330 b
	6-paddock	358 b	427 a	282 b	402 a
	11-paddock	366 b	426 a	259 b	409 a
	SE	12	6	9	9
ADL	Continuous	72.6 a	77.2 a	57.5 a	53.2 b
	6-paddock	61.3 b	79.3 a	44.7 b	77.1 a
	11-paddock	61.3 b	78.1 a	42.5 b	71.2 a
	SE	2.6	3.4	3.1	3.1
CP	Continuous	122 b	110 a	187 b	183 a
	6-paddock	152 a	117 a	219 a	140 b
	11-paddock	166 a	121 a	238 a	128 b
	SE	8.0	4.0	8.0	8.0

¹Means within a chemical constituent and column are not different if followed by the same letter. SE indicates standard error.

In addition, sampling strategies used on continuously stocked pastures often result in collection of forage that does not represent the portion of the canopy from which the animal is selecting.

Data from Bertelsen et al. (1993) showed how sampling approach can affect the conclusions drawn. In their Illinois study, an alfalfa (50%)–tall fescue (40%)–orchardgrass (10%) mixture was stocked continuously or rotationally, the latter including 6- and 11-paddock treatments. All treatments were grazed using a variable stocking rate to maintain a stubble height (post-graze for rotational) of 8 cm to 15 cm. Pasture samples to measure nutritive value were clipped to a 5-cm height pre-graze and post-graze on rotational treatments, and continuous pastures were sampled at comparable times in the same manner. In addition, extrusa samples were taken by reticulorumen evacuation at times similar to those of the pasture samples, and apparent total tract digestion was measured.

If pre-graze pasture samples or extrusa samples taken at the beginning of the stocking period were used to compare treatments, the nutritive value for the two rotational treatments generally was not different, but both were lower in NDF, ADF, and lignin, and higher in CP than the continuous treatment (Table 3.3). Based on post-graze pasture samples, there was no difference among treatments, but based on end-of-stocking-period extrusa samples, continuous had greater nutritive value than rotational (Table 3.3). Total tract digestibility of OM, NDF, ADF, and CP were not different among treatments. Thus, depending on the type of sample chosen for comparison, all possible conclusions can be drawn from the same study, i.e., that continuous is greater than rotational, that rotational is greater than continuous, or that there is no difference.

Rotational vs. Continuous Stocking.

Fourteen papers were reviewed that compared nutritive value of continuously and rotationally stocked pastures, but only four papers reported



Purported advantages of rotational vs. continuous stocking include superior persistence of grazing-sensitive forage species.”

sampling of the grazed portion of the canopy (by hand-plucking or use of fistulated cattle; especially relevant for continuous stocking) and sampled in such a way as to address the changes that occur during the stocking period on a paddock of a rotationally stocked pasture. No difference in nutritive value was found between rotational and continuous stocking of an alfalfa–tall fescue–orchardgrass mixture in Illinois (Bertelsen et al., 1993), bermudagrass in Florida (Mathews et al., 1994b), bahiagrass in Florida (Stewart et al., 2005), and crested wheatgrass in Utah (Olson and Malechek, 1988).

Of the other 10 papers where concerns about sampling method exist, six found no difference between stocking methods, three reported that rotational resulted in greater forage nutritive value than continuous, and one indicated that there were interactions of season with method of grazing. Thus, the effect of continuous vs. rotational stocking methods on forage nutritive value remains inconclusive. Given the issues related to pasture sampling, at present we must defer to measures of animal performance to assess this response to stocking method. This information is summarized later in the chapter.

Number of Paddocks per Pasture. Of the eight relevant studies, six (75%) found no difference in forage nutritive value due to number of paddocks, i.e., length of stocking periods. These included an alfalfa–tall fescue–orchardgrass mixture (6 vs. 11 paddocks; Bertelsen et al., 1993), bermudagrass (3 vs. 15 paddocks; Mathews et al., 1994b), bermudagrass (3 vs. 11 paddocks; Aiken, 1998), alfalfa (4 vs. 13 paddocks; Schlegel et al., 2000a), cool-season grasses (6 vs. 16 paddocks; Phillip et al., 2001), and bahiagrass (2, 4, 8, and 22 paddocks; Stewart et al., 2005). Two studies found differences due to number of paddocks, but one favored more paddocks (Kuusela and Khalili, 2002) and one favored fewer paddocks (Aiken, 1998).

Forage Botanical Composition and Species Persistence

Purported advantages of rotational vs. continuous stocking include superior persistence of grazing-sensitive forage species (Van Keuren and Matches, 1988). For example, after 3 yr of grazing alfalfa–white

clover–smooth brome grass in Ohio, excellent alfalfa stands remained on rotationally stocked pastures, but on continuously stocked pastures brome grass increased and alfalfa decreased (Davis and Pratt, 1956). There were 15 papers that addressed this issue, but the body of literature suggests that although stocking method plays a role in botanical composition and plant persistence, numerous factors contribute to the responses. Interacting factors include grazing intensity, morphology/growth habit of the grazed forage, cultivars within forage species, and the opportunity for diet selection.

Grazing Intensity and Stocking Method Interactions.

Pastures of rhizoma peanut in Florida grazed for 2 yr to a post-graze residual forage mass of 500 kg ha⁻¹ had less than 25% peanut in forage mass when grazing frequency was 7 d (simulated continuous stocking) and 55% when grazed every 49 d (rotational). If post-graze residual forage mass was 1500 kg ha⁻¹, stocking method had less effect; percentage peanut was 70% and 85% for simulated continuous and rotational treatments, respectively. Alfalfa–meadow brome grass pastures were continuously stocked in Manitoba, Canada (Popp et al., 1997a). Alfalfa percentage was greater for high than low stocking rates during 4 yr because high stocking rates had a negative impact on the grass. In contrast, when pastures were rotationally stocked, there was no consistent effect of stocking rate on alfalfa percentage.

Plant Morphology and Stocking Method Interactions.

In Virginia legume percentage by weight was higher with rotational vs. continuous stocking for alfalfa–orchardgrass and white clover–orchardgrass mixtures, but the increase was much greater for alfalfa than for white clover (Bryant et al., 1961). The stoloniferous white clover was likely more tolerant of continuous stocking, and it may have been at a competitive disadvantage for light during a greater portion of the season under rotational stocking. Legumes are not always favored by rotational stocking. In a phalaris–subclover mixture in temperate Australia, rotational stocking favored forage accumulation of the taller-growing grass, but reduced yields of the low-growing legume compared with continuous stocking (Chapman

et al., 2003). Subclover was favored by continuous stocking in part because of a better light environment for seedling recruitment. Callie bermudagrass pastures in Florida were stocked continuously and rotationally, and after 2 yr the stand averaged 85% Callie for both rotational treatments compared with 62% for continuous stocking (Mathews et al., 1994b). Continuous stocking provided a more favorable light environment than rotational allowing low-growing, less desirable common bermudagrass and bahiagrass to persist.

Cultivar by Stocking Method Interactions.

In Florida, when stocked continuously for 3 yr, upright-growing “Arbrook” rhizoma peanut decreased in percentage of forage mass from 89% to 66% compared with a decrease from 90% only to 87% for lower-growing “Florigraze” (Hernández Garay et al., 2004b). Common bermudagrass was overseeded with endophyte-free (Hoveland et al., 1997) or with endophyte-infected tall fescue in Georgia (Kuykendall et al., 1999b). After 3 yr of grazing, common bermudagrass had 14% more basal cover for continuous than rotational stocking when associated with endophyte-free fescue. In contrast, when associated with endophyte-infected tall fescue, common bermudagrass had 7% less basal cover under continuous than rotational stocking. This interaction was attributed to grazing preference for bermudagrass over infected tall fescue.

Pasture- and hay-type alfalfa cultivars were stocked rotationally or continuously in pure stands and in mixtures with meadow bromegrass in Manitoba, Canada (Katepa-Mupondwa et al., 2002). The four pasture types were more persistent than cultivars developed for hay use due to high mortality of the hay types under continuous stocking. After 3 yr of grazing in Georgia, populations of alfalfa ranged from 4 to 57 plants m^{-2} , demonstrating large genetic differences in persistence under heavy continuous stocking (Smith et al., 1992). In another Georgia study, after 3 yr of continuous stocking, hay types of alfalfa had 6 to 9 plants m^{-2} , grazing types had 40 to 48 plants m^{-2} , and a type selected for tolerance to continuous stocking had 64 plants m^{-2} and produced the most regrowth of any cultivar (Smith et al., 1989).

Diet Selection. The degree to which stocking method affects opportunity for diet selection can influence pasture botanical composition responses. When cattle selected bermudagrass over endophyte-infected tall fescue, it led to greater bermudagrass decline under continuous than rotational stocking (Kuykendall et al., 1999b). When Plains old-world bluestem was grazed using frontal rotational or continuous stocking in Oklahoma, a greater proportion of grass and lower proportion of forbs was seen on rotationally stocked pastures. The very high stocking rates associated with frontal stocking apparently reduced opportunity for selection; i.e., forbs were avoided under continuous stocking but grazed using frontal stocking.

Number of Paddocks per Pasture. Only two studies were found that evaluated the effect of numbers of paddocks in rotationally stocked pastures on botanical composition. Botanical composition was not affected by number of paddocks when alfalfa was grazed at two stocking rates in rotational pastures with either 4 or 13 paddocks in Michigan (Schlegel et al., 2000b). In Finland, content of white plus alsike clover was 17% and 13%, respectively, in pastures with 20 and 6 paddocks (Kuusela and Khalili, 2002).

Species Richness and Stocking Method.

Relatively few studies have assessed rotational and continuous stocking effects on species richness, i.e., the number of species within a biological community. In Iowa, after bromegrass and reed canarygrass pastures were overseeded with 11 temperate legumes, the continuously stocked swards had greater species richness at a small scale than rotationally stocked swards (Guretzky et al., 2007). At a larger scale, continuous stocking had greater species richness than rotational only for bunch grasses. In Wisconsin both rotational and continuous stocking supported high species richness and proportions of native plants, but rotational provided better erosion control and aquatic habitat protection (Paine and Ribic, 2002). Several studies from the Czech Republic and Iowa have found greater species richness in grazed vs. non-grazed areas (Pykälä, 2003; Guretzky et al., 2007; Pavlu et al., 2007). In contrast, Tracy and Sanderson (2000) found little effect from land use, including grazing, on plant species richness in the northeastern USA.



After 3 yr of grazing in Georgia, populations of alfalfa... demonstrat(ed) large genetic differences in persistence under heavy continuous stocking.”

Summary and Recommendations: Stocking Method

There is sufficient evidence from the pastureland literature (23 of 27 studies) to conclude that rotational stocking increases forage quantity-related responses relative to continuous stocking, and the average advantage for rotational stocking is about 30%. For this advantage to occur, rotationally stocked pastures must have either greater herbage accumulation rate or greater use efficiency of the forage mass. There are rational arguments to support both, but few studies have directly measured these responses. In most cases the quantity-related advantages of rotational stocking were measured in terms of forage mass, average stocking rate, or number of animal days of grazing, etc.

The effect of stocking method on forage nutritive value is inconclusive based on the

current literature due largely to limitations in sampling methods. The literature supports a conclusion that stocking method can alter pasture botanical composition and persistence, but in many situations, interactions with other factors make it impossible to generalize about the direction and magnitude of the responses. Likewise, with rotational stocking, the literature is inconclusive as to whether the number of paddocks per pasture affects plant productivity, nutritive value, and plant persistence. The literature supports the conclusion that grazed grasslands maintain greater species richness than non-grazed areas indicating that prescribed grazing is a key component of efforts to sustain species diversity of grassland communities.

In total, the literature supports the thesis that stocking method is an important grazing

The weanling bulls in the foreground were stocked at 7.5 head ha⁻¹ on stargrass pastures for a 300-d grazing season in Jamaica while the bull in the background was part of a group stocked at 2.5 head ha⁻¹. Average daily gain was 0.31 and 0.68 kg for animals from high and low stocking rate treatments, respectively (Hernández Garay et al., 2004). Photo by Lynn Sollenberger, University of Florida.



management decision. It is evident, however, that stocking method cannot compensate for inappropriate grazing intensity (stocking rate or sward height). Thus, it is imperative that grazing intensity receive primary focus in development of grazing recommendations, with stocking method used to fine tune the prescribed grazing practice.

SEASON OF GRAZING AND DEFERMENT

Timing grazing events is a prescribed grazing strategy that is thought to affect species composition and vigor of grassland communities. Timing is usually defined based on season of the year, and the associated environmental conditions, or plant growth stage. Objectives of controlling season of grazing may include 1) optimizing year-round distribution of forage quantity and nutritive value, 2) sustaining sward cover and improving persistence, and 3) facilitating seed production and natural reseeding. To assess the benefits of timing of grazing, the review was organized around the following general topical categories: 1) stockpiling for out-of-season use; 2) timing of grazing within the growing season in terms of initiation, termination, or deferment of grazing; and 3) timing of grazing for seed production and seedling recruitment. Fifty-two papers provided the basis for this assessment.

Stockpiling for Out-of-Season Use

Stockpiling, one of the most-used approaches of deferment of grazing, allows forage to accumulate in the absence of defoliation for use at a later time when growth of pasture is limited. There is abundant literature on this practice. Of the 52 papers reviewed for this section, 27 addressed stockpiling specifically and 15 of the 27 studied tall fescue. Common research topics were effects of forage species, nitrogen (N) fertilization rates, and timing of initiation and termination dates of stockpiling on forage nutritive value, distribution of quantity, plant growth in subsequent growing seasons, and toxicosis associated with endophyte-infected tall fescue.

Forage Quantity. In Virginia stockpiling tall fescue during autumn provided forage for winter that extended the grazing season and minimized hay feeding compared with other forage systems (Allen et al., 1992b). Allocating

0.27 ha of stockpiled tall fescue per stocker animal provided grazing from November through March with supplemental hay required only for 33 d (Allen et al., 1992a).

Date of initiation of stockpiling varies widely depending on the forage species and environment. In the upper Midwest USA, early initiation is often needed. For smooth brome grass in Minnesota, initiating stockpiling about 1 July, after seedhead production ended, optimized forage and leaf mass in October (Cuomo et al., 2005). In Nebraska delaying initiation of stockpiling of eight cool-season grasses from 15 July to 15 August reduced herbage mass in November by 30% (Volesky et al., 2008). Due to the longer growing season, later initiation is common in warmer regions of the USA and in other countries. Yet late initiation of stockpiling reduced quantity of forage for winter grazing in West Virginia with tall fescue (Collins and Balasko, 1981a), in West Virginia with a white clover–orchardgrass mixture (Belesky and Fedders, 1995), and in Ireland with perennial ryegrass or ryegrass–white clover pastures (Hennessy et al., 2006). Initiating stockpiling of bermudagrass in Arkansas in September produced only 30% to 40% as much as that initiated in August (Scarborough et al., 2004), but success depended upon August rainfall.

Extending the duration of stockpiling of eight cool-season grasses from November to February in Nebraska decreased herbage mass by 18% to 24% due to winter weathering losses (Volesky et al., 2008). Stockpiled forage mass of seven grasses in Wisconsin decreased 22% to 55% from first frost to March, depending on location and length of snow cover (Riesterer et al., 2000). Timothy and late-maturing orchardgrass needed to be grazed by December in that environment, while tall fescue, early-maturing orchardgrass, and reed canarygrass could be used throughout the December through March period.

Comparing different latitudes, forage accumulation of five cool-season grasses and white clover in Prince Edwards Island, Canada, was negligible after 56 d of stockpiling (Kunelius and Narasimhalu, 1993), while in Missouri tall fescue achieved maximum dry matter (DM) accumulation in mid-



It is evident, however, that stocking method cannot compensate for inappropriate grazing intensity (stocking rate or sward height).”



the increase in yield with duration of stockpiling must be balanced with the decrease in nutritive value.”

November after initiation of stockpiling on 1 August (Gerrish et al., 1994). Forage mass changed little after October for bahiagrass, bermudagrass, and kikuyugrass following August initiation of stockpiling in Texas (Evers et al., 2004). In Florida, late-summer stockpiled limpograss yield increased through 1 November and decreased through the winter and spring (Quesenberry and Ocumpaugh, 1982).

Forage Nutritive Value. Compromise between managing for yield and nutritive value is common to stockpiling programs. For example, bermudagrass yield in Texas increased by $0.15 \text{ Mg ha}^{-1} \text{ d}^{-1}$ from day 14 through day 56 of stockpiling, but rate of decline for in vitro dry matter digestion (IVDMD) was $2 \text{ g kg}^{-1} \text{ d}^{-1}$ (Holt and Conrad, 1986). Thus, the increase in yield with duration of stockpiling must be balanced with the decrease in nutritive value.

In West Virginia nutritive value of stockpiled tall fescue was greater for later initiation dates (Collins and Balasko, 1981b). In Nebraska delaying initiation of stockpiling of cool-season grasses from July to August increased IVDMD concentration and decreased NDF throughout the winter. Herbage CP of smooth bromegrass in Minnesota increased and ADF and NDF decreased as initiation of stockpiling was delayed (Cuomo et al., 2005). In Ireland proportion of green leaf during winter in perennial ryegrass and ryegrass–white clover pastures was increased by delaying initiation of stockpiling, and this was accompanied by a decrease in stem and dead herbage (Hennessy et al., 2006).

In Missouri nutritive value of stockpiled annual ryegrass, small-grain rye, and tall fescue declined from December through March (Kallenbach et al., 2003a, 2003b). In North Carolina nutritive value of tall fescue was not affected by endophyte status during stockpiling initiated in mid-August and extending through February (Burns et al., 2006), but forage in vitro true digestibility declined linearly and NDF increased linearly as length of stockpiling period increased (Burns et al., 2006). Similarly, forage NDF of tall fescue and festulolium in Missouri increased and total digestible nutrients (TDNs) and CP of the

stockpiled forage decreased from November to March (Dierking et al., 2008). In vitro true digestibility of tall fescue in Missouri declined by 90 (year 1) and 50 (year 2) g kg^{-1} during the 84 d of stockpiling (Curtis and Kallenbach, 2007). Similar responses were observed with five cool-season grasses and white clover in Canada (Kunelius and Narasimhalu, 1993), perennial ryegrass and white clover in Ireland (Hennessy et al., 2006), three C_4 grasses in Texas (Evers et al., 2004), bermudagrass in Arkansas (Scarborough et al., 2006), and limpograss in Florida (Quesenberry and Ocumpaugh, 1982).

Pasture Performance Following Use for Stockpiling. Early autumn initiation of stockpiling perennial ryegrass or ryegrass–white clover pastures in Ireland decreased tiller density in winter, and this effect persisted in spring (Hennessy et al., 2006). Initiation of new tillers in spring was inhibited in swards with high forage mass in autumn and winter due to shading at the shoot bases resulting in self-thinning.

In North Carolina persistence of tall fescue of varying endophyte status was not affected by length of the stockpiling period. Endophyte-free types had greater stand loss than endophyte-infected or novel-endophyte types, which were not different (Burns et al., 2006). White clover and orchardgrass were stockpiled in West Virginia (Belesky and Fedders, 1995). When stockpiling was initiated early, orchardgrass had fewer, larger tillers, and the clover had few growing points. Late initiation of stockpiling resulted in more clover than when initiated early.

Effect of Endophyte Status on Stockpiled Forage. Increasing level of endophyte infection (20%, 51%, and 89%) of stockpiled tall fescue in Missouri was associated with greater forage mass (4.35, 4.51, and 4.95 Mg ha^{-1} , respectively) during the grazing period. Also in Missouri, Kallenbach et al. (2003b) found mass of endophyte-infected fescue was 20% greater than for endophyte-free or nontoxic endophyte when harvested monthly from mid-December through mid-March. In North Carolina (Burns et al., 2006) and Arkansas (Flores et al., 2007), herbage mass of stockpiled tall fescue was not affected by endophyte status.

Novel endophyte and endophyte-free tall fescue stockpiled in Arkansas beginning in late summer and ending from December through February had similar DM and NDF disappearances (Flores et al., 2007). In Missouri, tall fescue with three levels of endophyte infection was stockpiled and grazed for 84 d starting 1 December (Curtis and Kallenbach, 2007). There was no effect of endophyte level on CP in either of 2 yr, whereas in vitro true digestibility was greater in 1 yr for the lowest endophyte level.

Following stockpiling of endophyte-infected tall fescue, total ergot alkaloid concentration was greatest at the beginning of the grazing period and decreased much faster than nutritive value during the period (Curtis and Kallenbach, 2007). It was recommended that low-endophyte pastures be grazed first and high-endophyte pastures last. This conclusion

was supported by additional Missouri research with stockpiled novel-endophyte, endophyte-free, and endophyte-infected tall fescue that was harvested monthly from mid-December through mid-March (Kallenbach et al., 2003b). Ergovaline was present only in toxic endophyte-infected tall fescue, but it declined by 85% from December through March.

Seasonal Timing of Initiation, Termination, or Deferral of Grazing

Reasons for altering season of grazing or deferring grazing, other than stockpiling for out-of-season use, include increasing productivity, nutritive value, and persistence of the pasture or maintaining botanical composition, reducing weed invasion, improving water use, and improving wildlife food and habitat. Most related research was conducted in Europe, New Zealand, and Australia, but there is some US literature.

Switchgrass is an example of a warm-season grass that can provide grazing during periods when cool-season grasses are not productive. Including warm-season grasses in a grazing system can diversify the landscape and improve wildlife habitat. Photo by Lynn Betts, USDA-NRCS.





Alternative water sources may reduce time livestock spend in surface water bodies and improve animal health, water quality, and wildlife habitat. Photo by Chris Coulon, USDA-NRCS.

Timing of Initiation. Big bluestem in Nebraska was grazed in May when tillers were 15 to 20 cm tall or not grazed until late vegetative or early stem elongation stages (Mousel et al., 2003). Grazing in May did not reduce season-long pre-grazing forage mass, but pastures grazed at stem elongation in June had limited regrowth. Grazing first at vegetative instead of stem elongation stage resulted in greater seasonal leaf yields and allowed for grazing in both August and September. May grazing did not negatively affect persistence,

but root mass, area, and volume in the top 30 cm of soil were lowest in paddocks grazed first at stem elongation (Mousel et al., 2005). In Iowa delaying spring grazing of smooth bromegrass increased forage mass at turn out from approximately 800 to 2700 kg ha⁻¹, but CP and IVDMD declined linearly as turn out was delayed.

Herbage mass was greater for perennial ryegrass in Ireland following late April vs. late March or early April turnout (Carton et al., 1989a). A greater proportion of smaller tillers during subsequent regrowth was associated with early defoliation and resulted in lower leaf extension rates (Carton et al., 1989b). In France early grazing of perennial ryegrass reduced subsequent pre-grazing herbage mass, but it increased sward nutritive value into the summer (O'Donovan and Delaby, 2008). Early turnout for timothy and tall fescue in Finland decreased pre-grazing herbage mass early in the growing season but not later (Virkajarvi et al., 2003). Reduced autumn regeneration of growth was observed in phalaris plants defoliated the previous spring at either early stem elongation or early boot stages (Culvenor, 1994). Avoidance of a heavy grazing during stem elongation in spring enhanced persistence when subsequent growth conditions were unfavorable due to dry weather.

Timing of Termination. Grazing perennial ryegrass, prairiegrass, and tall fescue swards every 30 d from August through November in Pennsylvania gave greater fall yield than grazing during September only, but the latter had greater spring yields than traditional stockpile and monthly grazing treatments (Hall et al., 1998). Greater tiller density in spring following grazing only in September resulted in greater spring yield for that treatment. In another Pennsylvania study on prairiegrass, spring yield decreased linearly as date of last defoliation the previous fall was delayed (Jung et al., 1994). Early fall harvest allowed time for replenishment of reserves prior to winter, but late fall harvest did not, especially when stubble was short. Tiller density in spring was greater for early than late fall defoliation.

In Quebec, Canada, autumn harvest of tall fescue taken after 15 September decreased ground cover and spring DM yield (Drapeau et

al., 2007). Harvesting or grazing tall fescue in the week preceding or following the first killing frost reduced spring growth and persistence. In Ireland delaying closure date of fall grazing of perennial ryegrass from 20 October to December decreased herbage mass through late May (Roche et al., 1996).

Timing of Deferral (Other than Stockpiling).

Deferral of grazing involves delaying onset of grazing or removing animals for a specific purpose before resuming grazing. Deferral of grazing of perennial ryegrass–white clover pastures in New Zealand throughout portions of the warm season increased annual herbage accumulation by 10% to 49% in the first year and 16% to 26% in the second (Harris et al., 1999). Deferral increased clover contribution, and amount of increase was positively related to duration of the deferral. The authors suggested that deferral resulted in lower soil temperatures and higher soil moisture that promoted survival of clover stolons and growing points. In New York white clover growth and recovery after grazing was poor following hot, dry weather in combination with grazing stress (Karsten and Fick, 1999). The authors recommended decreased grazing intensity during and for a short time after such weather events.

Humphrey and Patterson (2000) examined the question of how best to manage grazed pastureland in Scotland to promote biodiversity. Late summer grazing (early August to late September) was compared to no grazing, and species diversity declined with the no grazing treatment while it remained the same for the seasonal grazing treatment. The authors concluded that seasonal grazing was a useful management tool to promote plant biodiversity in pasturelands.

Seed Production and Seedling Recruitment

Grazing during the period of flowering and seed production has significant implications for seed production and seedling recruitment. Research on this topic is limited in the USA. In Florida seed yield of *aeschynomene* decreased when closure of autumn grazing was delayed (Sollenberger and Quesenberry, 1986). Maximum seed yields were achieved when autumn closure occurred 7 d to 14 d before first flower. Subsequent research showed that

discontinuing grazing at first flower or the week before was critical to achieving successful natural reseeding (Chaparro et al., 1991).

Summary and Recommendations: Season of Grazing and Deferment

Stockpiling extends the grazing season and reduces reliance on stored feed in many environments. In general, early initiation of stockpiling increases forage mass, but nutritive value is lower and duration of the regular grazing season on these pastures is shorter. Because weather conditions affect forage accumulation during autumn and impact both initiation and termination dates, choice of these dates is highly environment and forage species specific. In some environments, and with certain species, termination date is more flexible because mass and nutritive value of forage change relatively little during the late autumn through winter period. In other situations, termination date is critical because mass and nutritive value decrease rapidly after a defined date or period of stockpiling. Studies are limited on effects of stockpiling on subsequent stands, but early initiation of stockpiling to increase herbage mass during autumn and winter leads to decreased spring tiller density in some species.

The effect of endophyte status on forage mass and its ergovaline concentration must be considered when stockpiling tall fescue. In several studies, ergovaline declined rapidly in stockpiled endophyte-infected tall fescue during the late autumn and winter. Thus, other species or endophyte-free or novel-endophyte tall fescue should be grazed early in the utilization period, with endophyte-infected fescue grazed later after most ergovaline has dissipated.

Timing of initiation, termination, and deferral of grazing is important for maintaining cover and desired sward botanical composition. Relative to timing of initiation of grazing, most studies reviewed suggest a compromise between forage accumulation and nutritive value. Early turnout in spring often is associated with greater tiller production but lower forage mass at spring initiation that often carries over to subsequent grazing periods. Pastures grazed early after stockpiling have greater leaf percentage, less dead material, and greater



...ergovaline declined rapidly in stockpiled endophyte-infected tall fescue during the late autumn and winter.”



Efficiency of forage utilization can be increased by multispecies grazing due to less rejection of forage”

nutritive value. When termination date of fall grazing is important, its effect is often due to tiller dynamics or carbohydrate reserves.

Deferred grazing, other than stockpiling, has not been studied widely. Avoiding grazing during or immediately before a period of heat or drought stress is the most common practice described in the literature. There appears to be a need for research to more clearly delineate the effect of seasonality of grazing for the benefit of grassland management practitioners.

As need for high-quality forages in pastures increases, e.g., pasture-based dairying and grass-fattened beef, additional research into optimal timing of initiation, termination, and deferral of grazing is likely to be needed. There has been relatively little of this research done in the USA. The effects of timing of initiation of grazing on subsequent forage production and nutritive value, and the effects of timing of termination on persistence and regrowth suggest that this is an area that may benefit from increased research focus, especially when environmental responses are included.

TYPE AND CLASS OF LIVESTOCK

Different types of livestock have different physical characteristics, foraging strategies, and ingestive anatomy; thus it is expected their effect on pastureland will differ. This grazing strategy has received considerably less research attention than others addressed thus far. Only 15 papers described forage quantity, nutritive value, botanical composition, and plant persistence responses to type and class of livestock. Much of that literature focused on mixed grazing effects on plant responses, with fewer addressing type of livestock effects. No studies were found that compared plant responses to classes of livestock within a species.

Differences in Ingestive Anatomy and Behavior among Ruminants and Horses

Ruminants are commonly classified into feeding types based on ingestive anatomy and feed choices (Hofmann, 1989). Cattle and sheep are often categorized as “grazers” or “grass and roughage” eaters. Grazers have relative short lips, broad muzzles, and a cornified tongue that protects it during tearing of abrasive plant tissue (Van Soest, 1994). Goats are termed “intermediate feeders,” with some

characteristics of both “grazers” and “selectors.” Goats have a fairly narrow but deep mouth opening and mobile lips and tongue designed for selective ingestion of plants and plant parts including leaves and twigs of woody plant species (Van Soest, 1994).

Sheep have narrower mouths and a highly curved incisor arcade making them better suited anatomically for diet selection, including browsing, and grazing closer to ground than cattle (Walker, 1994), but sheep generally prefer grazing herbaceous material if quantity is not limiting (Benavides et al., 2009). Horses have mobile lips and a large mouth; they ingest forage by severing it between their upper and lower incisors. This mode of prehension causes horses to prefer shorter pasture than cattle, and horses are notorious spot grazers.

Individual or Multispecies Grazing Effects on Plant Response

Grazing two or more livestock species on the same land in a single growing season is known as dual use or multispecies grazing (Animut and Goetsch, 2008). Efficiency of forage utilization can be increased by multispecies grazing due to less rejection of forage due to dung contamination (Abaye et al., 1994), preference for particular species or plant parts, willingness to consume plants that are not preferred or would have adverse effects on the other animal species, and ability to gain access to forage (topography, terrain, or plant growth habit) that is not available to the co-grazing species. Because pastures often tend to be less species rich than rangeland, opportunities to take advantage of multispecies grazing may be fewer in pastureland than in rangeland.

Forage Quantity. In Virginia sheep grazed closer to cattle dung spots than did cattle to cattle dung spots, resulting in greater forage utilization and pasture uniformity in mixed-grazing pastures (Abaye et al., 1994). Lambs reached target weight sooner on mixed-grazing pastures, allowing earlier removal and avoidance of late-summer stress due to lack of available forage. Mixed cattle and sheep grazing alfalfa-orchardgrass pastures in Mexico promoted more homogeneous grazing than did cattle alone due to lower rejection of dung-contaminated forage (Mendiola-González et al., 2007).

The grazing behavior of different animal species also seems to be associated with observed differences in quantity of forage. In northwest Spain pastures grazed by cattle had taller mean height than those grazed by sheep (Benavides et al., 2009). Sheep were able to maintain their live weight at a lower sward height, and they grazed more intensively on the pasture area. In Australia a phalaris-subterranean clover pasture was grazed by cattle alone, sheep alone, or cattle + sheep (Bennett et al., 1970). Rank of forage mass was always cattle alone > cattle + sheep > sheep alone. Similarly, in alfalfa-orchardgrass pastures in Mexico, forage mass was lower and sward height shorter when lambs grazed alone than for heifers, and mixed grazing was intermediate. In ryegrass-white clover pastures in northern Spain, swards where goats grazed last had greater forage mass because goats grazed taller, non-grazed material and clumps, leading to more

uniformly high growth rates (del Pozo et al., 1998).

In summary, research assessing the effect of different livestock species on forage mass is limited. The most consistent response has been that forage mass or sward height is less on pastures grazed by sheep than on those grazed by cattle or goats. An experimental issue of concern for studies comparing mono- and mixed-species grazing is equalizing stocking rates among treatments. Failure to do so greatly limits the value of the research.

Forage Nutritive Value. Minimal research addresses the effect of type of livestock grazing on nutritive value of pastureland. In Virginia, Kentucky bluegrass and white clover pastures were grazed by cattle, sheep, or both, and trends in nutritive value were not consistent (Abaye et al., 1994). In some cases, nutritive value responses can be inferred based on

Shade can be a powerful attractant to livestock when temperatures are high, affecting livestock and manure distribution in the landscape. Photo by Carmen Agouridis, University of Kentucky.





Uncontrolled access of livestock to surface water bodies can negatively affect livestock health, water quality, and wildlife. Photo by Carmen Agouridis, University of Kentucky.

changes in botanical composition. White clover contribution increased in perennial ryegrass–white clover swards grazed by goats vs. sheep in Scotland (del Pozo et al., 1997) or grazed most recently by goats vs. sheep in Spain (del Pozo et al., 1998). In the latter case, grass stem and dead proportion were lower when pastures were grazed most recently by goats, and these differences would also be consistent with greater nutritive value on pastures grazed by goats than by sheep. Improvement in animal performance for both goats and steers followed shifts in botanical composition associated with multispecies grazing (Donaldson, 1979).

Forage Botanical Composition and Persistence. The majority of studies have assessed effects of type of livestock on botanical composition. Two common themes emerge. Goats or, to a lesser extent, sheep can reduce shrub and brush cover in abandoned or invaded pastureland, and a consistent pattern is seen of reduction in legume or forb composition of pastures associated with grazing by sheep relative to other grazers.

In Virginia pastures grazed by sheep (alone or with cattle) had at least 10 percentage units more bluegrass than when cattle grazed alone, five to seven percentage units less white clover, and three to six units less forbs (Abaye et al., 1997). They concluded sheep preferred broadleaf plants, both legumes and forbs, and sheep in mixed-grazing pastures

affected composition similarly but to a lesser extent than sheep alone. In Australia, after 3 yr of grazing a phalaris–subterranean clover pasture, percent clover was 57%, 46%, and 36%, respectively, for cattle, cattle and sheep, and sheep alone (Bennett et al., 1970). They concluded that clover benefited from cattle grazing because they consumed more grass stems and dead material than sheep, encouraging growth of clover. In an extensive review of United Kingdom grazing literature on mesotrophic “old meadow” pasture, Stewart and Pullin (2008) found support for the conclusion that sheep grazing can result in lower forb diversity than cattle grazing, especially at high stocking rates.

In northern Spain swards had higher live clover percentage and lower dead and grass stem proportions where goats grazed last than where co-grazed or sheep grazed last (del Pozo et al., 1998). The authors suggested goats were better able to deal with reproductive and senescent grass material and grazed it to lower residual heights. Studies in Scotland and New South Wales, Australia, showed the proportion of clover was greater with goat grazing than with sheep grazing (del Pozo et al., 1997; Holst et al., 2004).

In North Carolina overgrown hill land pasture (most prominent species were Kentucky bluegrass, tall fescue, and white clover) was not grazed, grazed by goats alone, or grazed by both goats and cattle to determine their effectiveness in reclaiming areas overgrown with invading herbaceous weeds and woody species (Luginbuhl et al., 1999). During the course of four grazing seasons, goats grazing alone or with cattle effectively shifted botanical composition of overgrown hill land pastures toward desirable forage species and controlled encroaching multiflora rose. In northern Spain, one-third of the treatment area was perennial ryegrass–white clover pasture and the remainder was shrubland (Benavides et al., 2009). Goats were more intentional in browsing than sheep and cattle, and mixed grazing with goats slowed brush encroachment and increased growth of herbaceous plants. In New South Wales, Australia, goats were an effective control strategy for nodding thistle in tall fescue–perennial ryegrass–white clover–subclover pastures (Holst et al., 2004).

Summary and Recommendations: Type and Class of Livestock

No evidence was found that breed or age of a particular species has significant effects on pasture characteristics, but species of livestock is important. Livestock species have minimal effect on forage quantity and nondocumented effects on forage nutritive value, but important and well-documented effects on botanical composition and persistence. The literature verifies that co-grazing or grazing by particular species can be used to manipulate botanical composition of pastures and that selection of livestock species is an important prescribed grazing tool for maintaining legumes in pastures and ridding swards of invasive, unwanted, or potentially toxic plants. Further research is needed, however, because studies to date have been relatively limited both geographically and in the forage species tested. In addition, most research is from outside the USA, leaving a significant gap in determining the potential of using particular livestock species or mixed grazing in the USA.

Stocking rate is a key consideration when comparing grazing by different types and classes of livestock, but choice of livestock species can be an excellent tool for improving vegetation condition. The literature consensus is that choice of animal species is less critical than grazing intensity, but more research is required to fully understand animal species-grazing intensity interactions (Stewart and Pullin, 2008).

DISTRIBUTION OF LIVESTOCK IN THE LANDSCAPE

Factors affecting livestock distribution on pastureland include position of water and shade, proximity to barns, topography, and feed sources (Mathews et al., 1996). As cattle frequent an area, they affect plants and soil and may influence water quality and quantity as well as riparian and watershed function (CAST, 2002). Much of the literature on livestock distribution focuses on water impacts. However, a total of 13 papers did specifically address plant responses. Major areas of discussion included the effect of topography, paddock size, and position of shade and water on forage mass and species composition.

Topography

On hill-country pastures in New Zealand, approximately 60% of dung accumulated in flat areas (hill summits or bottoms of slopes), and the proportion of dung in the remainder of the pasture decreased as slope increased (Rowarth et al., 1992). Deposition of dung is closely associated with time spent in a portion of the landscape (Dubeux et al., 2009), implying animals spent more time in flat areas. The literature does not allow separation of the effects of topographic distribution of livestock from the inherent characteristics (e.g., soil fertility, drainage, aspect) of a portion of a landscape. However, numerous studies describe topographic differences in plant responses under grazing.

A series of studies were conducted on cool-season grass pasture (smooth brome grass, Kentucky bluegrass, and reed canarygrass dominated) in Iowa that was overseeded with legumes. Summit (top, 0–5% slope), backslope (middle, 10–24% slope), and toeslope (bottom, 0–5% slope) landscape positions were compared under continuous and rotational stocking at the same stocking rate. Forage mass was greatest on toeslope positions (Harmony et al., 2001), and legume mass, proportion, richness, and diversity showed increasing trends at backslope positions compared with summit or toeslope. Sloping sites had greater numbers of species than flat sites. Shannon's Diversity Index was greater for sloping vs. flat areas and was ranked continuous > rotational > non-grazed (Barker et al., 2002). Species richness within grazed pastures was greatest on backslope positions, and species diversity was limited at summit and toeslope by grass competition (Guretzky et al., 2005). Legumes tended to be greatest and weeds least on backslope and with rotational stocking.

Also in Iowa, legume percentage cover increased as a function of slope, and the rate of increase was greater for rotational than continuous stocking and both were greater than non-grazed (Guretzky et al., 2004). Legumes were most successful at 15% to 20% slope. Success of legumes at these slopes was associated with less competition from grasses than at summit or toeslope, and competition from grasses was greatest where soil moisture was highest. No data were reported on



...co-grazing or grazing by particular species can be used to manipulate botanical composition of pastures”



Reducing
paddock size
produces greater
evenness of
forage use within
paddocks...”

proportion of time spent by livestock at various slopes, so it is not clear if varied grazing time played a role in the response. In southeast Queensland, Australia, slope position had relatively minor effects on species richness, but there was evidence of less diversity in more fertile areas, perhaps comparable to toeslopes in Iowa (McIntyre and Martin, 2001). In Israel wetland sites had significantly lower richness of annual legumes compared with upland sites (Noy-Meir and Kaplan, 2002), perhaps again associated with greater competition from well-adapted grasses in wetland areas.

Paddock Size

Patch grazing contributes to grassland degradation, even at low stocking rates (Barnes et al., 2008). Norton (2003) hypothesized that livestock in smaller paddocks or at higher stocking densities are more evenly distributed and access more forage. Reducing paddock size produces greater evenness of forage use within paddocks by limiting area available at one time and forcing grazing to occur more widely across the landscape as a whole (Hart et al., 1993). Making more effective use of pasture resources by distributing grazing more widely and uniformly across the landscape is an effective strategy for increasing livestock productivity (Hunt et al., 2007).

Proximity to Shade, Water, or Structures

In a diverse pasture landscape in northern Germany, grazing sites with a shorter distance to a water trough or pond were preferred by cattle, while sheep preferred grazing close to their shed (Putfarken et al., 2008). In the Northern Territory of Australia, installing additional water points in large paddocks improved uniformity of grazing distribution, and providing shade, especially away from water points, induced livestock to use more areas in the pasture (Hunt et al., 2007). In Alabama relief from heat stress was the major factor in habitat-use decisions by cattle during the warm season (Zuo and Miller-Goodman, 2004). At this location, livestock stood in surface water bodies, because of their cooling potential, even when alternative water and shade sources were provided.

Changes in soil N, phosphorus (P), and potassium (K) were compared around shade

and water sources in rotationally stocked kikuyugrass pastures in Hawaii (Mathews et al., 1999). Based on the magnitude of increases in soil nutrient concentration, the authors concluded that excreta deposition was greater around shade than water and that shade sources had a greater effect than water sources on distribution of cattle in the landscape.

In 0.33- to 1-ha bahiagrass pastures in Florida that were continuously stocked, herbage accumulation rate was 40, 33, and 20 kg ha⁻¹ d⁻¹, respectively, in zones that were less than 8 m (zone 1), 8 to 16 m (zone 2), or > 16 m from shade or water (Zone 3) (Dubeux et al., 2006). Response was due in part to greater accumulation of soil nutrients in zone 1. Herbage mass in the three zones was 2410, 2900, and 3030 kg ha⁻¹, respectively. This was associated with greater time spent by animals in zone 1 and corresponding reduction in forage mass. In the lowest of three management intensity treatments, forage N, P, and in vitro digestion were greater in zone 1 than zone 3, likely because of greater nutrient deposition via excreta in zone 1, and also because of greater resident time by animals, resulting in more frequent visits to a given patch with less mature forage.

Summary and Recommendations: Distribution of Livestock in the Landscape

There is sparse literature describing plant responses to livestock distribution. Within rolling topography, it is difficult to separate the effects of livestock distribution from those of aspect, soil fertility, and drainage. In general, sloping areas are thought to have shorter grazing time, greater species richness, greater legume proportion, and less herbage accumulation than summit or toeslope areas. These differences might serve to influence subsequent grazing behavior and time spent in various regions of the pasture, but this has not been quantified.

Shade and water are other major factors affecting livestock distribution. Shade seems to have a greater impact on livestock distribution than does location of water source, particularly during warm seasons or in warm climates. There is evidence that subdividing large grazing units into smaller paddocks

decreases heterogeneity in forage mass and amount of overgrazed areas within the pasture. Further, increasing the number of watering points in conjunction with decreasing pasture size may minimize spot grazing and reduce associated stand deterioration. These management interventions could be considered as part of a prescribed grazing plan in large pastures.

PURPOSE 2: IMPROVE OR MAINTAIN QUANTITY AND QUALITY OF FORAGE FOR GRAZING AND BROWSING ANIMALS' HEALTH AND PRODUCTIVITY

Grazing Intensity

A rich literature describes the nature of the relationship between grazing intensity and animal productivity. Because of complexities and costs associated with research utilizing reproductive livestock, most of this work has been conducted with growing animals. Because the fundamental relationships between grazing intensity and nutrient harvest do not vary among classes of livestock, and because animal growth rates often provide a more sensitive measure of production responses than changes in body energy stores or reproductive rates, the bulk of the literature relies heavily on results from studies with growing animals.

There is broad agreement that increasing grazing intensity, typically measured as stocking rate (animal units ha^{-1} for a grazing season), results in a decrease in performance of individual animals. The nature of this decrease, however, has been the subject of considerable discussion in the literature. A review by Hart (1993) describes several models of the stocking rate-gain response curve. Generally, on a given forage base, there is a critical stocking rate below which gain per animal is either unaffected or may increase slightly with increasing stocking rate. Models differ in their description of the gain per animal response above this critical stocking rate. Specifically, the decrease in gain per animal with increasing stocking rate has been described as linear with no threshold (e.g., Hart, 1978), or curvilinear with a concave (e.g., Mott, 1960) or a convex (e.g., Petersen et al., 1965) response surface (Fig. 3.3).



Even if the linear model is an oversimplification of the true biology of the association, it appears to adequately describe the response in the majority of studies in the literature. Thus, in this synthesis, various studies have been summarized with respect to the parameters of a threshold model in which gain is relatively unaffected at low stocking rates and declines in a linear fashion with increasing stocking rate.

Stimulated by the CEAP effort, and to better understand the effect of stocking rate on animal response, a comprehensive assessment of the relationship was undertaken across a large number of studies in the literature (Sollenberger and Vanzant, 2011). Because of the wide variation in individual animal weights in various studies, it was not adequate to describe stocking rates in terms of numbers of animals per unit area. Thus, stocking rates were described in $\text{kg live wt ha}^{-1}$, and these values were based on live weight at the beginning of the grazing season (i.e., $\text{kg initial live weight ha}^{-1}$). The influence of stocking rate was also evaluated as a function of metabolic body weight ($\text{wt}^{0.75}$).

The data included were obtained from non-rangeland US studies published in refereed journals over the last 48 yr. Two nonrefereed studies (Gerrish, 2000; Vanzant, 2010) were included to provide data from underrepresented geographical regions and because all of the essential data were available.

Livestock access to streams can cause stream widening, reduced water depth, and increased water temperature, all of which negatively affect wildlife habitat. Photo by Carmen Agouridis, University of Kentucky.

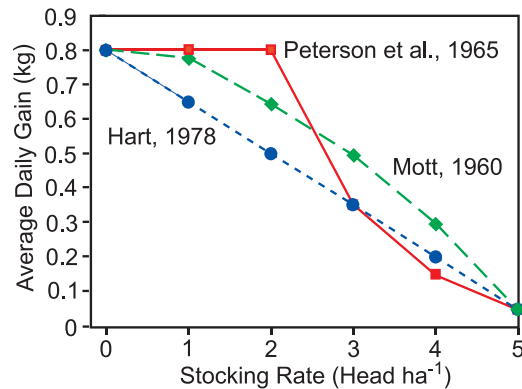


FIGURE 3.3. Models proposed to describe the response of average daily gain to increases in stocking rate include linear (e.g., Hart, 1978), curvilinear with a concave response surface (e.g., Mott, 1960), or a plateau followed by a convex response surface (e.g., Petersen et al., 1965).

The majority of the studies utilized growing beef cattle and reported rates of gain as affected by grazing intensity.

To provide a response criterion that could be quantitatively analyzed, average daily gain within each study was regressed on stocking rate, providing both a y -intercept and a slope value for each study. These y -intercept and slope data constituted the parameters for a subsequent meta-analysis. A multiple regression approach was used to evaluate the influence of several factors on the slope of the average daily gain response to stocking rate. From the 26 independent reports, 58 observations (treatment \times year combinations) were included in the multiple regression analysis. More detail on this procedure is provided by Sollenberger and Vanzant (2011).

A four-variable model was derived using all 58 observations, which accounted for 69% of the variation in slope of the average daily gain response to stocking rate. Fifty-six percent of the variation in the slope of the response was attributable to differences in the y intercept of average daily gain. Thus, from this data set, the strongest predictor of the slope of the average daily gain response to increasing stocking rate was the estimate of gain at a theoretical “zero stocking rate.” The greater the estimated gain of cattle at low stocking

rates, the more rapid the decrease in average daily with increasing stocking rate.

Any factor that leads to greater forage quality, and thus increases intake, will increase the rate at which forage is removed at a given stocking rate. Similarly, an increase in stocking rate ultimately accelerates the decrease in average daily gain. Much smaller, but significant, portions of the variation were explained by the presence of grass and/or legumes. Little difference was seen in the effect of grazing intensity on ADG between alfalfa and “grass-only” pastures, but the effect was greater in mixed grass-legume stands. The relationship between grazing intensity and animal performance is likely more complex in mixtures than in monocultures because of variable effects of grazing intensity on the responses of the different species. The analysis also showed that at higher latitudes, an increase in stocking rate caused a smaller reduction in ADG than did a similar increase in stocking rate at lower latitudes.

Occasional reports are found of improved animal performance with increased grazing intensity (Bryan and Prigge, 1994; Fike et al., 2003; Burns and Fisher, 2008). In general, such improvements occur when forage mass is sufficient to allow ad libitum intake and diet nutritive value to increase as grazing intensity increases. Within the range of stocking rates typically studied, however, the negative influence of increasing grazing intensity on individual animal performance appears to be caused by reduced forage intake due to decreasing forage mass, and the slope of the ADG response to stocking rate becomes even more negative as forage nutritive value increases.

The relative roles of forage quantity and nutritive value were determined to be as follows: Forage nutritive value sets the upper limit for individual animal response (e.g., average daily gain), the slope of the decline in daily gain with increasing grazing intensity, and the “critical” forage mass at which the decline in daily gain begins. Forage quantity determines the proportion of potential daily gain response that actually will be achieved from a defined forage. Further, it is the primary driver of the direction of the daily

gain response (negative) to increasing grazing intensity (Sollenberger and Vanzant, 2011).

Summary and Recommendations: Grazing Intensity

This literature synthesis supports the overriding importance of grazing intensity in determining animal performance on pasture. As was concluded for plant response, choices of stocking rate or sward stubble height are the most critical decisions affecting animal performance on grazed pastureland. The initial focus of prescribed grazing recommendations for maintaining quantity and quality of forage for health and productivity of grazing and browsing animals should rest squarely on implementing the proper grazing intensity.

STOCKING METHOD

The relative benefits of different stocking methods to animal production continue to be debated. Primary interest in stocking methods stems from the desire to improve the productivity and sustainability of pasture-based livestock production systems. Differences among stocking methods could occur due to 1) maintaining more productive or higher-quality forage species, 2) increasing forage accumulation rate, 3) increasing the percentage of available forage mass that is consumed by limiting animal selectivity, or 4) ensuring more uniform animal distribution across the pasture. Much popular literature suggests that stocking method, and, in particular, rotational stocking, can improve animal production from pasture-based livestock production systems. This assertion will be evaluated.

Recently Briske et al. (2008) published a comprehensive review of the scientific literature dealing with the implementation of rotational stocking on rangelands. Among their conclusions was that "The experimental evidence indicates that rotational grazing is a viable grazing strategy on rangelands, but the perception that it is superior to continuous grazing is not supported by the vast majority of experimental investigations."

Our goal was to conduct a similar analysis of the pastureland literature to determine what conclusions it supports about stocking methods. The 19 papers published in refereed journals from US research included 29 separate

comparisons of gain per animal response and 26 of gain per ha response on continuously and rotationally stocked pastures (Table 3.4).

Sixty-six percent of experiments (19 of 29) showed no difference in gain per animal between rotational and continuous stocking, 24% (6 of 29) showed continuous greater than rotational, and 14% (4 of 29) showed rotational greater than continuous (Fig. 3.4). Thus, the literature suggests that in most situations no difference is found among stocking methods in gain per animal. This is consistent with and follows the lack of conclusive evidence for an effect of stocking method on forage nutritive value, as reported earlier in this chapter.

With 26 observations, 69% (19 of 26) showed no difference in gain per ha between continuous and rotational stocking (Fig. 3.5). Gain per ha was greater for rotational than continuous stocking in 27% of observations (7 of 26), while continuous was greater than rotational in only 4% (1 of 26). Earlier in the chapter it was noted that 85% of studies comparing rotational and continuous stocking showed forage quantity advantages for rotational stocking. Thus, the question arises: Why would 85% of studies report rotational stocking has a forage quantity advantage, but only 27% report greater animal gain per ha?

One issue that merits attention is experimental methodology, especially whether the experiment was conducted using the same or variable stocking rates. When responses to stocking method of gain per animal and gain per ha were sorted based on whether stocking rate was the same or variable, the response of average daily gain was similar across methods (62% showed no difference for same stocking rate experiments vs. 69% for variable; Fig. 3.4). However, when gain per ha was measured, 92% of same stocking rate studies showed no difference between methods, while variable stocking rate studies showed no difference in 50% of cases (Fig. 3.5).

Why might this occur? Gain per ha is a function of average daily gain and stocking rate. When stocking rate is fixed at the same level on both continuous and rotational treatments, difference in gain per ha can only occur due to



...literature synthesis supports the overriding importance of grazing intensity in determining animal performance on pasture."

TABLE 3.4. Summary of experiments evaluating animal responses to continuous and rotational stocking.¹

Forage type ²	Location	Animal species ³	Animal class ⁴	Length of trial, years	No. of pasture replicates	
Irrigated alfalfa–tall wheatgrass	Tucumcari, NM	B	G	2	2	
Bahiagrass	Brooksville, FL	B	G	3	2	
Smooth brome grass–reed canary grass–quackgrass–timothy–Kentucky bluegrass	Ste. Anne de Bellevue, QC	B	DO	2	2	
Bermudagrass/-wheat- legume mix	Parsons, KS	B	DO	3	2	
Bermudagrass–E(+) tall fescue	Eatonton, GA	B	G	2	3	
Bermudagrass–wheat–annual ryegrass	Booneville, AR	B	G	2	2	
Tall fescue–orchardgrass–clover	El Dorado Springs, MO	B	G	1	2	
Bahiagrass	Brooksville, FL	B	DO	3	2	
Bermudagrass–E(–) tall fescue	Eatonton, GA	B	DO	3	2	
Alfalfa–meadow brome grass–Russian wild ryegrass	Brandon, MB	B	G	4	2	
Italian ryegrass	Jeanerette, LA	B	G	1	4	
Alfalfa–orchardgrass	Bozeman, MT	O	E	2	2	
			L			
Bermudagrass	Gainesville, FL	B	G	2	3	
Old world bluestem	El Reno, OK	B	G	2	2	
Alfalfa–tall fescue–orchardgrass	Baylis, IL	B	G	2	2	
E(+) tall fescue–ladino clover	Springfield, TN	B	DO	4	2	
E(+) tall fescue	Parsons, KS	B	G	1	2	
E(+) tall fescue–ladino clover						
Brome grass	Clay Center, NE	B	G	1	2	
				1		
Coastal Bermudagrass	Tifton, GA	B	G	3	4	

¹Comparisons between rotational (R) and continuous (C) stocking in livestock production (both on individual animal and per-hectare basis) are shown in the last two columns. R = C indicates that no significant differences were found between stocking methods; R > C, that response to rotational stocking was greater than response to continuous stocking; and C > R, that response to continuous stocking exceeded that of rotational stocking. ²E(+) indicates endophyte-infected tall fescue; E(–), endophyte-free tall fescue. ³B indicates bovine; O, ovine. ⁴G indicates growing; DO, dam and offspring; E, ewes; and L, lambs. ⁵V indicates variable stocking rates (different stocking rates used for continuously and rotationally stocked treatments); S, same stocking rate was used for continuous and rotational stocking. ⁶Multiple stocking rates were compared within each stocking method. ⁷Phillip et al. (2001) analyzed and reported responses separately

	No. of paddocks in rotation	Pasture size, ha	Stocking rate strategy ⁵	Livestock production		Reference
				Per head	Per hectare	
	5	1.3 to 1.6	V	R = C	R = C	Lauriault et al., 2005
	4	16	S	R = C	R = C	Willms et al., 2002
	6 and 9	1.8 to 2.7	S ⁶	R = C ⁷	R = C ⁷	Phillip et al., 2001
	8	4.0	S	R = C	R = C	Lomas et al., 2000
	8	0.81	V	R = C	R = C	Kuykendall et al., 1999b
	3 and 11	0.68	V	R = C ⁸ R = C	R > C ⁸ R = C	Aiken, 1998
	4	0.81	S	R = C	R = C	Lehmkuhler et al., 1999
	2 and 3	16	S	R = C	R = C	Hammond et al., 1997
	12	16	V	R = C	R > C	Hoveland et al., 1997
	10	3.7	S ⁹	C > R ⁹ R > C at low SR C > R R > C at high SR	R = C ⁹ R = C R = C R > C at high SR	Popp et al., 1997a
	3	3.9	V	C > R	R > C	Hafley, 1996
	8	1.6	V	R > C Y1: C > R Y2: R = C	Y1: R = C Y2: R > C R = C	Thomas et al., 1995
	3 and 15	0.3	V	R = C	R = C	Mathews et al., 1994b
	2	1.8	V	R = C ¹⁰ R = C R > C	R = C	Volesky et al., 1994
	6 and 11	2.5 to 4.5	V	R = C	R > C	Bertelsen et al., 1993
	7	6.5 to 11.3	S	R = C	R = C	Chestnut et al., 1992
	10	2.0	S	R = C C > R	R = C	Coffey et al., 1992
	8	16.2	S	R = C		Jung et al., 1985
			V	R = C	R > C	
	4	0.33	V	C > R	C > R	Hart et al., 1996

within each month of the grazing season. Values represent average responses across the entire grazing season, based on interpretation of their reported monthly responses and SE. Additionally, responses only represent calf gains. Cow weight changes, though reported by the authors, were excluded from this analysis because of the difficulty in associating these data with economic returns. ⁶In Aiken (1998), responses were reported separately for the cool-season, and warm-season phases of the study. Upper values refer to the cool-season phase; lower values to the warm-season phase. ⁹In Popp et al. (1997a), responses were analyzed and reported separately within each year from year 1–4 in order from top to bottom. ¹⁰In Volesky et al. (1994), responses were reported separately for early, mid-, and late season from top to bottom, respectively. Response to stocking method was similar for both SRs if SR response is not indicated.

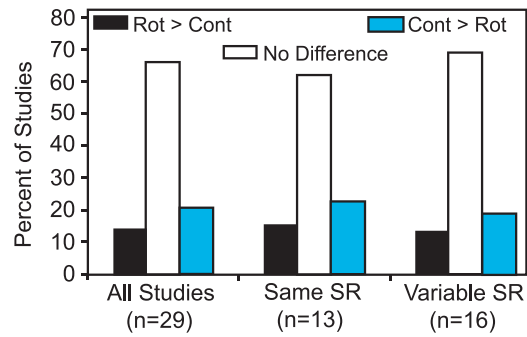


FIGURE 3.4. Comparison of rotational stocking (Rot) and continuous stocking (Cont) on average daily gain by grazing livestock. The 29 studies (all studies) were divided into those for which stocking rate was the same for both stocking methods (same SR) and those for which stocking rate was varied for both stocking methods based on some measure of forage height, mass, or allowance (variable SR).

differences in average daily gain. It has already been shown that rotational and continuous stocking rarely differ in average daily gain within the typical range of stocking rates used in most grazing experiments, so it is logical that experiments using the same stocking rate for both continuous and rotational stocking rarely show differences in gain per ha (Fig. 3.5).

In contrast, when a variable stocking rate is used, the researcher adjusts stocking rate periodically to maintain a specific pasture characteristic at the same level on both treatments. If one stocking method results in greater forage accumulation or more efficient utilization of forage mass, then increased stocking rate is needed on that treatment in order to maintain the same sward state. This may allow greater gain per ha to occur on pastures with greater forage accumulation or higher efficiency of utilization of forage mass, even if average daily gain is not different between treatments.

An important limitation of most research comparing stocking methods at the same stocking rate has been that only one stocking rate was imposed. The same stocking rates can be used effectively to compare stocking methods if animal performance response is measured at a range from quite low to quite high stocking rates. If forage quantity is greater on rotational pastures, then the

relative advantage in production per animal for rotationally stocked pastures is expected to be small or nonexistent at low stocking rates but measurable at high stocking rates. This occurs because at high stocking rates the quantity advantage of rotational stocking has greatest impact on individual animal performance. Studies using this approach show advantages in average daily gain for rotational stocking at high stocking rates (Popp et al., 1997a; Gerrish, 2000).

Summary and Recommendations: Stocking Methods

We conclude that average daily gain in the short term is generally not affected by stocking method, but in the long term, species composition may change with time due to stocking method and thus affect animal response. Most pastureland grazing trials are conducted for time periods of 3 yr or less that are not long enough to account for changes in species composition. The effect on gain per ha is less clear and appears to be confounded with grazing trial methodology. Studies that adjust stocking rate based on forage mass or forage allowance can account for differences in forage accumulation or efficiency of utilization of forage mass and are more likely to detect differences in gain per ha due to stocking method. Differences occurred in about 50% of the variable stocking rate studies, and in most cases rotational stocking was favored.

Results of this pastureland review are in general agreement with those found by Briske et al. (2008) for rangeland, with the exception that the likelihood appears to be greater for an advantage in gain per ha for rotational stocking of pastureland than rangeland. One conclusion of Briske et al. (2008) was that “a continuation of costly grazing experiments adhering to conventional research protocols will yield little additional information.” We agree that additional animal performance studies comparing stocking methods are unlikely to add significantly to our knowledge of plant and livestock responses *unless* special attention is given to specific sampling protocols and the studies are of greater duration. Additionally, these types of studies are warranted if they are done in conjunction with soil, water, and wildlife collaborators so that a more comprehensive set of longer-term responses can

be quantified, including many responses for which we currently have limited data.

One striking difference for pastureland studies (Table 3.4) and those reported for rangeland (Briske et al., 2008) is the longest pastureland study was 4 yr, but most rangeland studies were at least 5 yr, with some extending as long as 25 yr. This is important because 1) environmental conditions can interact with grazing management such that multiyear studies are necessary and 2) management influences on pasture productivity are often cumulative across years. For example, increased gain per ha in a given year may be achieved simply by increasing stocking rate, which may not be sustainable over the long term. Likewise, strategies that improve plant health and vigor may take several years to result in appreciable increases in pasture productivity.

Finally, benefits of rotational stocking have been the subject of much controversy over the years, and this conversation is likely to continue. Our assessment suggests that the greatest impacts of the choice of stocking method are likely to be number of animals that can be supported on the pasture and, in the long term, the species composition of the sward. These effects are important, but in our judgment are less important than proper management of grazing intensity by the land manager. Thus, the starting point in developing prescribed grazing practices for benefiting animal health and production is to understand the achievable goals for use of the available resources and then optimizing grazing intensity to accomplish them for the desired time period.

SEASON OF GRAZING AND DEFERMENT

Throughout much of the central and eastern USA, a variety of options are available to extend the grazing season. Somewhat surprisingly, however, a paucity of information is encountered in the literature regarding animal performance responses to season of forage use. The main systems that incorporate season of use as a primary factor are stockpiled and complementary forage systems, particularly those designed to utilize both cool- and warm-season forage species during the pasturing season.

Stockpiled Forage Systems

A long-accepted management practice (Taylor and Templeton, 1976) of stockpiling tall fescue is the most common strategy for extending the grazing season in mid-latitude states of the Midwestern and eastern USA (Collins and Balasko, 1981b). Utilization of stockpiled forages represents a substantial reduction in feed costs compared with harvested forages because there is no need for mechanical harvesting and handling (Hitz and Russell, 1998; Lalman et al., 2000). There is evidence that livestock performance on grazed, stockpiled forages exceeds that of the same forages when harvested (Allen et al., 1992a). Cows grazing stockpiled tall fescue–alfalfa or smooth bromegrass–red clover in Iowa were able to maintain greater or equal body weight and condition scores, but consumed between 1030 and 1070 fewer kg cow⁻¹ of stockpiled forage than cows in drylot (Hitz and Russell, 1998). They attributed this partly to improvements in diet quality afforded by opportunities for selective grazing within the stockpiled, as compared with the harvested forages.

One potential mitigating factor with respect to livestock response on stockpiled tall fescue is the degree of endophyte infestation. Indeed, part of the interest in using tall fescue for fall/winter forage in stockpiled systems is the recognition that endophyte toxicity will

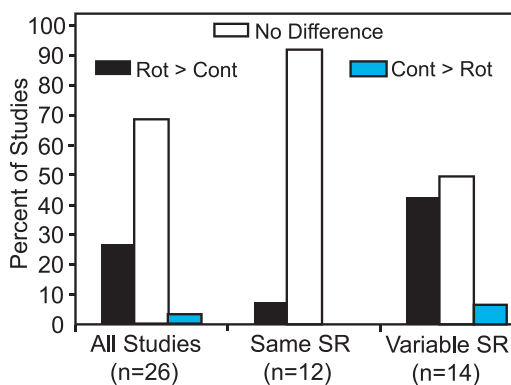


FIGURE 3.5. Comparison of rotational stocking (Rot) and continuous stocking (Cont) effects on gain per ha by grazing livestock. The 26 studies (all studies) were divided into those for which stocking rate was the same for both stocking methods (same SR) and those for which stocking rate was varied for both stocking methods based on some measure of forage height, mass, or allowance (variable SR).

be less in cooler seasons. However, results of studies evaluating the influence of endophyte presence in stockpiled fescue systems are mixed. Endophyte presence decreased gains of steers grazing stockpiled fescue (Beconi et al., 1995), and cows with calves lost weight more rapidly when grazing stockpiled tall fescue with high (89%) than with low (20%) endophyte levels (Curtis and Kallenbach, 2007). However, in both of these studies, differences were ameliorated after cattle were removed from tall fescue and the experimental groups were treated similarly.

No effect of endophyte infestation level was detected for calf gain, either during or subsequent to the stockpile phase (Curtis and Kallenbach, 2007). Similarly, average daily gain of growing cattle was similar when grazing endophyte-free, endophyte-infected, or novel-endophyte stockpiled tall fescue in winter (Drewnoski et al., 2009). However, animal grazing days and weight gain per ha were greater with endophyte-free tall fescue than with either of the other forages. In Georgia average daily gain of yearling heifers grazing endophyte-infected tall fescue was lower than when grazing novel-endophyte tall fescue in autumn through spring, but equal in summer (Franzluebbers et al., 2009). Due to seasonal changes in stocking density, gain per ha was lower with endophyte-

infected than with novel-endophyte tall fescue in spring and autumn only, and was greater with endophyte-infected tall fescue in the summer.

Based on limited data from supplementation studies of cattle grazing stockpiled tall fescue, protein is not limiting for beef cattle production. In a study using a supplement of either nondegraded protein or an isocaloric control for primiparous heifers on stockpiled tall fescue, the body condition score, body weight, calf weight, milk production, and postpartum interval were not affected (Strauch et al., 2001). Improved weight gains and body condition scores of heifers grazing stockpiled endophyte-infected tall fescue were achieved by supplementing with whole cottonseed (Poore et al., 2006), but these responses were likely due to energy from the cottonseed, rather than to protein.

Though considerable research has been done on the quality and forage yield of other forages for stockpiled fall and/or winter grazing (Davis et al., 1987; Lalman et al., 2000; Mislevy and Martin, 2007; Dierking et al., 2008), a lack of information is seen in the refereed literature on animal responses with these forages.

Complementary Forage Systems

Complementary forage systems are those that capitalize on forages having yield and forage quality distributions different from the dominant forages in a region. Thus, in regions in which warm-season grasses dominate, cool-season species are utilized to extend the grazing season and increase animal production (Vogel et al., 1993; Moore et al., 1995; Fontaneli et al., 2000; Volesky and Anderson, 2007). Alternatively, warm-season forages are often planted to complement dominant cool-season species that have low productivity in summer (Belesky and Fedders, 1995).

Improvements in cow-calf productivity and enterprise profitability have been observed when cultivated pastures, double-cropped with cool- and warm-season species, were included in a bermudagrass-based forage system (Bagley et al., 1987). In a comparison of four different year-long forage systems for stocker cattle production based primarily on cool-season species, improved gain was seen per ha and per

Varying herbage mass and color of "Wrangler" bermudagrass show distribution of urine in a sward grazed by mares at a stocking rate of 2.3 head ha⁻¹. Photo by Charles Dougherty, University of Kentucky.



steer, increased number of stocking days, and reduced need for stored forage for a system that included a complementary perennial warm-season forage component (Allen et al., 2000).

Animal performance is not always improved by use of complementary forages. In Georgia there was no apparent benefit to using a complementary forage system compared to bermudagrass alone (Brown et al., 2001; Brown and Brown, 2002). Milk production and calf average daily gain in cow-calf production were greater with systems based on bermudagrass than on tall fescue, and intermediate with a complementary forage system that utilized bermudagrass from June to October and tall fescue from November to May.

Factors other than forage species can influence the relative efficiencies of forage systems. Management strategies that influence forage quantity or quality across time can affect animal response within a seasonal-use system. In annual pastures, effects of deferment on animal production were dependent on stocking rate, length of deferment, and initial plant density (Smith and Williams, 1976). In one year of three, time of year was associated with decreased forage intake within heavily and continuously stocked pastures, but not for lighter stocking rates, nor within rotationally stocked pastures (Popp et al., 1997a, 1997b). Even differences among cultivars in distribution of yield and forage quality across the growing season can be sufficient to warrant differing recommendations for season of use (Redfearn et al., 2002).

The relative effectiveness of a given forage for seasonal use depends on the rates and timing of fertilization (Collins and Balasko, 1981a; Vines et al., 2006; Guretzky et al., 2008). Furthermore, fertilization strategies will have a large influence on the input costs of various systems and effects on the environment and ecosystem (Wood et al., Chapter 5, this volume).

The sheer complexity of forage systems makes it difficult to anticipate how overall system efficiency will be affected by management. For example, forage systems that improved average daily gain of stocker cattle also resulted in lower forage production, requiring higher

use of conserved forages (Allen et al., 1992a). Growth and carcass quality responses of cattle on forage-based finishing systems were more responsive to forage fed during the wintering phase than to forage fed during the subsequent finishing phase (Allen et al., 1996). These types of responses cannot be predicted from forage yield and nutritive value studies alone. Well-designed animal performance studies conducted for a sufficient time period are critical for understanding the relationships and real applicability of forage systems to a given region.

Summary and Recommendations: Season of Grazing and Deferment

In most environments one finds seasons when forage quantity and quality limitations can be mitigated by stockpiling regionally important forages. This is an important prescribed grazing strategy to extend the grazing season, reduce cost of production and improve animal health and performance. Development of year-round complementary forage systems that take advantage of cool- and warm-season species is an important element in achieving desired levels of animal performance and reducing costs. These systems also contribute to ecosystem services that can be achieved by maintaining plant cover and growth in the sward for as much of the year as possible.

TYPE AND CLASS OF LIVESTOCK

The utilization of pasture to support more than one species of animal has been purported to increase individual animal performance, yield of livestock product per unit land area, and ecosystem stability (Walker, 1994). The focus is on the first two of these assertions.

The conceptual basis underlying the grazing of multiple species on the same land area derives from the competitive exclusion principle (Hardin, 1960), which states that two species cannot both successfully occupy the same ecological niche. Thus, in natural settings, different species of grazing animals occupying the same area will occupy different niches, particularly with respect to their dietary selection behaviors. Differences in ingestive anatomy and grazing behavior among livestock species and their relationship to diet selection were described earlier in the chapter. Because these



Well-designed animal performance studies conducted for a sufficient time period are critical for understanding the relationships”



There is no clear picture emerging: ...sometimes a grazer benefits and sometimes a browser.”

behaviors permit more complete utilization of the existing forage base, it is theoretically possible for a given area to support a greater combined stocking rate of multiple species compared with the stocking rate of either species grazing alone.

In a broad sense, interactions among comingling herbivores can be described as competitive, supplementary, or complementary (Kinyua and Njoka, 2001). These interactions include competition for limited forage resources (competitive relationship), no dietary overlap (supplementary relationship), or the actions of one (or both) benefits the forage quantity or nutritive value for the other (complementary). Other potential mechanisms for interactions exist, including effects on parasite load, or by one animal species utilizing plant species that are potentially toxic to the other. Little research on multispecies grazing is available from pastures of the USA, so the following review is supplemented by research conducted elsewhere.

Individual Animal Performance

Across a range of stocking rates and sheep:cattle ratios, mixed grazing improved lamb gains by an average of 7% and cattle gains by an average of 11% (Nolan and Connolly, 1989). This occurred in the presence of an average increase in stocking rate of about 2%, indicating the presence of a complementary relationship that benefited both species. In Texas cattle gains were greater when grazing with sheep and goats together than when grazed alone (Taylor, 1985); likewise sheep gains were increased by grazing with cattle and goats, as was percent lamb crop and wool production. However, neither gain nor mohair production of goats was improved by co-grazing with cattle and sheep. Some reports document only minor effects on either species. In a 10-yr study in Utah, cattle gains were slightly depressed (1.01 vs. 1.04 kg d⁻¹) when cattle co-grazed with sheep rather than grazing alone, whereas lamb gains were improved slightly (0.25 vs. 0.23 kg d⁻¹) when grazing with cattle rather than alone (Olson et al., 1999). In Australia benefits of mixed-species grazing were typically noted for sheep, but not for cattle (Bennett et al., 1970; Hamilton et al., 1976).

The effects on individual animal performance were evaluated from a variety of co-grazing studies (Prins and Fritz, 2008), but the results did not support any broad generalizations. In contrast to ecological theory, which suggests that small grazers outcompete large ones and that large grazers facilitate small ones, they found that “There is no clear picture emerging: sometimes a small species benefits from a large one but sometimes a large one to the detriment of the smaller; sometimes a grazer benefits and sometimes a browser.”

Another mechanism for benefit is reduced parasite loads, particularly in sheep that are co-grazed with cattle (Brelvi, 1979; Bown et al., 1989). A decrease was seen in gastrointestinal helminths and greater weight gains in lambs that had co-grazed with sheep and cattle than in lambs grazing only with sheep (Jordan et al., 1988). In contrast, calves that had co-grazed with sheep had greater gastrointestinal helminth burdens and lower weight gains than those that had grazed only with cattle. In the United Kingdom, sequential grazing with cattle following sheep reduced lamb fecal egg counts, even with regular anthelmintic treatment (Marley et al., 2006).

Greatest growth rates were observed in lambs from mixed-grazing systems, leading to the conclusion that most performance differences were due to factors other than parasite control. Likewise, differences in lamb growth rates with alternate cattle/sheep grazing were due to pasture quality, as no differences were seen in nematode burdens in lambs between alternate grazing vs. sheep-only systems (Moss et al., 1998). Thus, factors other than changes in forage mass and forage quality can mediate effects on animal performance with mixed-grazing systems even though most authors point to forage-mediated effects as the primary drivers.

Production per Unit Land Area

Although some reports suggest that increases in livestock weight gain per ha are almost assured with co-species grazing, the available literature shows a more complex picture. For example, at a medium stocking rate, mixed-species grazing increased weight gain per ha by 16% above cattle-only grazing (Dickson et al., 1981). Similarly, production per ha was greater with

sheep or mixed-species grazing than with cattle alone (Olson et al., 1999). Conversely, grazing sheep and goats together did not increase productivity per ha, and in a drought year, dramatic weight loss was experienced by sheep grazing with goats, as compared with sheep alone (Wilson and Mulham, 1980).

In a review of the literature, there was no consistent pattern of response of livestock production per ha to co-species grazing (Prins and Fritz, 2008). In six of seven studies reported, gain per ha with combined sheep/cattle grazing was greater than with cattle alone. However, in only one of four studies were combined-species gains greater than gains reported for sheep alone. Further, in only one of three studies did co-grazing goats and cattle result in greater gain per ha than grazing cattle alone. In none of three studies where sheep and goat co-grazing were evaluated was gain per ha improved by co-grazing as opposed to single-species grazing.

Some observers suggest that factors that can influence the competitive balance between forage species can alter the potential influence of co-species grazing on livestock productivity. Drawing general conclusions seems premature, and additional research is required to better understand the biological and ecological mechanisms at play. Though some efforts have been made, much more remains to be done, particularly on temperate pastures in the USA.

Experimental design and appropriate data collection are critical in co- and multispecies grazing studies because of difficulties in determining substitution equivalents between different species. Care must be taken to ensure that any observed increases in gain per ha from combining animal species are not simply a function of increased stocking rate. In other words, the research needs to ensure that a similar increase in gain per ha would not occur simply by addition of animals of the same species.

Substituting one animal species for another based on actual weight is quite common in the existing literature, even though it is generally recognized that animal unit equivalents will be more closely aligned with *metabolic* body weight than with absolute body weight (Allen

et al., 2011). Stocking rates based on actual live weight can be effectively used when dealing with a single species, but utilizing a metabolic body weight-based animal unit becomes critical when dealing with animal species having large variation in individual weights.

Designing Multispecies Grazing Systems

Strategies have been identified to help quantify degree of dietary overlap (e.g., Abrams, 1980; Squires, 1982), yet it is difficult to establish specific recommendations of animal species, ratios, and numbers based on “degree of dietary overlap” (Scarnecchia, 1985, 1986). Determining these is complex and optimal solutions will differ depending on management goals. In addition, other management factors must be considered such as whether it is desirable to graze different animal species sequentially, rather than simultaneously, in order to allow a greater degree of species-specific management, e.g., mineral supplementation. Such strategies will have different effects on system productivity.

Ultimately models may be developed to allow reasonable prediction of system performance under single- vs. mixed-species grazing strategies (Scarnecchia, 1990). However, at present, we are dependent on empirically established relationships that will necessarily be constrained to specific forages and geographic and climactic conditions. A need exists for research to establish these relationships and

Factors including water sources, shade sources, topography, fencing, salt and feed sources, and season affect the distribution of livestock on pasturelands resulting in unequal distribution of nutrients and varying intensity and frequency of grazing. Photo by Carmen Agouridis, University of Kentucky.





animal production responses to mixed-species grazing are affected by complex interactions among forage, animal, environmental, and management factors”

provide the data necessary for modeling efforts, particularly on pastureland in the USA.

Byington (1985) identified opportunities for increased utilization of multispecies grazing in the eastern USA. These included increased costs associated with forage production, perception by producers of the need for change, availability of technology and knowledge for design and implementation of multispecies grazing systems, and availability of markets for livestock products from such systems. In the 27 yr since Byington documented these factors, the “opportunities” they represent have increased, yet one still finds a lack of robust, systems-oriented research to provide livestock producers with the essential knowledge of how to best implement multispecies grazing practices.

Summary and Recommendations: Type and Class of Livestock

The direction and magnitude of animal production responses to mixed-species grazing are affected by complex interactions among forage, animal, environmental, and management factors, all of which restrict the ability to predict system performance. Conducting meaningful research in this area is challenging and expensive, but it can be accomplished when careful attention is paid to experimental design to eliminate potentially faulty assumptions, especially as they relate to preconceptions regarding proper species substitution ratios and stocking rates. Ultimately, reasonable prediction of system output will depend on sophisticated modeling efforts that are based on quality field research.

DISTRIBUTION OF LIVESTOCK IN THE LANDSCAPE

Generally, effects of grazing distribution on animal production are indirect, mediated through alterations in the type and quantity of forage on offer, and possibly through energetic costs associated with foraging behavior, e.g., distance traveled. Because of the large effects of grazing, treading, and manure and urine deposition by herbivores on vegetation structure and botanical composition, a primary effect of manipulating livestock distribution is alteration in the spatiotemporal diversity of pasture forage mass (Rook and Tallwin, 2003) and botanical biodiversity (Ash et al., 2004; Sanderson et al., 2004). Theoretically, productivity should

be maximized when grazing pressure is evenly distributed, yet few data relate the spatial distribution of animals within a pasture with animal performance. Thus, emphasis is often placed at the level of forage production, which is reviewed elsewhere in this chapter.

Some management practices to alter spatial distribution of animals within pastures, e.g., fencing and location of salt or supplemental feed, indirectly affect animal health and performance through controlled access to specific forage types or altering distance traveled. Literature regarding these indirect effects on animal performance is limited. For other strategies, e.g., provision of alternate water sources and adequacy of shade, effects are more direct. Although the literature does allow some generalizations to be made, the data are sufficiently limited to preclude quantitative prediction.

Fencing and Pasture Size

Subdividing large pastures with fences often increases the uniformity of pasture utilization, although a point exists at which further division presents no additional advantage (Heady and Child, 1999). Little research is at hand to provide quantitative relationships between pasture size and uniformity of use. Grazing distribution and animal performance were evaluated in Wyoming pastures ranging from 24 ha to 207 ha (Hart et al., 1993). The 207-ha pasture was designed to create heterogeneity in grazing utilization, in part by including a maximum distance to water of 5.0 km compared with a maximal 1.6-km distance in the small pastures. Uniformity of pasture utilization was improved, daily distance traveled by cattle was less, and cattle gains were greater in the small, as compared with the large pasture. Unfortunately these effects of pasture size cannot be separated from the effects of distance from water. In an effort to better understand the influence of pasture size, Hacker et al. (1988) evaluated crested wheatgrass pastures ranging from 1 ha to 8 ha in size. No difference was found in overall pasture utilization, uniformity of utilization, or animal weight gain.

Alternate Water Sources

The importance of providing alternate sources of drinking water, i.e., in addition to existing

natural water bodies, varies depending on levels of total dissolved solids, minerals, microbial contamination, and other water quality factors. Thus, it is difficult to make generalizations on benefits of alternate water sources. Nonetheless, several studies have demonstrated the potential for water source to affect a variety of animal health parameters.

Both cryptosporidia and campylobacter can cause scours in young animals (Merck, 2008) and can be transmitted via drinking water. Starkey et al. (2006) found a 37% increase in cryptosporidium infection in young cattle drinking from springs or streams, as compared with well water. The difference was likely associated with lower levels of fecal contamination in well water. In the United Kingdom, the number of bovine fecal pats within a 5-m radius of a surface water sampling site was positively related to the concentration of *Campylobacter* spp. in the water source (Kemp et al., 2005), suggesting that increased animal presence in and around riparian areas could potentially facilitate spread of disease. Work from the Netherlands indicated that dairy cattle drinking from water sources other than public water supplies (originating either from wells or from streams) had an increased incidence of *Staphylococcus aureus*-mediated mastitis (Schukken et al., 1990, 1991).

A few studies have linked differences in animal growth performance with varying water supply sources. In eastern Oregon, gains by cows and calves were increased across a 42-d grazing period (in each of 2 yr) by providing trace-mineralized salt and water sources away from a stream (Porath et al., 2002). Although part of the response could have been due to provision of trace-mineralized salt, the authors suggest that improvements in performance were likely associated with more uniform grazing distribution in pastures with water sources away from, and other than, the stream. In other research, suckling calves that were provided clean water gained 9% more than those drinking directly from ponds, and yearling heifers provided with clean water gained 20% to 23% more than those drinking pond water (Willms et al., 2002).

Treating “dugout” water by aeration or coagulation/chlorination significantly

reduced *Escherichia coli* load, as well as concentrations of some mineral constituents, and increased dissolved oxygen concentrations (Lardner et al., 2005). Steer gains averaged about 0.1 kg d⁻¹ greater with treated as compared with untreated water. These responses occurred in the absence of increased parasite load, which, when present, would be expected to increase the benefits of water treatment. Thus, direct benefits to animal health and performance can be derived from providing clean water sources, particularly when levels of bacterial or protozoal contamination are high.

Provision of alternate water sources may not always attract animals away from surface waters. Off-stream water sources served as an attractor for cattle when the temperature-humidity index was moderate, but failed to decrease time spent in riparian zones when the index was high (Franklin et al., 2009). This suggests that when surface waters can contribute to thermoregulation, cattle were less likely to be attracted away from them.

Shade

Heat stress can adversely affect animal production, primarily by decreasing feed intake (Nienaber et al., 1999; Nienaber and Hahn, 2007). Thermoregulatory behaviors are important in grazing animals since cattle will seek out shade and can increase the time spent under shade without necessarily affecting grazing time (Tucker et al., 2008), although at least one study showed that time spent under shade did reduce grazing time (Coleman et al., 1984). Little information is available directly relating performance of grazing animals to shade provision.

Shade benefited sperm motility and morphology in bulls exposed to warm ambient temperatures (Coleman et al., 1984). In feedlot and free-stall housing studies, shade reduced respiration rates and body temperatures of cattle (Brown-Brandl et al., 2005; Eigenberg et al., 2005; Kendall et al., 2007) and increased average daily gain (Mitlöhner et al., 2002). In Australia shade acted as a protectant from the photosensitization and hyperthermic effects of toxins derived from *Hypericum perforatum* that was orally dosed to sheep (Bourke, 2003). Susceptibility to heat stress of animals



...several studies have demonstrated the potential for water source to affect a variety of animal health parameters.”



...key management factors include minimizing distance to water, providing alternatives to surface water to increase drinking water quality, and providing shade.”

grazing endophyte-infected tall fescue is of great significance to livestock producers in the southeastern USA (Paterson et al., 1995), and this effect may be mitigated partially by shade.

Summary and Recommendations: Distribution of Livestock in the Landscape

There are few data relating spatial distribution of animals in a pasture with animal performance, but it is likely that distance to water is more important than pasture size with respect to optimizing distribution of grazing and animal performance. Direct benefits to animal health and performance can be derived from providing alternate water sources, but this response is primarily related to water quality and is most likely to occur when levels of bacterial or protozoal contamination are high in existing water sources. Shade is a key factor affecting livestock distribution, and although direct links between shade and improved animal performance are limited, well-documented cases are found of improvement in animal comfort and well-being from shade. Thus, from an animal health and production perspective, key management factors include minimizing distance to water, providing alternatives to surface water to increase drinking water quality, and providing shade.

PURPOSE 3: IMPROVE OR MAINTAIN SURFACE AND/OR SUBSURFACE WATER QUALITY AND QUANTITY

Nutrients, sediment, and pathogens from pastures must be transported to sensitive locations to affect water quality. Greatest risk of transport is associated with highly permeable soils, severe slopes, insufficient vegetative cover, high water tables, and proximity to streams and wetlands.

GRAZING INTENSITY

Similar to forage characteristics and animal performance, the most important grazing management variable associated with ecosystem health of upland and riparian areas is grazing intensity (Van Poollen and Lacey, 1979; cited by Mosely et al., 1999). Challenges to reviewing the literature describing the effects of grazing intensity on water quality and quantity include standardizing the unit of measure for grazing intensity, defining the

period of stocking, and noting the stocking method used (Trimble and Mendel, 1995; Bilotta et al., 2007). Evans (1998) argues for defining grazing intensity in terms of “damage it does to the landscape” rather than in terms of forage characteristics. Others have suggested that grazing intensity be defined based on factors such as hoof impacts and urine and manure deposition and not solely on vegetation consumption (Bilotta et al., 2007).

Water Quality

Nutrients. In continuously stocked swards in Ohio, nitrate-nitrogen ($\text{NO}_3\text{-N}$), mineral-N, and total P in runoff did not increase with grazing intensity, but organic-N and total organic carbon (C) levels did increase (Owens et al., 1989). In Nebraska the presence of grazing resulted in increased $\text{NO}_3\text{-N}$ and soluble-P concentrations in runoff and greater chemical oxygen demand (Schepers et al., 1982). Increasing grazing intensity increased levels of ammonium-nitrogen ($\text{NH}_4\text{-N}$), $\text{NO}_3\text{-N}$, total P, total organic C, and chemical oxygen demand in runoff. Increased vegetative cover with decreased grazing intensity can reduce nutrient movement into waterways (CAST, 2002). More details on nutrient losses are covered in Chapter 5 (Wood et al., this volume).

Sediment. Few studies have examined the effect of grazing intensity on sediment discharge to streams, despite the fact that sediment is a leading cause of impairment in the nation’s streams (EPA, 2009). Increased concentrations of sediment in runoff occurred with increased grazing intensity, and these increases resulted in greater predicted values for $\text{NH}_4\text{-N}$, total Kjeldahl N, total organic C, and chemical oxygen demand (Schepers et al., 1982). Three stocking rates (1.5, 2.0, and 3.0 animal units ha^{-1}) were studied in Texas pastures, and the highest stocking rate led to the greatest amount of sediment loss of nearly 1500 kg ha^{-1} (Warren et al., 1986). In Ohio sediment concentrations in runoff increased with grazing intensity, and these data support the recommendation to exclude livestock from riparian areas (Owens et al., 1989).

Pathogens. Although research links the presence of cattle to increased levels of fecal coliforms in streams (Doran and Linn, 1979;

Tiedemann et al., 1987; Howell et al., 1995), studies examining pathogens or pathogen indicator levels in relation to grazing intensity are rare; for pasturelands, none was identified. Increasing stocking rate reduced soil microbial biomass and N mineralization potential (Banerjee et al., 2000). Because grazing intensity can impact soil microbial populations, it is reasonable to expect pathogenic populations would be similarly affected.

Hydrology

Few studies have investigated the relationship between grazing intensity and water quantity. Most studies have focused on how soil compaction and soil structural properties alter infiltration rates (Bilotta et al., 2007). No study was found that measured direct changes in runoff volume or timing; however, it is expected that such differences exist based on results from infiltration studies. Infiltration studies showed that soil structural changes associated with grazing increased with stocking rate. As stocking rate increases, the animal traffic over any particular area increases and leads to compaction and further breakdown of soil structure and water-stable aggregates. Infiltration rates decreased as grazing intensity increased from “moderate” to “heavy,” but they were not different when the change was from “light” to “moderate” (Gifford and Hawkins, 1978; Usman, 1994; Trimble and Mendel, 1995).

In Texas the heaviest stocking rate produced the lowest infiltration rates for the first 30 min of a simulated storm, but no differences were detected between the light (60% of heavy) and moderate (80% of heavy) stocking rates. After the first 30 min there was no further difference in infiltration rate among stocking rates (Warren et al., 1986). Difficulties in drawing conclusions from the literature regarding the “magnitude of the relationship between soil damage and stocking rate” have been attributed to nonstandardized measurement techniques and parameters, different livestock types, climate, simulated versus natural rainfall, and prior land use differences (Bilotta et al., 2007).

Stream Morphology

Research into the effects of grazing intensity on the morphology of streams in pasturelands is limited. Seasonal adjustment of stocking rate

based on visual observation of forage mass was recommended as a best management practice to counter streambank erosion in central Kentucky (Agouridis et al., 2005a), particularly during mid- to late summer when forage mass was low and the cooling waters of the stream attracted animals. In New Zealand grazing impacts were greater on smaller streams due largely to their greater accessibility to livestock, since streambanks were closer to water level and water depth was shallower (Williamson et al., 1992). The authors noted that stream morphology was impacted on smaller streams (< 2-m width) when grazing was intensive and the streamside soils were wet.

Summary and Recommendations: Grazing Intensity

Despite intuitive statements regarding the importance of grazing intensity as a controlling variable in ecosystem health (measured as water quality, water quantity, and riparian and watershed function) (Van Poolen and Lacey, 1979; Mosely et al., 1999), little research has been conducted in this area. Increases in grazing intensity have been linked to increased nutrient, sediment, and fecal coliform loading; streambank erosion; and soil compaction that results in decreased infiltration rates (Table 3.5). Thresholds for grazing intensity, above which substantial environmental impacts occur, have not been established.

A beneficial first step would be to conduct an evaluation of grazing intensity in pasturelands, similar to that done by Trimble and Mendel (1995), to better determine these thresholds. Since research regarding the environmental impacts of grazing intensity is scarce, other grazing studies should be examined to glean relevant information to construct a database for analysis, including those where the focus was on stocking duration and stocking method. In humid areas, of which pasturelands dominate, precipitation is of a much greater magnitude than in many rangelands and, as such, is in excess of infiltration capacity more often than in other climates of the USA (Trimble and Mendel, 1995). As such, the grazing effects on soils, such as reduction in infiltration capacity, will likely exert a significant influence over the hydrograph. Research is needed on effects of grazing intensity on soil characteristics coupled with water infiltration and runoff.



Increases in grazing intensity have been linked to increased nutrient, sediment, and fecal coliform loading; streambank erosion; and soil compaction”



limited research has been conducted to evaluate the effects of rotational vs. continuous stocking on environmental responses”

STOCKING METHOD

Current grazing management practices are primarily designed to improve forage and animal performance with the overarching goal of increasing profit (Fitch and Adams, 1998; Bellows, 2001). Yet grazing management may also serve as a means to improve environmental responses such as water quality and quantity, riparian health, and watershed function. When riparian areas are grazed, continuous stocking at high grazing intensities has been shown to adversely impact water quality, hydrology, stream morphology, and habitat (Schepers et al., 1982; Kauffman and Krueger, 1984; Belsky et al., 1999; Agouridis et al., 2005a). Rotational stocking may provide environmental benefits, but although a large volume of literature is available that describes forage and animal responses to stocking method, limited research has been conducted to evaluate the effects of rotational vs. continuous stocking on environmental responses. Understanding the potential environmental benefits of alternative stocking management practices will be important in evaluating their overall use and effectiveness.

Water Quality

Surface Waters. Mean total-P in runoff was 34% greater with continuous stocking to maintain a 5-cm height than with rotational stocking leaving a 5-cm post-graze stubble, and 3.7 times greater than rotational stocking leaving a 10-cm post-graze stubble (Haan et al., 2006). The latter did not differ from a non-grazed sward. Percent surface cover by forage was correlated negatively with total-P load in runoff, leading to the conclusion that pasture management should ensure sufficient residual forage mass to reduce the kinetic energy of rainfall. Similarly, a literature review showed that vegetation cover was greater, on average, using rotational than continuous stocking, indicating that a change in stocking method could have long-term implications for water quality (Earl and Jones, 1996). These results do not implicate continuous stocking, in general, as a water quality hazard; instead they indicate that this method in combination with high grazing intensity reduces cover and endangers surface waters. The nearly three-fold higher P in runoff associated with leaving 10- vs. 5-cm of stubble under rotational stocking (Haan et al., 2006) supports the

concept that grazing intensity is the key factor affecting this response.

Kuykendall et al. (1999a) found total Kjeldahl-N, ammonium, total P, and dissolved-reactive-P in surface water was similar for rotational and continuous stocking of pastures receiving broiler litter additions. Results may not apply to pastures not receiving litter.

Winter feeding areas on pastures have been associated with greater runoff, sediment, and P loads as compared with non-use areas leading to research in Ohio to evaluate continuous and rotational stocking methods over winter (Owens et al., 1997; Owens and Shipitalo, 2006). In the continuous method, cattle were fed hay in one pasture during the dormant period (November–April), while in the rotational method, cattle were rotated through pastures to eat stockpiled tall fescue and fed hay. Losses of total-N were 1.9 to 2.5 times greater with the continuous as compared with the rotational method. Organic-N made up over 70% of the N transported in surface runoff from the continuous method. Like Haan et al. (2006) and Earl and Jones (1996), the authors noted less vegetative cover in the continuous than the rotational method (50 vs. ~100%). It should be noted that the rotational overwintering area had more area per cow (i.e., lower stocking rate) than the continuous overwintering area.

Groundwater. Nitrogen, particularly $\text{NO}_3\text{-N}$, is of concern with regard to groundwater. Rotational stocking of cattle was compared with hay production, both without fertilizer, for groundwater $\text{NO}_3\text{-N}$ concentrations in Ohio (Owens and Bonta, 2004). Within a 5-yr period, peak groundwater $\text{NO}_3\text{-N}$ concentrations decreased from levels greater than the EPA standard of 10 mg L^{-1} to less than 5 mg L^{-1} for both practices. These results suggest that a livestock producer can achieve lower $\text{NO}_3\text{-N}$ losses and acceptable groundwater $\text{NO}_3\text{-N}$ concentrations under haying or rotational stocking with low or no N inputs, even in an area with previous high N loading. Based on this and other studies on eastern Ohio watersheds, the authors suggest that N inputs for grazing systems in this region should not exceed 100 kg N ha^{-1} annually to maintain groundwater $\text{NO}_3\text{-N}$ concentrations

TABLE 3.5. Water quality, hydrology, and streambank morphology responses to grazing intensity.

Response ¹	Response to increased grazing intensity	Stocking rate ²	Reference
NO ₃ -N, mineral-N, total P	No change	No livestock, 17 cows (26 ha) ⁻¹ summer only grazing, 17 cows (26 ha) ⁻¹ year-round grazing	Owens et al., 1989
Organic-N, TOC, sediment	Increased	No livestock, 17 cows (26 ha) ⁻¹ summer only grazing, 17 cows (26 ha) ⁻¹ year-round grazing	Owens et al., 1989
NO ₃ -N	Increased	60% available forage utilization, 80% available forage utilization, and 80% available forage utilization with grain supplement (33% dry matter intake)	Stout et al., 2000
NO ₃ -N, NH ₄ -N, total P, soluble P, COD, TOC, sediment	Increased	No livestock, 35–40 cow-calf pairs (40 ha) ⁻¹	Schepers et al., 1982
Sediment loss	Increased	0.68, 0.51, and 0.32 ha AU ⁻¹	Warren et al., 1986
Soil microbial biomass, N mineralization potential	Decreased	2.2 and 1.1 steers ha ⁻¹	Banerjee et al., 2000
Infiltration rates	Decreased	0.65, 1.2, and 2.5 AUM ha ⁻¹	Trimble and Mendel, 1995
Infiltration rates	Decreased	0.34, 0.68, and 0.51 ha AU ⁻¹	Warren et al., 1986
Streambank erosion	Increased	0 to 1600 kg ha ⁻¹	Agouridis et al., 2005a

¹TOC indicates total organic C; COD, chemical oxygen demand. ²AU indicates animal unit; AUM, animal unit months.

below 10 mg L⁻¹, though this annual rate of N may be too high to allow lowering of existing high NO₃-N levels in groundwater. Rates are regionally specific, as 200 kg N ha⁻¹ yr⁻¹ did not affect soil profile NO₃-N water quality in bermudagrass pastures or hay fields in Georgia (Franzluebbers and Stuedemann, 2003b). Further, NO₃-N leaching from bermudagrass hay fields was minimal when N was applied at < 90 kg N ha⁻¹ growth period⁻¹ (typically 3–4 growth periods yr⁻¹) in Florida (Woodard and Sollenberger, 2011).

The effects of summer and winter rotational stocking practices on NO₃-N and dissolved reactive-P were also studied (Owens et al., 2008). Groundwater discharge from small watersheds affected the flow and water quality from larger watersheds. It was estimated that 50% of the NO₃-N loads and 30% of the dissolved reactive-P loads in the stream flow originated from groundwater. Examination of water quality trends prior to cessation of fertilizer application indicated that it would likely take several years for the effects of a change in grazing management to become measurable in terms of water quality. In karst terrain, subsurface drainage and nutrient

transport to groundwater can be rapid. Several years may be required before past land uses are no longer influential, particularly with respect to soil nutrient concentrations (Zaimes et al., 2008a).

Sediment. Sediment loss from pastures can be influenced by ground cover, sward height, treading damage, surface slope, and soil moisture (Haan et al., 2006). Sediment loss from a continuously stocked sward maintained at a height of 5 cm was nearly twice that from a rotationally stocked treatment with a 5-cm post-graze sward height (Haan et al., 2006) because of greater average cover for rotational than continuous stocking. Maintaining good vegetative cover limited soil loss from pastureland in Ohio where cattle were overwintered (Owens et al., 1982; Owens et al., 1983b; Owens and Shipitalo, 2009). Changing management on an area from rotational stocking in summer plus continuous overwinter stocking to summer-only rotational stocking reduced annual soil loss from 2.3 to 0.15 Mg ha⁻¹ (Owens et al., 1997). Sovell et al. (2000) compared rotationally and continuously stocked pastures in southeastern Minnesota and found that streams in continuously stocked



modifications to cattle management could reduce fecal coliform levels in shallow groundwater.”

pastures had higher turbidity levels than those in rotationally stocked sites.

Pathogens. Few studies have examined the effect of stocking method on pathogenic organism levels either in surface water or in groundwater. Fecal coliform levels in Minnesota streams were greater within continuously than rotationally stocked pastures (Sovell et al., 2000). Although research on bacterial movement from pastures usually focuses on surface runoff, studies in karst terrain show surface water can rapidly move into springs and wells. In central Kentucky, fecal bacteria populations frequently exceeded primary contact standards at all sites sampled (Howell et al., 1995). Fewer samples exceeded primary contact standards from pastures that were intensively grazed and then rested than from pastures stocked continuously. Therefore, modifications to cattle management could reduce fecal coliform levels in shallow groundwater. In West Virginia, successful forage management practices allowed for increased stocking rate, but also led to increased levels of fecal bacteria in groundwater (Boyer, 2005).

Hydrology

Hydrograph shape is influenced by variables including soil compaction, upland and riparian vegetation, and stream morphology; all that can be influenced by grazing activity (Kauffman and Krueger, 1984; Agouridis et al., 2005a). However, few studies have examined effects of different stocking methods on hydrology. Although not statistically significant, Haan et al. (2006) showed that water infiltration rates ranked in order of rotationally stocked to a 10-cm stubble height (67 mm h^{-1}), non-grazed (62 mm h^{-1}), rotationally stocked to a 5-cm stubble height (57 mm h^{-1}), and continuously stocked (55 mm h^{-1}). Subsequently, percentage of rainfall that became runoff was similar from non-grazed (6.4%) and rotationally stocked to 10-cm stubble height treatment (12.7%), but both had less runoff than did rotationally stocked to a 5-cm height (20.7%) and continuously stocked treatments (21.9%).

In a multiyear study in eastern Ohio, a small watershed was rotationally stocked in the summer and used continuously as a wintering paddock (Owens et al., 1997).

Runoff during both the summer and winter was higher than from an adjacent watershed that was stocked rotationally in summer only. Reduced vegetative cover during winter was an important factor causing increased runoff. Monthly runoff was greater with continuous than rotational stocking 75% of the time (Owens and Shipitalo, 2009). In Georgia, however, no difference was seen in annual surface runoff volume between pastures treated with broiler litter that were continuously or rotationally stocked year-round (Kuykendall et al., 1999a).

Stream Morphology

Numerous studies have shown that uncontrolled livestock grazing can negatively impact stream morphology (Kauffman and Krueger, 1984; Trimble, 1994; Owens et al., 1996; Agouridis et al., 2005b). In Iowa continuous, rotational, and intensive rotational (six or more paddocks, 1- to 7-d grazing period, 30- to 45-d rest period) stocking were compared (Zaimis et al., 2008b). Streambank erosion rates were not different among the treatments, but the intensive rotational treatment had a lower percentage of severely eroding streambanks than the other grazing treatments. Pastures with exclusion fencing had streambank erosion rates of 22 mm yr^{-1} , while rates were $101 \text{ to } 171 \text{ mm yr}^{-1}$ for continuous stocking, $104 \text{ to } 122 \text{ mm yr}^{-1}$ for rotational stocking, and $94 \text{ to } 170 \text{ mm yr}^{-1}$ for intensive rotational stocking. Thus grazing increased streambank erosion.

In Minnesota a higher percentage of suspended sediment occurred in the stream, and a higher percentage of exposed streambank soil was found for continuously compared with rotationally stocked sites (Sovell et al., 2000). In Wisconsin, Lyons et al. (2000) measured lower amounts of streambank erosion and suspended sediment in the stream where intensive rotational stocking was practiced, compared with continuous stocking. They concluded that intensive rotational stocking could be substituted for development of riparian buffer strips when only streambank erosion and suspended sediment were considered. Similar conclusions were made in Minnesota if the grazed sites were managed in an environmentally sustainable manner (Magner et al., 2008). It is unlikely

that riparian benefits from changing from continuous to rotational stocking will be realized unless sufficient time is allocated for streambanks to recover and for establishment of riparian vegetation, particularly woody species (Fitch and Adams, 1998).

Summary and Recommendations: Stocking Method

The majority of a small number of studies indicate that rotational stocking is less detrimental to water quality, hydrology, and stream morphology than is continuous stocking (Table 3.6). A few studies indicated reduced ground cover from grazing can lead to increased runoff and lower quality of surface waters from grazed pastures. Accumulation of additional forage mass and ground cover during regrowth periods accounts for some of the benefits attributed to rotational stocking. However, additional research is needed to fill knowledge gaps, specifically on effects of vegetation characteristics (e.g., types, height, percent cover) on water quality and hydrology, on impact of grazing methods in karst areas and how to reduce such impacts (e.g., sinkhole protection), and the effects of stocking methods on reducing transfer of pathogenic organisms to waterways.

The literature suggests a role for rotational stocking in protecting water quantity and quality. The choice of continuous or rotational stocking, however, is likely to be less important from an environmental perspective than ensuring that an appropriate stocking rate is maintained, season and duration of grazing in riparian areas are controlled, or even excluded depending on site conditions, and a sufficient riparian buffer is established and maintained to enhance water quality, streambank stability, and in-stream and riparian habitat.

SEASON OF GRAZING AND DEFERMENT

Pasturelands in the USA are largely located in humid regions in which annual precipitation amounts exceed annual evapotranspiration (Trimble and Mendel, 1995), resulting in periods of high runoff (Di and Cameron, 2002). A large portion of US pasturelands receive more than 1000 mm of rainfall annually (NOAA, 2005) with spring months typically the wettest and late summer to early

autumn months the driest. Periods of high soil saturation coupled with seasonal changes in water requirements of pasture species affect runoff or drainage volumes and constituent (e.g., N) transport rates (Owens et al., 1983a; Stout et al., 1998; Di and Cameron, 2002; Owens et al., 2003) as well as streambank stability (Scrimgeour and Kendall, 2002). Furthermore, the large presence of karst topography in pasturelands (Veni, 2002) may have management-specific implications with regards to water quality. Research is limited on environmental effects due to season and grazing deferment practices, particularly in light of the climatic and geologic characteristics associated with pasturelands. Such knowledge is vital to develop management strategies that minimize factors such as $\text{NO}_3\text{-N}$ leaching and enhance benefits such as biodiversity in pasturelands.

Water Quality

Nutrients. Season of grazing and deferment have significant effects on $\text{NO}_3\text{-N}$ leaching due to 1) accumulation of $\text{NO}_3\text{-N}$ in the soil coupled with high runoff or drainage, 2) seasonal demands of plants, and 3) high levels and nonuniform waste dispersal of N by grazing livestock (Di and Cameron, 2002). For example, 60% to 90% of the N ingested by a cow is returned to the pasture, largely via urine, and is nonuniformly distributed (Haynes and Williams, 1993). These “patches” contain N levels well in excess of plant needs, thereby creating potential for $\text{NO}_3\text{-N}$ leaching when excess precipitation occurs.

Timing grazing to coincide with increased nutrient demands from forage is one method to reduce the transport of excessive nutrients to surface and/or ground waters. Stout et al. (1997) examined $\text{NO}_3\text{-N}$ losses from seasonal urine deposits on cool-season pastures in Pennsylvania. Loss increased during the year from 18% of that deposited in spring to 28% in summer and 31% in autumn. Soil type caused differences in that Hartleton Channery silt loam lost 41% to 56% of the $\text{NO}_3\text{-N}$, while Hagerstown silt loam lost only 16% to 19% (Stout et al., 1998). Part of the difference was attributed to increased plant growth and more N uptake on the Hagerstown soil. Based on these studies, Stout et al. (1997, 1998) point to the need to manage grazing to minimize $\text{NO}_3\text{-N}$ leaching particularly in autumn when



The literature suggests a role for rotational stocking in protecting water quantity and quality.”



In July 40% of the urine-N was recovered by plants, but in November recovery was negligible.”

plant growth slows and through the later winter and early spring before growth resumes.

Similarly, $\text{NO}_3\text{-N}$ levels were greater in subsurface flows from winter grazing and feeding areas as compared with summer-grazed areas in Ohio (Owens et al., 1983c). Plant uptake of urine-N declined linearly and soil levels increased linearly due to monthly urine-N applications between July and November (Cuttle and Bourne, 1993). In July 40% of the urine-N was recovered by plants, but in November recovery was negligible. Similarly, only 3% of the urine-N was found in the soil in July compared with 66% in November. This accumulated N was lost over the winter. When ^{15}N -labeled urine was applied to plots during May through October, the largest N losses occurred with late-season application due to decreases in N utilization rate by plants (Decau et al., 2003). Over a 2-yr period, small seasonal increases were seen in total-N and $\text{NO}_2^- + \text{NO}_3^-$ levels in a monitored stream due to early-season and late-season grazing compared with no grazing. There were higher levels of total P in the stream with all-season grazing compared with the other treatments (Scrimgeour and Kendall, 2002).

Sediment. Few studies have examined the effect of season and grazing deferment on sediment production and loss. In Ohio over 60% of sediment loss from grazed pasture occurred during November through April (Owens et al., 1997). Greatest losses occurred during March through June, and the smallest losses occurred from August through October. Estimated annual sediment losses were 2.3 Mg ha^{-1} when summer rotational stocking was combined with winter stocking and feeding on the same area, 0.15 Mg ha^{-1} with only summer rotational stocking, and $< 0.1 \text{ Mg ha}^{-1}$ with no grazing. McDowell et al. (2005) examined the effects of unrestricted grazing, grazing restricted to 3 h, and no grazing during wintering of dairy cattle. Sediment loads in runoff were six times greater with unrestricted grazing and two times greater from restricted grazing as compared with no grazing.

Pathogens. Since bacteria of fecal origin are mesophilic, it is expected that season and grazing deferment would impact populations. Numbers of *E. coli* in streams associated with

grazing and forestry land uses were greater during the warmer summer and autumn months than in winter and spring (Donnison et al., 2004). A similar trend occurred with fecal coliforms in sheep-grazed pastures in England (Hunter et al., 1999). Similarly, when pastures in the karst region of West Virginia were grazed during spring and summer, the fecal coliform levels in resurgent groundwater peaked in the summer, declined in autumn, and returned to pre-grazing levels during winter (Pasquarell and Boyer, 1995). With grazing deferment in Australia, McDowell et al. (2005) noted that *E. coli* levels in overland flow increased with unrestricted winter grazing by dairy cattle but not for grazing restricted to 3 h d^{-1} .

Hydrology

Although seasonal variation in precipitation, plant growth, and hence runoff and drainage occurs in pasturelands (Di and Cameron, 2002; NOAA, 2005), little research has examined the effects of season and grazing deferment on surface and subsurface hydrology. In Ohio pastures, $\geq 50\%$ of the November through April precipitation was routed to subsurface flow, but it was $\leq 20\%$ of that during May through October (Owens et al., 2003). This was mainly due to reduced evapotranspiration during the November through April dormant season. This changed water quality; greatest loss of nutrients occurred during the dormant season with surface waters largely transporting P, K, and total organic-C, while subsurface waters transported N, Ca, Mg, Na, and Cl (Owens et al., 1983b).

Stream Morphology

Excluding livestock completely from riparian areas improved streambank stability (Trimble, 1994; Owens et al., 1996; Zaines et al., 2008a), but few reports have examined the potential of limited grazing on morphological parameters. Scrimgeour and Kendall (2002, 2003) noted a 50% increase in bank stability and three to five times more vegetation when livestock were excluded from riparian areas as compared with allowing early- or late-season grazing. They concluded that use of deferred grazing was not likely to produce more stable banks or greater riparian vegetation.

Streambanks did not recover during the off-season from the erosive effects of grazing

TABLE 3.6. Water quality, hydrology, and streambank morphology responses to stocking method.

Response ¹	Comparison ²	Difference	Note	Reference
TP and sediment loss	C > R > N	TP: C was 1.3 times greater than R (5 cm); R (5 cm) was 2.8 times greater than N; C was 3.7 times greater than N	Percent ground cover was directly correlated to TP and sediment loss	Haan et al., 2006
		Sediment loss: C was 2 times greater than R		
TKN, NH ₄ , TKP, DRP, runoff	C = R	Not significant at $P \geq 0.10$	Pastures were subjected to broiler litter applications	Kuykendall et al., 1999a
TN, runoff volume	C > R	TN: C was 1.9–2.5 times greater than R	TN: Ground cover was less than 50% for C and about 100% for R	Owens and Shipitalo, 2009
		Runoff: C greater than R 75% of time	Runoff: Amount of winter vegetative cover indirectly correlated to runoff volumes	
FC	C > R	C was over 2 times greater than R for stream mean values	FC levels still exceeded water quality standards	Howell et al., 1995
Annual soil loss	C > R	C was 15.5 times greater than R	Increased runoff with C, attributed to increased soil compaction and decreased vegetation	Owens et al., 1997
Streambank erosion	C, R > N	C and R were 2–5 times greater than N	Consideration should also be given to constituents such as P in streambanks	Zaimes et al., 2008a
Turbidity, FC, fines, exposed streambanks	C > R	Turbidity: C was about 1.5 times greater than R;	Turbidity strongly correlated with TSS for studied streams	Sovell et al., 2000
		FC: C was about 2 times greater than R;		
		Exposed streambanks: C was about 9 times greater than R		
Fines (embeddedness), streambank erodability	C > R	Fines (embeddedness): C was about 2 times greater than R;	Streambank erosion significant source of sediment to streams	Lyons et al., 2000; Weigel et al., 2000
		Streambank erodability: C was about 1.5 times greater than R		

¹TP indicates total P; TKN, total Kjeldahl N; TKP, total Kjeldahl P; FC, fecal coliforms; TOC, total organic C; and COD, chemical oxygen demand. ²C indicates continuous stocking; R, rotational stocking; N, non-grazed.

(Agouridis et al., 2005b), suggesting other factors such as prior land use, soil types, and geology should be carefully examined before season of grazing deferment is discounted as a streambank management strategy. Since soil strength is decreased under saturated conditions, Bellows (2001) recommended that grazing of riparian areas be permitted only after streambanks “dried out.”

Summary and Recommendations: Season of Grazing and Deferment

The largest effects of grazing on water quality typically occurred during the dormant season (i.e., fall/winter months), particularly

NO₃-N leaching and sediment loss. However, the highest levels of fecal organisms were often found in water during the summer months when temperatures were warmest (Table 3.7). Similarly for hydrology, greater runoff rates occurred during the dormant season when evapotranspiration was lowest. Research on grazing management impacts on streambanks is limited, but results suggest that removal of livestock from riparian areas during periods of high soil saturation is warranted.

Winter feeding on pasture significantly alters water quality and hydrology, but more research

TABLE 3.7. Water quality, hydrology, and streambank morphology responses to season.

Parameter	Comparison ¹	Difference	Note	Reference
NO ₃ -N	A > Su > Sp	18% loss in Sp, 28% in Su, 31% in A	Differences attributed to plant uptake	Stout et al., 1997
NO ₃ -N	W > Su	W nearly twice Su	Subsurface flows	Owens et al., 1983c
Urine-N	Plant uptake: Su > A	Plant uptake: 40% in Su, negligible in A;	Linear decline in plant uptake and linear increase in soil levels	Cuttle and Bourne, 1993
	Soil levels: A > Su	Soil levels: 3% in Su, 66% in A		
¹⁵ N-labeled urine	Plant uptake: Sp > A	Average plant uptake: 62% Sp, 17% A	Uptake by plants varied with soil type	Decau et al., 2003
Sediment	Late A, W, and early Sp > late Sp, S, and early A	Accounted for over 60% of loss	Greater losses during dormant season	Owens et al., 1997
Escherichia coli	Su and A > Sp and W	2–3 log difference	Attributed to warmer temperatures	Donnison et al., 2004
Fecal coliforms	Su > A; recovery in W	August peak with decline until November	Seasonal variation related to presence/absence of cattle, amount of soil water present, bacterial storage in soil, and bacterial die-off rates	Pasquarell and Boyer, 1995
Subsurface flow	Late A, W, and early Sp > late Sp, S, and early A	Late A, W, and early Sp (dormant season): over 50% from precipitation;	Greater amounts of precipitation becoming subsurface flow during dormant season	Owens et al., 2003
		Late Sp, S, and early A (growing season): 20% or less from precipitation		

¹Sp indicates spring (March–May); Su, summer (June–August); A, autumn (September–November); and W, winter (December–February).

is needed to develop management strategies to minimize effects on surface and subsurface waters. Excluding grazing livestock from riparian areas during sensitive time periods, e.g., when evapotranspiration levels are at their lowest, is a good option, while cattle still graze and can be fed hay on nonriparian pastures during the dormant period. Best management practices need to be developed for these winter feeding areas to minimize environmental impacts.

Importantly, complete livestock exclusion from portions of pasturelands, such as riparian areas, may not be the best solution for the ecosystem. Some level of vegetation disturbance is likely needed to maintain or improve biodiversity on pasturelands (Connell, 1978). However, questions remain as to the level and timing of such disturbances and what biodiversity component is the benefactor. Such knowledge will allow for improved management of

pasturelands and their riparian areas to support livestock production and increase diversity of desired plant, mammalian, avian, and benthic species.

TYPE AND CLASS OF LIVESTOCK

A large body of literature describes the environmental impact of beef cattle on grazing lands, particularly with regard to grazing management and livestock distribution (Clark, 1998; Belsky et al., 1999; Agouridis et al., 2005a), but little is available for dairy cattle, horses, sheep, or goats. A review of the literature revealed a notable lack of research in many areas related to environmental impact due to livestock type. Most available research focused on effects of pathogenic organisms on water quality.

Animal Size

Larger animals exert more pressure on the soil than smaller animals, leading to altered soil

structure (Bilotta et al., 2007), which, in turn, affects both hydrology and erosion processes on pastures and along streambanks (Trimble and Mendel, 1995; Belsky et al., 1999; Agouridis et al., 2005a). The differing types of livestock also produce differing amounts of urine and manure, which vary in microbial content and nutrient concentration. Thus, it is expected that animals of different sizes will have different effects on water and the environment (ASABE, 2005; Weaver et al., 2005).

Grazing Characteristics

Preferred location of grazing, biting mechanisms, and amount of forage consumed daily vary among types of livestock. Cattle typically prefer to forage in riparian areas and avoid steep slopes (Marlow and Pognacnik, 1986; Evans, 1998; USDA-NRCS, 2003), whereas sheep graze predominately in the uplands (Platts, 1981; Arnold, 1984; Glimp and Swanson, 1994). Cattle also tend to damage the riparian environment to a greater extent than horses (Trimble and Mendel, 1995; Menard et al., 2002).

SURFACE WATER QUALITY

Streambank Erosion. Different types of livestock may alter streambanks or riparian areas differently due to grazing preferences. For example, cattle-grazed pastures had significantly more streambank erosion than horse-grazed pastures (Zaimes et al., 2006). Sheep prefer to graze uplands but will graze riparian areas if stocked at high rates (Platts, 1981). At high stocking rates, sheep grazing riparian areas led to increased stream width by four-fold and reduced mean depth to 20% of previous levels. This change in channel morphology resulted in increased water temperature.

Pathogenic Organisms. Livestock producers often allow access to open water bodies such as streams and ponds as a source of drinking water, resulting in an increased level of activity along the water's edge. Manure may contain pathogenic organisms such as *Cryptosporidium* spp., *Giardia* spp., or *E. coli*, which can be carried by runoff into nearby surface waters, and even infiltrate to ground waters during rainfall events (Niemi and Niemi, 1991). Furthermore, these pathogens that enter surface waters may be resuspended by the higher

stream flows produced during runoff-producing rainfall events (Stephenson and Rychert, 1982).

Livestock wastes serve as a source of both *Giardia* and *Cryptosporidium* on pastures. *Giardia* was found in 38% of sheep, 29% of cattle, and 20% of the horse waste sampled (Olson et al., 1997). *Cryptosporidium* was found in 23% of pastured sheep, 20% of pastured cattle, 17% of pastured horses, 50% of manure from beef cattle feedlot pens, and 68% of the manure from dairies (Anderson, 1991, 1998). Dairies in the eastern USA had a higher percentage of positive samples than those in the western USA, perhaps due to greater pasture use and higher rainfall in the East resulting in billions of oocysts being washed into surface waters. A "hydrologic connection" was proposed as the primary means for transfer of organisms to the water from land deposits of the manure (Atwill et al., 1999). Overland flow accounted for 99.8% of oocyst transport, and only 0.2% was attributed to subsurface flow.

Animal manure is a major source of *E. coli* O157:H7, which has been isolated both in depositions and in rectal samples from cattle, sheep, horses, and wildlife (Wang et al., 1996; Renter et al., 2004). *E. coli* O157:H7 was detected in 16% of rectally retrieved manure samples in the United Kingdom and 1.9% to 5% in the USA (Sargeant et al., 2000; Oliver et al., 2005). Bovine manure, especially from dairy cattle, contains the highest concentration of *E. coli* O157:H7 among livestock (Wang et al., 1996). Since most enteric organisms are capable of fermenting lactose, lactating cows provide an optimal environment for the organism. *E. coli* O157:H7 was four times more prevalent in deposits of fresh manure from calves than adult cattle (Renter et al., 2004). Drinking water is thought to be a major contributor to the re-inoculation and subsequent excretion of *E. coli* O157:H7 in adult cattle (Wang et al., 1996).

Nutrients. Concentrations of nutrients are related to the type of manure and urine excreted (e.g., animal type) and with the volume (e.g., animal size). In dairy pastures in central Pennsylvania, as the amount of urine applied increased, the volume of urine leached increased, indicating that larger livestock are



Livestock wastes serve as a source of both *Giardia* and *Cryptosporidium* on pastures.”



As cattle frequent an area, they remove vegetation, concentrate waste, and may compact the soil, providing ideal conditions for runoff contributions to waterways”

TABLE 3.8. Range of pathogens sizes in comparison to soil particles sizes.

Soil particle size ¹		Pathogen class ²		
Classification	Diameter (µm)	Classification	Diameter (µm)	Examples
Sand	50–2000	Protozoa	5–1000	<i>Cryptosporidium</i> and <i>Giardia</i>
Silt	2–50	Bacteria	0.5–6	<i>Escherichia coli</i>
Clay	< 2	Viruses	0.02–0.75	Rotavirus and enterovirus

¹USDA Textural Classification (McCuen, 2005). ²Adapted from Oliver et al. (2005).

likely associated with greater NO₃-N leaching from pastures (Stout, 2003).

Groundwater Quality

Pathogenic Organisms. The depth to which pathogens can travel depends on both the organism’s dimensions and the soil matrix (Table 3.8) (Oliver et al., 2005). Protozoa such as *Cryptosporidium* spp. and *Giardia* spp., which typically range in diameter from 3 µm to 1 mm, can pass through sand and coarse silt particles, but face greater difficulty traveling through a soil matrix comprised largely of clay particles. Hence, soils comprised largely of clay with low bulk density are more effective at removing protozoa, and likely bacteria, than are high bulk density, sandy soils (Atwill et al., 2002).

Nutrients. Dairy cattle on pasture caused a 60% to 70% increase in the NO₃-N load to a cave stream in southwestern West Virginia (Boyer and Pasquarell, 1996). Concentrations of NO₃-N were also high in an area where beef cattle congregated for shade and water. These results indicate that groundwater contamination is particularly a concern in karst terrain where downward flow readily occurs.

Summary and Recommendations: Type and Class of Livestock

Although pasturelands support a sizeable percentage of the cattle, horses, sheep, and goats in humid areas of the USA, little research has been done to assess their relative influence on water quality, hydrology, riparian health, and watershed function. Most of the research has been conducted with beef cattle and particularly on effects of livestock distribution. Few studies have assessed the effects of livestock type and age on water quality, hydrology, riparian health, and watershed function. From the comparative studies conducted, results suggest that 1) young calves are a greater source of pathogens such as *Cryptosporidium*, *Giardia*,

and *E. coli* O157:H7 than adult cattle; 2) dairy cattle have a higher presence of such pathogens than other livestock; and 3) dairy cattle make a greater contribution to N and pathogen loading of waterways than other livestock.

Research is needed to better assess the effects of animal size, manure characteristics, and microbial differences on the environment. In particular, lacking is research on effects of horses and sheep. The carrying capacity of a pasture needs to be thought of in new terms, not just forage based but also environment based (Evans, 1998). By better understanding the effects of different types of livestock at different ages on the environment, the negative effects can be mitigated by developing best management practices such as riparian buffers and refining grazing methods to prevent problems such as overgrazing.

LIVESTOCK DISTRIBUTION IN THE LANDSCAPE

Water sources, shade sources, topography, fencing, salt and feed sources, and season affect the distribution of livestock on pasturelands. This results in unequal distribution of nutrients, bacteria, and other contaminants in the pasture (Agouridis et al., 2005b). As cattle frequent an area, they remove vegetation, concentrate waste, and may compact the soil, providing ideal conditions for runoff contributions to waterways, hence influencing water quality and quantity as well as riparian and watershed function (CAST, 2002). Luring cattle away from riparian areas is an important goal of prescribed grazing and can decrease nutrient, bacteria, sediment, and other pollutant loads to waterways.

Much research has been conducted in western USA rangelands, where researchers have noted that livestock grazing alters watershed hydrology, stream morphology, soil structure,

water quality, and riparian habitat (Belsky et al., 1999; Agouridis et al., 2005a). Knowledge gained from rangeland studies is helpful; however, the transferability of the results to pasturelands in the eastern USA is uncertain because plant species and precipitation magnitude and intensity are markedly different (Hershfield, 1961; Trimble and Mendel, 1995). Responses of watersheds, stream systems, and associated riparian areas to grazing are not universal (Juracek and Fitzpatrick, 2003), even among pasturelands in the eastern USA, and thus prescribed grazing practices are not immediately transferable and cannot be expected to elicit similar responses for a range of ecosystems (Sarr, 2002). An understanding of local riparian systems and the functions they perform is a necessary step in managing livestock grazing (Fitch and Adams, 1998).

This section addresses management interventions designed to alter livestock distribution in the landscape, with the goal of achieving production while maintaining or improving water quantity and quality. These interventions include providing alternate water and shade sources and use of exclusion fencing and riparian buffers.

Alternate Water Sources

Few studies have examined the ability of alternate water sources (e.g., water trough) to affect grazing distribution patterns on pasturelands, and thus affect water quality, hydrology, morphology, or habitat. Among existing studies, results are mixed with regard to the effectiveness of alternate water sources. For example, installation of a water trough in Virginia reduced amount of time cattle spent in the stream by 89% and in the riparian area by 51% (Sheffield et al., 1997). In Georgia, even when the area of nonriparian shade was small, a water trough reduced the amount of time cattle spent in the riparian area (Byers et al., 2005). Conversely, research in North Carolina and Alabama showed no change in time cattle spent in riparian areas following trough installation (Line et al., 2000; Zuo and Miller-Goodman, 2004) or that a trough did not eliminate continued use of riparian areas for lounging (James et al., 2007). Ambient temperature and the degree to which livestock rely on the riparian area for cooling may contribute to these different findings. During the warm

season in humid environments, livestock increase use of riparian areas for cooling during midday and the afternoon (Zuo and Miller-Goodman, 2004). Additionally, livestock age may be important, as older cows seek heat relief by frequenting streams rather than drinking water from a trough (Line et al., 2000).

Water Quality. Installing a water trough in the pasture improved water quality in three Virginia streams (Sheffield et al., 1997). Cattle spent 89% less time drinking from the streams, resulting in reductions in total suspended solids (90%), total N (54%), total P (81%), sediment-bound P (75%), fecal coliforms (51%), and fecal streptococci (71%). Having water troughs available reduced median base flow loads for dissolved reactive P by 85%, total P by 57%, total suspended solids by 95%, and *E. coli* by 95% (Byers et al., 2005). Conversely, no significant water quality improvement accrued from use of an alternate water source in one study in North Carolina (Line et al., 2000).

Stream Morphology. Use of an alternate water source did not reduce streambank erosion in a riparian area grazed by cattle in Kentucky (Agouridis et al., 2005b). In contrast, a 77% reduction in streambank loss was observed after installing a water trough in Virginia (Sheffield et al., 1997). The difference in results may be due to varying weather conditions, stream characteristics, and/or stocking rates, which differed among experiments.

Shade Sources

Shading, both natural and artificial, reduced the heat load to cattle by 1400 kJ h⁻¹ (Ittner et al., 1951) and can be an effective modifier of livestock distribution. In warm weather, livestock spend a disproportionate amount of time in shade (Dubeux et al., 2009), and areas around shade were a more powerful draw to livestock than areas around water troughs (Mathews et al., 1999). Addition of artificial shade in the greater pasture did not alter time cattle spent in riparian areas containing large trees (Zuo and Miller-Goodman, 2004). They concluded that if natural shade was accessible, cattle would not use artificial shade either alone or in combination with an alternate water source. In Georgia establishment of nonriparian shade is advocated as a means of



if natural shade was accessible, cattle would not use artificial shade either alone or in combination with an alternate water source.”



Unrestricted grazing of cattle has been linked to water quality impairments, streambank erosion, and in-stream habitat alterations in pasturelands.”

luring cattle away from riparian areas (Byers et al., 2005). No study was found that evaluated effects of alternate shade sources on water quality and hydrologic, morphologic, and biotic responses.

Exclusion Fencing

Several studies have examined either the effects of unrestricted grazing on riparian ecosystems and water quality or on the effectiveness of exclusion fencing to mitigate grazing effects on riparian areas. Unrestricted grazing of cattle has been linked to water quality impairments, streambank erosion, and in-stream habitat alterations in pasturelands. Relative to exclusion, unrestricted cattle access resulted in a four-fold increase in total Kjeldahl N, five-fold increase in total P, four-fold increase in ammonium, 11-fold increase in total suspended solids, 13-fold increase in turbidity, and 36-fold increase in *E. coli* in stream water (Vidon et al., 2008). Increases in loads of dissolved reactive-P, total P, and total suspended solids were found during storm events and when cattle were permitted free access to the stream; the latter also increased *E. coli* load (Byers et al., 2005).

Streams with riparian grazing had greater amounts of eroding banks, greater percentages of suspended sediment, greater water temperatures, larger reductions in invertebrate food sources, and lower density of macrobenthos and brown trout when compared with streams not affected by grazing (Wohl and Carline, 1996). Population declines were attributed to the increased sediment loads and composition of suspended sediments in the stream.

Fenced riparian buffers in Wisconsin can be grazed for a short duration during selective periods (up to 20 d per season; Bellows, 2001) and still minimize grazing damage. This practice allows farmers to utilize production from the riparian pasture and could also promote propagation of sensitive species such as buffalo clover, which typically grows along the edge between forest canopy and grasslands and requires periodic disturbance (USFW, 2003).

Water Quality. Lack of exclusion fencing permitted livestock to deposit urine and feces directly into streams resulting in elevated N

and P levels in Maryland (Shirmohammadi et al., 1997). In the Cannonsville, New York, watershed, 11,000 dairy cattle deposited 7% of all fecal deposits into pasture streams. This was a total deposition of 2800 kg of P in streams, and an additional 5600 kg of P was deposited within 10 m of streams (James et al., 2007). Recent efforts to exclude pastured cattle from streams as part of the Conservation Reserve Enhancement Program have already reduced in-stream deposition of fecal P by 32% (James et al., 2007). Cattle exclusion reduced mass loads of total-N fractions in the stream by 21% to 52% compared with grazed pasture in 2 of 3 yr in Alberta, Canada (Miller et al., 2010).

Nitrate plus nitrite (33%), total Kjeldahl N (78%), total P (76%), and sediment loads (82%) decreased following the installation of exclusion fencing and establishment of a riparian buffer in North Carolina (Line et al., 2000). They theorized that continued maturation of trees and other vegetation in the riparian strip increased N removal efficiency. The fenced buffer also decreased fecal coliforms (66%), enterococci (57%), turbidity (49%), and suspended sediment (60%) in the stream. A 20% to 31% reduction in total-N and a 17% to 26% reduction in suspended sediment at low-flow conditions were measured after installing exclusion fencing (Galeone, 2000).

Exclusion fencing reduced total load of suspended solids and N and P constituents due to reduced streambank erosion. Suspended sediment concentrations were reduced by 47% to 87% for base flow conditions following exclusion fencing, bank stabilization, and installation of rock-lined stream crossings along two Pennsylvania streams (Carline and Walsh, 2007). The decrease in concentration of suspended sediment was attributed largely to reduction in bank erosion and to a vegetation increase of nearly 50% following riparian restoration efforts. Concentrations of total suspended solids decreased by 75% to 83% at the study sites.

Cattle were identified as the primary source of steroid excretion in the USA, accounting for over 90% of the estrogens and over 40% of the androgens released yearly (Lange et al., 2002). The majority of the estrogen was excreted by pregnant cows (Lange et al., 2002; Shore and

Shemesh, 2003). Research regarding livestock distribution patterns in relation to hormone levels is sparse. Kolodziej and Sedlak (2007) detected steroids in 86% of samples from a California stream with unrestricted cattle access. They concluded that use of exclusion fencing to limit direct deposition of wastes into streams should be considered.

Limiting manure deposition in riparian areas reduces bacterial loads to streams. Laboratory experiments using a rainfall simulator showed a 95% reduction in bacterial loads if there was a minimum distance of about 2 m between the feces and the stream. Fecal bacteria can survive in manure deposits for over 100 d (Wang et al., 2002); thus the time horizon for potential introduction to a waterway, whether surface or subsurface, is lengthy. Once in the stream, bacteria survive in the bottom sediments, which function as reservoirs for the organisms (Van Donsel and Gelreich, 1971; Stephenson and Rychert, 1982). Clay-sized bottom sediments have been linked to greater survival rates (Burton et al., 1987; Sherer et al., 1992; Howell et al., 1995), a fact needing careful consideration in light of the increased sediment loads attributed to grazing.

Hydrology. Few studies have been conducted to determine changes in water quantity as a result of implementing exclusion fencing. Establishment of a 16-m wide riparian buffer protected by exclusion fencing reduced water discharge to the stream due to increased levels of evapotranspiration and infiltration of the riparian buffer while soil bulk density decreased and hydraulic conductivity increased (Line et al., 2000). These results correspond to work by Sartz and Tolsted (1974), who linked higher runoff volumes and peak flows with grazing. Following animal removal, runoff volumes returned to non-grazed conditions within a 3-yr period, which was attributed to vegetative recovery and improved infiltration. Grazing was simulated on runoff plots, and runoff decreased as vegetation and litter coverage increased (Hofmann and Ries, 1991). Grazing was also simulated on poorly and well-drained soils, and runoff volume generated from lightly grazed plots on poorly drained soils was similar to heavily grazed plots on well-drained soils (Butler et al., 2008). They concluded that grazing should be limited in riparian areas with poorly

drained soils as the runoff volume was linked to high levels of exported $\text{NH}_4\text{-N}$ and total N.

Stream Morphology. Streams are not universal in their response to grazing or in their ability to naturally recover once grazing has stopped (Sarr, 2002). Therefore, the decision to install exclusion fencing should be based in part on the geomorphic characteristics of the stream. While monitoring continuously stocked pastureland in Ohio, Owens et al. (1989) found grazing increased sediment transport and

Fencing can be used to exclude livestock from streams and streambanks. Photo by Tim McCabe, USDA-NRCS.





A three- to six-fold increase in streambank erosion was associated with unrestricted grazing”

indicated exclusion fencing may be needed. When exclusion fencing was installed, annual sediment concentration was reduced by 57% and soil loss by 41% from 2.5 to 1.4 Mg ha⁻¹. A three- to six-fold increase in streambank erosion was associated with unrestricted grazing as compared with streambanks protected by exclusion fencing. This translated into an estimated net erosion rate of 40 m³ km⁻¹ yr⁻¹ of grazed streambank (Trimble, 1994).

Continuous, unrestricted, year-long stocking at high stocking rates in the eastern USA was implicated as a major factor causing stream widening (Trimble, 1994). Streambank erosion rates of 22 to 50 mm yr⁻¹ were measured when adjacent areas were grazed; this equates to an estimated erosion rate of 6 to 61 Mg km⁻¹ yr⁻¹ (Zaimes et al., 2008a). Phosphorus losses associated with the streambank materials were 3 to 34 kg km⁻¹ yr⁻¹. No change was seen in stream cross-sectional area between reaches with excluded riparian areas and those without (Agouridis et al., 2005b); however, along the unrestricted reaches, localized streambank erosion occurred quickly in areas with frequent cattle movement and slowly in areas where cattle loitered.

Other Livestock Distribution Options

Livestock distribution options such as supplemental feeding (e.g., salt, mineral, hay) and topography have not been examined in pasturelands, but supplemental feeding practices on rangeland can reduce cattle impacts in riparian areas (McInnis and McIver, 2001; Porath et al., 2002). Topography also affects cattle distribution (USDA-NRCS, 2003), and linkages have been found between slope and forage utilization rate.

Summary and Recommendations: Livestock Distribution in the Landscape

Most livestock distribution on pasturelands literature addresses exclusion fencing and riparian buffers, with relatively little research on effects of shade, alternate water sources, and supplemental feeding. Research from rangeland systems suggests that each of these could be a beneficial best management practice for pasturelands. While exclusion fencing and riparian buffers can reduce negative effects of grazing livestock on stream ecosystems, farmers are often reluctant to adopt the practices

because of costs of installing an alternate water source and maintaining fencing (Barao, 1992; Soto-Grajales, 2002; Agouridis et al., 2005a; Zaimes et al., 2008a).

Adoption of best management practices is positively linked to information access and social networks with other farmers and agencies (Prokopy et al., 2008). Farmers who are most likely to incorporate management practices were younger with higher education levels and had larger acreage farms, greater amount of capital, and access to a larger labor supply. Such knowledge should aid conservationists in extending these practices to producers.

Riparian buffers are a component of exclusion fencing, but can also be used independently as a management tool. Riparian pasture can be grazed for up to 20 d per season with minimal damage, which allows farmers to utilize the area for production, while improving forage species mix and water quality (Bellows, 2001). Research is needed to understand the effects of livestock distribution on shallow groundwater quality and recharge, particularly in karst areas that are prevalent in pasturelands of the eastern USA (Veni, 2002). As noted by Owens et al. (2008), groundwater discharge has an appreciable effect on stream quality and flow. Thus, in smaller watersheds, where a large percentage of land use may be in one practice such as grazing, land use may have a greater effect on both stream water quality and flow.

PURPOSE 4: REDUCE ACCELERATED SOIL EROSION, AND MAINTAIN OR IMPROVE SOIL CONDITION

Grazinglands typically have greater soil organic matter concentration than neighboring crop lands (Franzluebbbers, 2005; Johnson et al., 2005). Soil organic matter is an ecological cornerstone by providing nutrients to plants, stability and water-holding capacity to soil, and energy to soil microorganisms. Through soil microbial processing of plant-derived organic matter, a long-term reservoir of nutrients accumulates along with gradual mineralization such that eutrophication of receiving water bodies is avoided (Franzluebbbers et al., 2000a; Franzluebbbers, 2008). Additionally, soil aggregates are built to store more

water for plant uptake and to withstand degenerative forces of erosion and compaction (Franzluebbers et al., 2000b, 2001). Carbon and N are organically sequestered in soil to limit greenhouse gas emissions (Franzluebbers and Stuedemann, 2001, 2002), and a diversity of soil organism communities develop to stabilize ecosystems against various perturbations (Franzluebbers et al., 1999; Jangid et al., 2008).

GRAZING INTENSITY

Optimum grazing intensity on pastures is needed to maintain vigorous vegetative cover, which is a key determinant in controlling soil erosion. High stocking rate results in a greater proportion of forage consumed than low stocking rate, and soil loss is expected to be greater under high than low stocking rate due to less vegetative and residue cover of the soil. The stocking rate at which soil loss exceeds a critical threshold of sustainability has not been determined, in general or in specific regions. However, high runoff and soil erosion can occur even on pastures with low stocking rate if vegetative cover is reduced due to animal behavior patterns, e.g., in loafing areas, along walking trails, and in animal-handling zones. Animal behavior is a key variable that makes grazinglands a more complex arena for ecological investigation than croplands because in croplands production and harvest are more uniformly distributed within fields.

Literature describing soil erosion and soil condition responses to stocking rate in the humid regions of the USA is sparse. Far more data are available to compare soil erosion and soil condition between hay harvested and grazed perennial grass systems or cropped and perennial grass systems (Barnett et al., 1972; Giddens and Barnett, 1980; Sharpley and Smith, 1994; Franzluebbers et al., 2000a, 2000b; Sharpley and Kleinman, 2003; Causarano et al., 2008).

In Oklahoma, Potter et al. (2001) reported soil organic C and N at the end of 10 yr of grazing with a range of stocking rates on two sites of degraded pasture. Pastures were initially dominated by annual ragweed and gradually became dominated by native grasses. On a Durant loam (30% ± 5% clay; Udertic

Argiustoll), soil organic-C declined with increasing stocking rate (Fig. 3.6) whereas on the neighboring Teller silt loam (17% ± 5% clay; Udic Argiustoll), soil organic-C increased slightly. These inconsistent responses occurred both within surface soil (0- to 30-cm depth), and deeper in the soil profile (to 60-cm depth). Stocking rate had a similar effect on total soil-N.

On a landscape dominated by Madison-Cecil-Pacolet soils (Typic Kanhapludults) in Georgia, a 12-yr grazing trial on Coastal bermudagrass (years 1–5) and bermudagrass overseeded with tall fescue (years 6–12) showed soil organic-C was maximum at a moderate stocking rate (Fig. 3.7). Response of soil organic-C and N deeper in the profile showed similar responses at the end of 5 yr (Franzluebbers and Stuedemann, 2005) and were even more pronounced at the end of 12 yr (Franzluebbers and Stuedemann, 2009). These results suggest that moderate to heavy stocking will optimize soil organic-C and N fractions compared with nonharvested or hayed management.

In Georgia total and particulate organic N in the 0- to 6-cm depth were greater under high than low stocking rate at the end of 4 yr (Franzluebbers and Stuedemann, 2001), but at the end of 12 yr were not different between stocking rates throughout the soil profile (Franzluebbers and Stuedemann, 2009). Extractable P, K, and Mg were not different

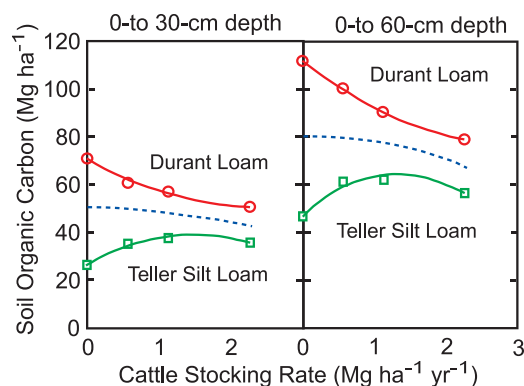


FIGURE 3.6. Content of soil organic-C at two depths following 10 yr of grazing management with different cattle stocking rates on Durant loam and Teller silt loam soils near Marietta, Oklahoma. Non-grazed pastures were achieved using exclosures. Adapted from Potter et al. (2001).



Optimum grazing intensity on pastures is needed to maintain vigorous vegetative cover, which is a key determinant in controlling soil erosion.”



nutrient cycling within the pasture makes it possible to avoid the high demand for continuous nutrient input with hay harvest.”

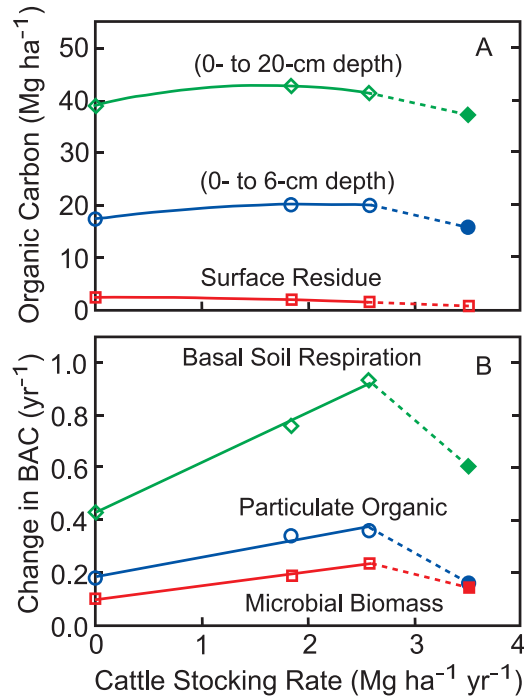


FIGURE 3.7. (A) Content of soil and surface residue organic-C at the end of 5 yr of management. Adapted from Franzluebbers et al. (2001). (B) Relative annual change from baseline (0.0) in biologically active carbon (BAC) fractions of soil organic matter at a depth of 0–6 cm during 4 yr of management on Typic Kanhapludults near Farmington, Georgia. For both A and B, open symbols indicate no grazing and two stocking rates; filled symbols, forage removed as hay. Adapted from Franzluebbers and Stuedemann (2003a).

between stocking rate treatments during the first 5 yr, but tended to be somewhat greater with grazing than without grazing and much greater with grazing than with hay harvest (Fig. 3.8). Residual inorganic N in the upper and lower rooting zone followed the same pattern as other soil nutrients, but tended to decline with increasing stocking rate in samples below the rooting zone (Fig. 3.8). These results suggest that moderate to heavy stocking can improve soil chemical properties relative to nonharvested grass and that nutrient cycling within the pasture makes it possible to avoid the high demand for continuous nutrient input with hay harvest. Plant-essential (i.e., Mn, Cu, and Zn) and nonessential elements (i.e., Cd, Cr, and Pb) accumulated with cattle grazing compared with nonharvested or hayed areas. This indicated greater sorption of trace elements by soil organic matter, especially as

related to the dynamics of biologically active fractions (Franzluebbers et al., 2004b).

Stocking rate effects on soil organic matter and soil condition in the humid region of the USA have been determined to a much lesser extent than in the semiarid and arid regions of the USA (Milchunas and Lauenroth, 1993; Conant and Paustian, 2002; Derner et al., 2006), as well as in humid and arid regions of other countries (Greenwood and McKenzie, 2001; Bilotta et al., 2007). In a review of stocking rate effects on soil aggregation, Greenwood and McKenzie (2001) reported that most studies ($n = 8$; outside the humid USA) found animal grazing generally reduced aggregation. Most changes were small at low stocking rate and greater with intensive treading, which causes compaction. Greenwood and McKenzie (2001) cited 22 studies from around the world, most of which found an increase in bulk density with increased treading.

Although increased stocking rate generally compacts soil, the extent may be mitigated by controlling the timing and intensity of grazing and knowing whether the soil surface is firm enough to withstand the traffic. Penetration resistance may be a more discerning soil response to the impact of animal treading than soil aggregation or bulk density. Long-term studies are needed on stocking rates with measurements of soil penetration resistance, bulk density, and aggregation at different times of the year and at different durations of stocking rate treatments.

Summary and Recommendations: Grazing Intensity

Establishment of pastures helps reduce soil erosion and improves soil quality on previously degraded cropland. Limited evidence also shows that grazing at moderate levels can further increase environmental benefits, in addition to the important economic return to producers. Some evidence in the humid USA suggests that overgrazing can lead to increased soil erosion, and reduction in soil condition. Literature outside the humid USA supports the concept that excessive stocking rate leads to increasing soil erosion and declining soil quality. A great need exists for establishing a comprehensive grazing intensity study (soil, water, air,

plant, and animal responses) in one or more locations within the humid USA.

STOCKING METHOD

Rotational stocking in the humid USA should provide more uniform forage consumption across pastures and allow sufficient rest of forages to promote greater production (Chestnut et al., 1992; Hoveland et al., 1997). Pastures with greater plant production via an improved stocking method would be expected to have lower soil erosion and greater soil quality. While intuitive, essentially no data are available in the scientific literature from the humid region of the USA to support a claim for positive effects of rotational stocking alone, or in comparison with continuous stocking, on soil erosion or soil condition.

Summary and Recommendations: Stocking Method

An urgent need exists to obtain information on how and to what extent stocking method affects soil erosion, soil condition, and soil C sequestration in the humid USA, especially since recommendations without a science base could mislead landowners, policy makers, and agro-environmental stakeholders. Although scientific rationale may be limited for additional studies comparing stocking methods from a plant or animal response perspective, this is not the case regarding soil and environmental issues. This deficit in information suggests a need for such comparisons at several strategically selected sites throughout the humid pastureland regions of the USA. Teams of the best scientists nationally in the areas of soil, plant, water, wildlife, and animal response should be assembled to coordinate these studies. If so, the treatment selection and response measurement should be done in a manner that will generate conclusive and transferable results as well as data for modeling. Conclusions from this comprehensive work would serve as an authoritative guide to future prescribed grazing recommendations.

SEASON OF GRAZING AND DEFERMENT

The capacity of soil to withstand compaction forces of animal treading, resulting in significant deformation, destabilization, and

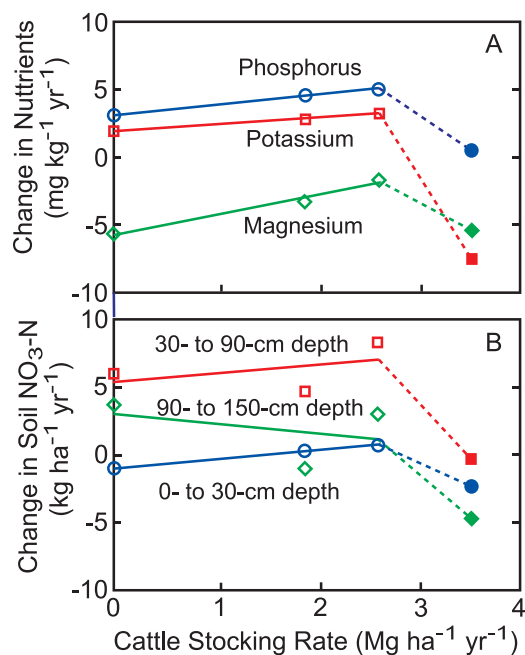


FIGURE 3.8. (A) Effects of 5 yr of grazing management on changes from the baseline condition (0) of extractable phosphorus, potassium, and magnesium in the surface 15 cm of Typic Kanhapludults near Farmington, Georgia. Adapted from Franzluebbers et al. (2002, 2004a). (B) Changes in residual NO₃-N in the upper rooting zone (0- to 30-cm depth), lower rooting zone (30- to 90-cm depth), and below the rooting zone (90- to 150-cm depth). Adapted from Franzluebbers and Stuedemann (2003b). For both A and B, open symbols indicate no grazing and two stocking rates; filled symbols, forage removed as hay.

loss of infiltration capacity, can be exceeded especially under wet conditions (Bilotta et al., 2007). Soil can be expected to be saturated during much of the winter in the southeastern USA and in the spring in the central and northeastern USA. These seasons are therefore the most vulnerable times for soil to experience severe animal trampling effects. Intuitively, deferring grazing to periods of limited active forage growth (e.g., winter and spring) might contribute to increased soil compaction. However, allowing forage to accumulate to a high level prior to grazing might be beneficial to controlling erosion by providing a longer period of forage and residue cover. Grazing of winter cover crops may also be an effective farm-diversity strategy, but the effects on soil erosion control and soil condition need to be quantified.



Organic matter-rich surface soil absorbs compactive forces much like a sponge, often rebounding in volume once forces are removed.”

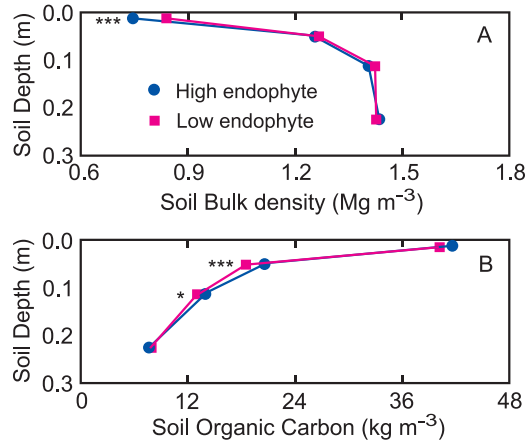


FIGURE 3.9. Depth distribution of soil bulk density (A) and soil organic carbon (B) at the end of 8 to 15 yr of grazing tall fescue containing low or high levels of endophyte infection on a Cecil sandy loam (Typic Kanhapludult) near Watkinsville, Georgia. Adapted from Franzluebbers et al. (1999). * and *** indicate means at that depth are different at the 0.05 and 0.001 probability levels, respectively.

In the southern USA, perennial cool-season grasses are often grazed during late winter and throughout spring during typically wet conditions. However, because of active forage growth, soil can also dry quickly, and trampling may not always cause damage. In Georgia soil organic-C and N were greater under long-term stands of cool-season tall fescue (typically grazed in spring and autumn) than under warm-season bermudagrass (typically grazed in summer) (Franzluebbers et al., 2000a). Soil bulk density under grazed tall fescue on Cecil sandy loam (Typic Kanhapludult) in Georgia did not show signs of excessive compaction, partly due to the long-term accumulation of soil organic matter at the soil surface (Fig. 3.9), which mitigated compactive forces. Organic matter-rich surface soil absorbs compactive forces much like a sponge, often rebounding in volume once forces are removed. Effects of winter grazing of deferred growth may be different in colder areas; frozen soil may resist compaction, but nutrient runoff may become more important (Clark et al., 2004).

Annual cool-season forages are often planted as a cover crop following summer crops or sod-seeded into perennial grass pastures in the southeastern USA. On a Typic Kanhapludult in

Georgia, soil bulk density at the end of 3 yr of winter grazing of rye by stocker cattle was the same (1.50 Mg m^{-3}) as when the cover crop was not grazed (both following full-season soybean) in a system using conventional tillage to remove compaction on a biannual basis (Tollner et al., 1990). However, when no-tillage management was used every year the bulk density was greater (1.60 vs. 1.52 Mg m^{-3}) when the cover crop was grazed than not grazed.

In a pasture-crop rotation study in Georgia, soil bulk density during 5 yr of winter grazing of rye by cow-calf pairs was not different from that of non-grazed winter cover-cropping (Fig. 3.10). Soil aggregation and penetration resistance were also not affected by grazing of cover crops. Water infiltration was reduced 28% by grazing of winter cover crop compared with non-grazed rye, but was reduced only 19% by grazing of summer cover crop compared with non-grazed pearl millet (Franzluebbers and Stuedemann, 2008b). Soil organic-C and N fractions were little affected by grazing of cover crops, in either summer or winter (Franzluebbers and Stuedemann, 2008a).

In Coastal Plain soils prone to hardpan development in the E horizon, soil compaction in long-term cropped soils is a continual concern due to inhibition of adequate root penetration deep into the soil profile. Introducing cattle grazing onto winter wheat or cover crops has led to soil compaction and restricted plant growth. On a Plinthic Paleudult in South Carolina, stocker cattle grazing winter wheat planted after disking and chisel-plowing resulted in greater soil penetration resistance with a linear increase related to grazing duration (Worrell et al., 1992). Wheat grain yield declined with longer grazing time, but cattle weight gain increased. On a Plinthic Kandiudult in Alabama, soil hardpan development was alleviated best with paratilling, even with winter grazing of cover crops following cotton or peanut in summer (Siri-Prieto et al., 2007).

On three soils in Oklahoma (Mollic Albaqualf and two Udic Argiustolls), soil bulk density and penetration resistance were greater following grazing of wheat (conventionally tilled) to early joint stage than when wheat was not grazed (Krenzer et al., 1989). Greater bulk density

occurred to a depth of 9 cm in two soils and to 21 cm in a third soil. Winter grazing of wheat increased penetration resistance to depths of 16, 18, and 28 cm, respectively.

Summary and Recommendations: Season of Grazing and Deferment

Animals grazing forage on unstable soil, attained either through soil loosening to ameliorate previous compaction or from excessively wet conditions, can have detrimental effects on soil bulk density, soil aggregation, and penetration resistance, which in turn negatively affects productivity and environmental quality (Bilotta et al., 2007). Although some indirect evidence in the humid USA, especially in the South, is available to make this claim, a great need still is seen for more comprehensive studies to understand the multitude of soil changes (e.g., soil erosion, soil structure, soil organic matter, and soil nutrients) in response to stocking method, season of grazing, and duration of deferment. For example, it is unclear how these practices affect long-term accumulation of soil organic matter and what this impact might be on subsequent soil quality, environmental outcomes, and forage and animal productivity. Studies should be expanded to include soil responses in riparian areas.

TYPE AND CLASS OF LIVESTOCK

Little comparative evidence exists in the humid USA to assess the impact of livestock type and class on soil erosion and soil condition. Further, many other factors (such as climate, soil type, forage type, management practices, etc.) could confound interpretations from a group of isolated projects studying different types and classes of livestock. As noted by Bilotta et al. (2007) in their excellent review of animal grazing effects on soils, vegetation, and surface waters, data from outside the region or even country may be useful, but data must be used with caution because of the many differences in climate, soil type, vegetation, and grazing management style that could limit transferability. There is a great need to determine the impact of single-species, single-age, mixed-species, and mixed-age livestock effects on soil erosion and soil condition in the humid USA. If data were available, modeling may help with transferability by sorting out the variables and their effects.

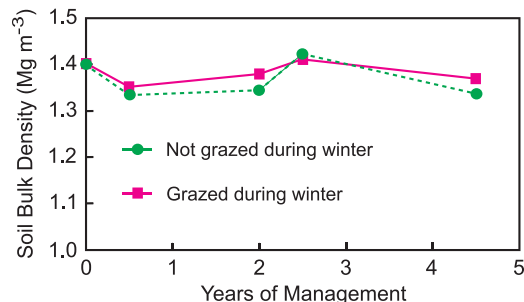


FIGURE 3.10. Changes in soil bulk density (0- to 12-cm depth) during the first 5 yr of cropping with grain sorghum or corn during summer and a cover crop of rye that was not grazed or grazed by cow-calf pairs during winter. Crops were grown using no-tillage management on a Cecil sandy loam (Typic Kanhapludult) near Watkinsville, Georgia. Grain sorghum and corn data were averaged. Treatment means within a sampling time were not different between not grazed and grazed systems at the 0.05 probability level. Adapted from Franzluebbbers and Stuedemann (2008b).

LIVESTOCK DISTRIBUTION IN THE LANDSCAPE

Cattle tend to congregate around shade and water sources and, therefore, can affect the distribution of manure and nutrients in pastures. Short-term grazing studies in small paddocks at several locations in the humid USA have shown greater concentration of P and K near shade and watering areas than farther away (West et al., 1989; Wilkinson et al., 1989; Mathews et al., 1994a). Longer-term studies have shown greater concentration of inorganic nutrients (N, P, K, and Mg) and organic constituents (e.g., total, particulate, and microbial C and N fractions) near shade and water sources than farther away (Franzluebbbers et al., 2000a; Schomberg et al., 2000; Franzluebbbers and Stuedemann, 2010).

In Georgia, soil organic C at the end of 5 yr of Coastal bermudagrass management was greater nearest shade and water sources at surface depths to 12 cm, but not below. Total C in soil and stubble was nearly 4 Mg C ha⁻¹ greater near shade than farther away; a large difference considering the average pasture stock of C was about 43 Mg ha⁻¹ (Franzluebbbers and Stuedemann, 2010). In tall fescue pastures grazed by cattle for 8 to 15 yr, soil organic-C was greatest near shade and water sources and declined logarithmically with increasing



An important ecosystem service of pastureland is providing wildlife habitat and food supply.”

distance. Soil organic-C to a depth of 30 cm was 46.0 Mg C ha⁻¹ at 1 m from shade, 43.2 Mg C ha⁻¹ at 10 m from shade, 39.9 Mg C ha⁻¹ at 30 m from shade, 40.5 Mg C ha⁻¹ at 50 m from shade, and 39.4 Mg C ha⁻¹ at 80 m from shade (Franzluebbers et al., 2000a). The zone within a 10-m radius of shade and water sources became enriched in soil organic-C, most likely because of the high frequency of cattle defecation and urination, which would increase fertility level and subsequent forage growth (Dubeux et al., 2006).

To minimize the probability of N contamination of surface and groundwater supplies (since total N also increased with soil organic-C), shade/water sources should be moved periodically, positioned on the landscape to minimize flow of percolate or runoff directly from these areas to water supplies, and avoided during routine fertilization. In Pennsylvania livestock concentration areas caused an increase of soil P within a 20- to 40-m radius, which led to greater P concentration in runoff (Sanderson et al., 2010). The authors stated that if livestock concentration areas were surrounded by sufficient vegetation, risk of surface water quality deterioration could be mitigated.

PURPOSE 5: IMPROVE OR MAINTAIN THE QUANTITY AND QUALITY OF FOOD AND/OR COVER AVAILABLE FOR WILDLIFE

An important ecosystem service of pastureland is providing wildlife habitat and food supply. Within the pastureland context, research quantifying the effects of prescribed livestock grazing strategies on wildlife is limited. Most research has focused on wildlife responses to grazing intensity. Of the 52 wildlife papers reviewed, 34 (65%) reported grazing intensity responses. Avian responses to prescribed grazing strategies in pastureland were studied in 38 of 52 papers (73%), but this assessment will also include invertebrates, reptiles, amphibians, fish, and mammals.

Implementing a grazing management plan to enhance wildlife habitat requires an interdisciplinary approach because such a plan depends upon knowledge of plant community dynamics, life cycle and habitat requirements of affected wildlife species, and potential effects on

livestock (Vavra, 2005). Further, Vavra suggests that any habitat change made for a featured species may create adverse, neutral, or beneficial changes for other species, and development of a grazing management plan on a field scale is rarely sufficient; understanding complementary grazing practices on a landscape scale is required.

GRAZING INTENSITY

Grazing intensity is widely viewed as the grazing management strategy having the greatest impact on plant and livestock responses. Thus, it is reasonable that wildlife response to livestock grazing intensity has been evaluated more than to any other prescribed grazing strategy.

Birds

Throughout North America, populations of birds that rely on grasslands are declining faster than any other type of bird, and in Pennsylvania 82% of grassland-associated avian species have declined in number in the last three decades (Giuliano and Daves, 2002). The reasons are not known, but greater grazing intensity is thought to play a role. In Great Britain the sheep population has more than doubled since 1950, and associated severe grazing pressure has been implicated in changes in vegetation structure and bird populations (Evans et al., 2005). Grazing intensity can affect avian populations by altering plant species composition, vegetation cover, litter mass, food supply, predator populations, and degree of nest disturbance. In a review of livestock grazing impacts on sage grouse habitat, 10 of 17 studies showed direct effects from livestock grazing, but the authors concluded that indirect effects of grazing on habitat were of even greater significance (Beck and Mitchell, 2000). Both direct and indirect effects of grazing intensity on avian abundance, species richness, nest site selection, and nesting success are assessed.

Avian Abundance and Species Richness. In the St. Lawrence River area of Quebec, Canada, grazed and moderately grazed grassland contained six times more birds than intensively grazed grassland (10.4, 11.7, and 1.6 birds ha⁻¹, respectively) (Bélanger and Picard, 1999). No species or species group showed a preference for intensively grazed pasture, and the authors

concluded that stocking rate exceeding 1 cow ha⁻¹ is detrimental to avian abundance. In Scotland low-intensity mixed grazing by cattle and sheep increased the abundance of meadow pipit due to its effect on food availability (Evans et al., 2006b). Arthropod abundance and species diversity increased with greater habitat heterogeneity (Dennis et al., 2008). In a review of grazing effects on habitat for a wide range of birds, Derner et al. (2009) recommended against restriction of grazing and argue for use of livestock as “ecosystems engineers.” They indicate that using heterogeneity-based management, instead of emphasizing exclusively uniform use of vegetation, can alter vegetation structure and improve habitat for grassland birds.

The relationship between avian abundance and grazing intensity varies among bird species (Durant et al., 2008). Sward structure preferences also exist, with some avian species preferring more and others less variation in structure. In Queensland, Australia, it was hypothesized that avian foraging height was a good predictor of bird sensitivity to livestock grazing (Martin and Possingham, 2005). Their model predicted that 31 bird species would decline with increased grazing intensity, and this was confirmed by field observations. They concluded that instead of searching for patterns of population change in response to specific grazing treatments, ecologists should consider the mechanisms underlying the change, one of which is avian foraging height.

In another Australian woodland study, any level of livestock grazing was detrimental to some birds, particularly the understory-dependent species (Martin and McIntyre, 2007). Provided that trees were not cleared, however, a rich and abundant bird population existed under moderate levels of grazing, but high grazing intensity resulted in a species-poor bird assemblage. In a review of grazing effects on sage grouse habitat, both positive and negative effects of grazing by cattle were found (Beck and Mitchell, 2000). Periodic grazing was useful to remove mature grass and rejuvenate forbs that are a food source, but high grazing intensity eliminated most forbs.

Nesting Site Selection. In Quebec, Canada, nest density was 0.3, 0.5, and 0.05 nests ha⁻¹,

respectively, for non-grazed, moderately grazed, and intensively grazed common pastureland (Bélanger and Picard, 1999). Stocking rates exceeding 1 cow ha⁻¹ were detrimental to the presence of birds that frequent this area.

During the spring nesting season of wading birds in France, fields with low grazing intensity were occupied by more birds than the landscape average (Tichit et al., 2005). Different species of waders showed different preferences to grazing intensity, however, and the authors highlight the importance of maintaining a variety of grazing regimes if conservation of waders was to be achieved at the community level.

In Montana plots not grazed by cattle had reduced forb cover, greater litter cover, greater litter depth, and increased ratings of visual obstruction for birds (Fondell and Ball, 2004). Nest density was most highly correlated with high visual obstruction rating. In Louisiana mottled ducks preferred to nest where vegetation height was greater than at random points within the habitat (Durham and Afton, 2003), and it was recommended that stocking rate and timing of grazing be managed to promote tall, dense stands during the March–June nesting season.

Nesting and Reproductive Success. In Kentucky pastures were not grazed or were grazed by cattle at 1 animal unit ha⁻¹ to determine effects of grazing on grasshopper sparrow (Sutter and Ritchison, 2005). Clutch sizes averaged 4.5 and 3.9 in non-grazed and grazed areas, respectively, and nest success was 70% in non-grazed vs. 25% in grazed swards. There was greater invertebrate biomass, more litter, and taller and denser vegetation in non-grazed areas. Most unsuccessful nests were depredated, and higher predation rates were attributed to less concealment in grazed areas. The authors attributed reproductive success in non-grazed areas to greater availability of prey and greater concealment from predators resulting in less nest disturbance.

In Montana nest success was similar between grazed and non-grazed plots for two bird species, but greater in non-grazed areas for two other species, due to less predation and less trampling (Fondell and Ball, 2004). The



heterogeneity-based management, instead of emphasizing exclusively uniform use of vegetation, can alter vegetation structure and improve habitat for grassland birds.”



...management alternatives that avoid intensive grazing during the breeding season would benefit many bird species.”

authors suggested that management alternatives that avoid intensive grazing during the breeding season would benefit many bird species. In west Texas nest losses due to trampling were directly proportional to stocking rate (Koerth et al., 1983). In Louisiana successful nests of mottled ducks were found in areas with a greater number of plant species and greater vegetation density than unsuccessful nests (Durham and Afton, 2003). Mammalian predators caused most failures, and the authors recommended managing stocking rate and timing of grazing to promote tall, dense stands during the nesting season.

In England black grouse reproductive success was compared in pastures where sheep were stocked at regional average rates and a third of normal levels (Calladine et al., 2002). Proportion of hens retaining broods late in the chick-rearing period was 54% and 32% for low vs. normal stocking rate, indicating that manipulation of grazing intensity can contribute to conservation of black grouse. In Scotland sheep were stocked at rates of 2.7, 0.9, and 0.6 ewes ha⁻¹, or swards were not grazed to evaluate effects on meadow pipit (Evans et al., 2005). The highest stocking rate was associated with the smallest eggs and lowest stocking rate with the largest eggs, but non-grazed plots had smaller eggs than lightly grazed plots. There was no effect of egg size on fledgling success. The authors suggested that grazing intensity affected the food supply and the amount of resources that the parents could allocate to egg production.

As with avian abundance, nesting success is not always affected by grazing intensity. In Idaho (Austin et al., 2007) and Oregon (Ivey and Dugger, 2008), no difference was found in nesting success of the sandhill crane due to livestock grazing. In both environments the major factor affecting nesting success was water level and its effect on predation. In Missouri nest success of the prairie chicken was related to amount of litter and presence of forbs and woody cover (McKee et al., 1998). Nest success declined with increasing woody cover, with decreasing grass and forb cover, and when litter cover was above 25%. More litter delayed grass growth, reduced nest cover, and increased small mammal populations resulting in increased predation.

Mammals

Field vole abundance in pastureland is important because of their role as a food source for other species and because they damage young trees by chewing on bark (Evans et al., 2006a). Vole abundance was greater in plots with low vs. high stocking rate and with low stocking rate of sheep plus cattle compared with sheep alone. Low stocking rate favored voles because of greater food resources and greater cover to protect from avian predators.

In Oregon several species of small mammals had lower abundance in heavily vs. lightly grazed sites, and biomass of small mammals was lower under heavy grazing (Johnston and Anthony, 2008). Preference was evident for vegetative cover, and a reduction in grazing pressure was recommended to increase small mammal biomass.

In Greece lightly grazed pastures were less preferred by brown hares compared with moderately grazed ones, and non-grazed pastures were less preferred by hares than grazed ones (Karmiris and Nastis, 2007). Greater use of moderately grazed pastures by hares was associated with reduced herbage height and density, allowing hares to see approaching predators.

Cattle grazing intensity (0%, 50%, 70%, and 90% removal of standing crop) of rough fescue during autumn in Montana did not alter pasture species composition for subsequent grazing in spring by elk and deer (Short and Knight, 2003). The 50% and 90% removal treatments reduced live herbage mass the subsequent spring but not in summer. It was recommended that autumn grazing remove 70% of herbage mass to reduce standing dead material the subsequent spring.

Reptiles

The spur-thighed tortoise is an endangered reptile present in semiarid and Mediterranean agro-ecosystems where livestock grazing occurs in Spain (Anadon et al., 2006). The main threat to the tortoise is habitat loss and fragmentation. Tortoises selected areas with intermediate annual grass cover and rejected areas with low and high grass cover.

Invertebrates

Foliar arthropods are an important component of bird diets. Increasing stocking rate of sheep and replacing cattle with sheep have been associated with declines in many upland birds in Scotland, and a link may exist between declines in bird populations and availability of arthropod prey (Dennis et al., 2008).

In Scotland arthropod biomass was lower in areas grazed with sheep at the commercial density than at one-third that density during 3 yr (Dennis et al., 2008). In Sweden insect species richness was negatively affected by increasing grazing intensity and decreasing sward height (Söderström et al., 2001). In the Northeast USA, low stocking rates and high soil moisture were most highly positively correlated with number of macroinvertebrates (Byers and Barker, 2000).

Unlike many insect groups, spiders do not have strong host-plant associations (Bell et al., 2001), so sward structure of grasslands is more important than plant species present. Low grazing intensity leads to deeper litter layers and more architecturally diverse vegetation, which increases spider diversity, especially the number of web spinners. Rigid vegetation favors web spinners, so livestock avoidance of certain weed species provides structure for webs. Dung spots and other products of animal grazing encourage tall vegetation that provides structural support for webs. Grazing at low intensity appears to be preferable for most spiders, and a mosaic of short and taller patches may benefit spiders. In heavily grazed areas, e.g., by sheep, provision of some areas not closely grazed to allow accumulation of litter provides good habitat for spiders.

The effects of stocking rate on habitat score of water bodies and macroinvertebrate populations were determined on five first-order western Virginia streams (Braccia and Voshell, 2006). Habitat score decreased from non-stocked to intermediate grazing intensity (154 cattle ha⁻¹) and remained relatively unchanged with heavy and very heavy grazing intensities (2.1 and 2.9 cattle ha⁻¹, respectively). The physical habitat metrics of suspended sediment and substrate homogeneity in water were the largest drivers of macroinvertebrate

populations. In a New Zealand riparian area, intensive grazing reduced streamside vegetation and increased bank damage, thus increasing stream temperatures and in-stream sedimentation. This, in turn, negatively influenced macroinvertebrate communities (Quinn et al., 1992).

Summary and Recommendations: Grazing Intensity

The effect of grazing intensity on wildlife has received far more attention than any other grazing strategy, and most research has focused on avian response. The literature supports the conclusion that grazing intensity affects avian species abundance and richness, nest site selection, and nesting success. High grazing intensity reduced avian abundance due to loss of preferred habitat for nesting, destruction of nests due to trampling, and fewer invertebrate food sources (Fuller and Gough, 1999).

In some cases, low grazing intensity positively affects bird populations because of less trampling damage of nests by livestock and an increase in voles and other small mammals that serve as food for owls and raptors, but it can also increase nest predation of ground-nesting birds as a result of greater population of small mammals. Söderström et al. (2001) indicated that the importance of landscape composition for mobile organisms, such as birds, implies that management strategies should focus on providing diverse habitats within the wider countryside and not exclusively on single pastures or the grazing management of those pastures.

Clearly, selecting the proper grazing intensity should be a primary focus in developing and carrying out management plans for agroecosystems in which livestock production and wildlife preservation are concurrent objectives. The literature is equally clear, however, that responses to grazing intensity can vary widely among wildlife species. Thus, choice of grazing intensity must be evaluated within the context of what management practices benefit the broad array of wildlife present in the ecosystem and not only a high-profile species.

Further, indirect effects of grazing intensity can be as important, or in some cases more



...grazing intensity affects avian species abundance and richness, nest site selection, and nesting success.”



Riparian buffer strips in combination with fencing can be used to exclude or limit livestock access to riparian areas, improving water quality and wildlife habitat. Photo by Carmen Agouridis, University of Kentucky.

important, than direct effects on target wildlife populations. Indirect effects can be mediated through changes in vegetation abundance or structure, plant sources of food, water quality, and abundance of prey and predators. Although excessive grazing intensity is clearly detrimental, an argument for allowing grazing in the landscape can be made based on the concept of livestock as “ecosystems engineers” that can alter vegetation structure in positive ways and improve habitat for grassland birds (Derner et al., 2009).

In a review of North American grasslands, Frisina and Mariani (1995) suggest that grazing management strategies should focus on sustaining healthy vegetation and ensuring the presence of wildlife species or communities that play a role in ecosystem dynamics. Long-term management practices should allow only base-line or “natural” levels of soil erosion and maintain good

water quality, with a broad ecosystem focus instead of meeting the needs of one or two charismatic wildlife species and a particular class of livestock. Grazing intensity is a very important prescribed grazing tool in achieving these objectives.

STOCKING METHOD

Only eight studies were found that examined the effects of stocking method of pastureland on macroinvertebrate, small mammal, and bird responses. The plant community is closely linked to mammalian and avian populations, and as such the effects of stocking method on vegetation response can have significant indirect impacts on habitat selection and reproductive success.

Birds

In Saskatchewan, Canada, no difference was found between season-long and rotational stocking in duck nest success (25% vs. 20%)

(Ignatiuk and Duncan, 2001). Residual vegetation did not differ among treatments. Nest success in pastures was greater than that in cultivated fields, suggesting that expanding area of pasture may increase duck populations. They concluded that cattle stocking rate exerts a greater influence on vegetative response than stocking method.

In southwestern Wisconsin, grassland bird species richness, dominance, and density were compared on rotationally and continuously stocked riparian areas and on cropland with a 10-m non-grazed buffer strip (Renfrew and Ribic, 2001). No difference was seen in bird responses among land-use types. Rotational stocking did not support more grassland birds than continuous stocking. Instead, bird density was related to vegetation structure, with higher density found on sites with deeper litter, which generally were the non-grazed buffer strips.

In west Texas, loss of nests due to cattle trampling was 15% and 9% under continuous and rotational stocking, respectively, and was directly proportional to stocking rate, suggesting that stocking method had little effect (Koerth et al., 1983). In southwestern Wisconsin, beef heifers on pasture were rotated each day, every 4 d, or every 7 d to determine if stocking method affected percent trampling of simulated bird nests (Paine et al., 1996). Nest survival (new nests were placed before each grazing cycle) after eight grazing events per treatment averaged 25% and was not affected by treatment. Nest destruction decreased with increased vegetation height, density, and percent cover. The authors suggested that better nest protection can be achieved by allowing cattle grazing when forage is plentiful and leaving a large amount of residual forage.

In Canada, early-hatched waterfowl are more likely than late-hatched to enter the breeding population, so a study was conducted to determine factors that favored success of early-season nests (Emery et al., 2005). Managed cover types (especially delayed hay production) provided greater nesting success than unmanaged cover types (13% vs. 5%). The authors suggested that managers can influence growth of the breeding population through restoration, protection, or management of

nesting cover. Rotational stocking and delayed grazing were not better than unmanaged grazing.

Small Mammals

In Wisconsin both abundance and species richness of small mammals were greater on buffer strips than on both continuously or rotationally stocked riparian areas, and stocking methods were not different (Chapman and Ribic, 2002). No evidence was found that small mammals responded to the development of greater cover during rest periods of rotational stocking or that conversion from continuous to rotational stocking had significant influence on small mammal communities in riparian areas. Conversion of land from grain to grass production, however, benefited small mammal communities.

Macroinvertebrates

In Wisconsin continuous stocking of riparian buffers negatively affected macroinvertebrate assemblages, but those present had a high tolerance for organic pollutants (Weigel et al., 2000). Woody buffers supported species with a low tolerance for organic pollutants while rotationally stocked pastures and grass buffers had species with intermediate tolerance. When grazing occurred along Minnesota streams, impairment of water quality was greater at sites stocked continuously than rotationally (Sovell et al., 2000). No difference was seen in macroinvertebrate populations, however, between continuous and rotational stocking.

Summary and Recommendations: Stocking Method

A limited number of studies have evaluated effects of livestock stocking methods on wildlife. With the exception of certain riparian macroinvertebrate assemblages, which are responsive to water quality changes due to stocking method, choice of stocking method did not have a significant effect on wildlife responses. Because of the limited data available, further studies are warranted, as was elaborated in the soil response section of this chapter. Based on the literature available at present, choice of livestock grazing intensity on pastureland appears to be more critical for success of wildlife than is choice of stocking method.



Conversion of land from grain to grass production... benefited small mammal communities.”



Increasing use of warm-season grasses...was recommended to support increased bird populations.”

SEASON OF GRAZING AND DEFERMENT

Seven studies assessed the effect of season of pastureland grazing on wildlife responses. Six of the studies focused on avian species with emphasis on nest site selection and nesting success.

Avian Nest Site Selection and Nesting Success

Durant et al. (2008) reviewed livestock grazing effects on sward structure and the effect of timing of grazing on breeding wader birds. Early-spring-nesting birds were primarily affected by the high intensity of grazing during the previous autumn that reduced spring forage growth. Later-nesting species were more likely to be dependent on spring grazing patterns. Restricting livestock grazing or using reduced stocking rates in April through May is recommended so birds do not avoid areas where livestock are present or so livestock do not disturb nests. They concluded grazing may have, according to the season and bird species, positive or negative effects on bird breeding success. They noted that heterogeneity on a larger spatial scale is often important to site selection, so results also depend on factors beyond the individual pasture level.

In North Dakota nest density of upland sandpipers was lower for treatments where cattle were present during the nesting season (spring, both spring and autumn, and season-long grazing), but treatment did not affect nesting success (Bowen and Kruse, 1993). They recommended that areas with breeding populations of upland sandpipers include a complex of pastures under various management practices, including those that are not disturbed during spring.

In California nest density for various ducks in summer and geese and sandhill cranes in winter was measured in pastureland that was not grazed or was rotationally stocked with cow-calf pairs from 1 July through 1 November (Carroll et al., 2007). Nest initiation occurred in March through May, but all were inactive by 1 July when grazing began. Rotational stocking during the grazing season provided short, grassy vegetation that favored nesting by geese and cranes during the following winter, and still allowed vegetation to recover sufficiently for

the beginning of duck nesting in late March. Grazed sites had greater nest density.

Grazing during the late spring nesting period reduced herbaceous cover that is critical to concealing sage grouse nests from predators (Beck and Mitchell, 2000). Tall grass cover was greater at successful nests than depredated nests. It was concluded that sage grouse prefer canopy cover of tall grasses (> 18 cm) and shrubs for nesting, forbs and insects for brood rearing, and herbaceous riparian areas for late-season foraging (Crawford et al., 2004). Light to moderate grazing in the early season can promote forb abundance in both upland and riparian habitats that favor grouse. More intensive grazing can allow invasion by undesirable plant species.

The decline in grassland bird populations in Pennsylvania was associated with widespread use of cool-season grasses that are mowed or grazed during early April to late June, when most grassland birds are nesting (Giuliano and Daves, 2002). When a portion of the farm was planted to warm-season grasses, 42 avian species were found in warm-season and 30 species in cool-season fields. Abundance of birds was 1.6 times greater in warm- than cool-season grass fields, nesting success was 1.3 times greater, and fledge rates were 1.8 times greater. Warm-season pasture provided greater cover during the nesting period and lower disturbance rates. Increasing use of warm-season grasses in the region was recommended to support increased bird populations.

Invertebrates

In Alberta, Canada, total invertebrate biomass was greatest during late-season and all-season grazing as compared with early-season grazing (Scrimgeour and Kendall, 2003), which was attributed to the presence of large species in late season. Total density changed little among treatments, which the authors attributed to the short duration (2 yr) of the study. They hypothesized that a longer time frame would be required to produce changes in invertebrate food resources before increases in invertebrate numbers could be realized. More studies of longer duration are needed to determine effects of timing of grazing on invertebrates.

Summary and Recommendations: Season of Grazing and Deferment

Most studies on effects of season of grazing on wildlife assessed the effect of timing on vegetation characteristics at potential avian nesting sites or on nesting success. Desirable site characteristics vary among avian species, but heterogeneity in sward structure at the landscape scale can provide a wider range of sward characteristics for nest site location. Incorporating additional pastureland species, e.g., warm-season grasses in temperate regions, provides variation in sward structure within the landscape, and differences in seasons of growth of these species make it relatively easy to vary the timing of grazing in support of wildlife populations.

TYPE AND CLASS OF LIVESTOCK

Only two papers were found that addressed the role of type and class of livestock on wildlife. Both papers focused primarily on effects of livestock species on sward heterogeneity and its subsequent effect on population of invertebrates that are important prey for some grassland birds. In Scotland increasing stocking rate of sheep and replacing cattle with sheep were associated with declines in many upland birds that may be linked to availability of arthropod prey. At 18 and 30 mo, arthropod biomass was twice as great in non-grazed and sheep plus cattle treatments than in pastures grazed with sheep only (Dennis et al., 2008). Including cattle increased sward structural diversity and arthropod abundance, likely favoring bird populations over time. Similarly, in a review of spider populations in pastureland, greater variation or patchiness in sward height favored spiders (Bell et al., 2001). The authors cautioned against grazing by sheep at high stocking rates and recommended use of lower stocking rates and/or mixed grazing to create a mosaic of short and tall swards.

DISTRIBUTION OF LIVESTOCK IN THE LANDSCAPE

There has been limited research (11 papers cited) on effects of livestock distribution in pastureland on wildlife, with most considering exclusion of livestock from waterways and construction of riparian buffers. Agriculture activities may contribute the largest amount of sediment to streams, primarily through row crop cultivation

in flood-prone areas and livestock grazing in riparian areas (Waters, 1995).

Birds

In Florida breeding pairs of crested caracaras selected pastureland as home range more than forest, oak scrub, and marsh (Morrison and Humphrey, 2001). Compared with pairs nesting in natural areas, those nesting on land used for cattle ranching exhibited higher rates of breeding-area occupancy, attempted breeding during more years, initiated egg laying earlier, exhibited higher nesting success, and more often attempted a second brood after successfully fledging a first. Reasons for these responses are not clear nor are the effects of specific grazing practices, but the importance of pastureland habitat to reproduction of crested caracaras is well established.

In Portugal species richness of grassland wintering birds was determined primarily by the broader landscape context, and abundance was determined mostly by field management (Moreira et al., 2005). High species richness was associated with diverse landscapes, high stream density, and forest and shrub cover that act as sources of nonagricultural avian species to pastureland. Fields located in homogeneous, arable landscapes tended to be species poor though they had the highest abundance of seed-eating birds, particularly winter visitors.

In Wisconsin a variety of land uses including alfalfa hay field, dry pasture, and cool-season grass pasture were evaluated for grassland bird species richness. Structure and composition of the landscape and patch size were the most important factors to consider in affecting species richness and management for grassland birds (Sample et al., 2003).

Reptiles and Amphibians

In Pennsylvania there was no effect due to exclusion of beef cattle from riparian areas for 1 to 2 yr on abundance, richness, or biomass of all reptile and amphibian species combined (Homyack and Giuliano, 2002). Northern queen snakes and eastern garter snakes were more abundant in riparian areas where cattle were excluded. The authors suggested that these reptiles and amphibians likely require > 4 yr to respond to changes in management due to reproductive potential, proximity to



Desirable site characteristics vary among avian species”



...pastureland is one component of a diverse landscape and not the sole source of wildlife habitat in a given region.”

nearest remnant population, and dispersal ability. Also, such areas likely did not have sufficient time for vegetation, water quality, and macroinvertebrate populations to recover, thus allowing herpetofauna to recolonize the sites. This underscores the need for longer-term studies to allow the ecosystem to equilibrate.

Invertebrates and Fish

Stream physical habitat and fish communities were evaluated in Wisconsin during 13 yr (Wang et al., 2006). Only stream segments with riparian buffers protected by exclusion fencing showed major improvements in stream physical habitat. Improvements in fish community structure were not found for any of the implemented practices; however, annual measurements varied substantially, and this pointed to the need for long-term studies.

While examining macroinvertebrate communities in Pennsylvania streams with exclusion fencing and riparian restoration, Carline and Walsh (2007) found only modest improvements in community composition and structure. Treatments improved macroinvertebrate density in the stream, which was attributed to lower suspended sediment levels. Installation of exclusion fencing in Pennsylvania allowed channel revegetation and a 30% increase in total number of macroinvertebrates (Galeone, 2000). In Wisconsin continuous stocking reduced macroinvertebrate populations more than did rotational stocking, woody buffer strips, or grass buffer strips (Weigel et al., 2000).

Mammals

In Wisconsin buffer strips led to increased species richness of small mammals and greater abundance (3–5 times) compared with managed intensive rotational stocking (Chapman and Ribic, 2002). Additionally, small mammal abundance was greatest within 5 m of the stream, regardless of the presence or absence of buffers, indicating the importance of stream-side zones as habitat. In southwestern Pennsylvania, small mammal species richness was 1.7 times greater and abundance was 2.2 times greater when livestock were excluded (Giuliano and Homyack, 2004). Results were attributed to 2.3 times greater litter cover and benefits from vertical vegetation obstruction.

In Spain the Iberian ibex is a wild goat that is endemic to the Iberian Peninsula and is a close relative of the domestic goat with similar feeding habits (Acevedo et al., 2007). The presence of the domestic goat caused the ibex to occupy a different habitat, often one that was suboptimal.

Summary and Recommendations: Livestock Distribution in the Landscape

The literature indicates that pastureland grazed by livestock provides important habitat for wildlife species and that it is possible to manage pastureland for the benefit of both livestock and wildlife. It must be recognized, however, that pastureland is one component of a diverse landscape and not the sole source of wildlife habitat in a given region. Further, pasture species have different growth habits and are grazed differently by different herbivores. Thus, distribution of livestock throughout the diverse landscape can produce important niches for particular wildlife species (e.g., the crested caracaras in Florida) and the diversity of landscape features required by other species. Restricting livestock access to surface waters is justified by the current literature. Changes in water quality affect invertebrate populations relatively quickly, and buffer strips associated with livestock restriction result in relatively rapid increases in abundance and richness of small mammal populations. Restoring richness and abundance of reptiles, amphibians, and fish is a longer-term process that may require several years, but one that appears to be achievable.

OVERALL CONCLUSIONS AND RECOMMENDATIONS

GRAZING INTENSITY Achieving Purposes of Prescribed Grazing through Managing Grazing Intensity

The literature strongly supports the conclusion that grazing intensity is the prescribed grazing practice having the greatest impact on forage, animal, soil, water, and wildlife responses in pastureland. Grazing intensity affects forage mass and nutritive value and plays a major role in vigor and species composition/richness of plant communities. Increasing grazing intensity decreases forage mass on pastureland, and this is the primary determinant of the strong negative correlation between individual animal performance and grazing intensity. Increases

in grazing intensity have been linked to greater nutrient, sediment, and fecal coliform loading in water bodies, streambank erosion, and soil compaction resulting in decreased rainfall infiltration rates.

Evidence in the literature exists that increasing soil erosion, soil compaction, and declining soil quality are caused by excessive stocking rate. Avian species abundance and richness, nest site selection, and nesting success all have been negatively affected by high grazing intensity. The literature is equally clear, however, that the response to grazing intensity can vary widely for different wildlife species. Consequently, choice of grazing intensity must be evaluated considering the needs of livestock and the requirements of the broad array of wildlife species present in the ecosystem and not just those of a single high-profile species.

In conclusion, selecting the proper grazing intensity should be a primary focus in developing and carrying out management plans for agroecosystems in which livestock production, ecosystem health, and wildlife preservation are concurrent objectives. If conservation planning fails to identify, achieve, and maintain the proper grazing intensity, the secondary factors such as choice of stocking method, season of grazing and deferment, or any other prescribed grazing strategy will not be able to overcome this failure.

Further, when climatic or other conditions lead to deviation of ecosystem balance away from the defined goals, some form of adaptive management must be implemented to correct grazing intensity and other factors to allow the system to equilibrate. Thus, in addition to the skill in planning, designing, and implementing the prescribed grazing standard, educational programs are needed to assist the manager in recognizing changes and adjusting management strategies to achieve system goals. This would be aided by a process of periodic monitoring by NRCS to assist in evaluating the success of the practice and in identifying needs for adaptive management.

Gaps in the Published Literature regarding Grazing Intensity

The general nature of the relationship between forage quantity and grazing intensity and that

between individual animal performance and grazing intensity has been well defined. Despite statements regarding the importance of grazing intensity as a controlling variable in ecosystem health, little research has been conducted in that area. Critical thresholds for grazing intensity, above which lead to occurrences of substantial environmental impacts, have not been established in the USA for pasturelands. This would be a valuable first step. Then the interactions among the predominant or desired forage, livestock, and wildlife species occupying the grassland need to be quantified. This will likely need modeling efforts.

A great need also exists for conducting comprehensive grazing intensity studies (measuring soil, water, air, wildlife, plant, and animal responses) in several locations within the humid USA. This work would best be done by well-funded and accomplished multidisciplinary teams of scientists at strategically selected and appropriately equipped regional centers. Team members need not all work at one location but could be brought together to develop experimental protocols for the project and to synthesize the data generated.

Once data are accumulated and evaluated, modeling approaches can assist in transferring the technology and expanding inference of responses to a wider range of ecosystems. This requires more education of the NRCS personnel and others to train producers, but it would help advisors predict and monitor the appropriate grazing strategies for a given site. Models could integrate site-specific information on crop and pasture systems to define, from a landscape perspective, the role of the pasture in providing ecosystem services, including water quality and habitat for wildlife. This approach would inform decision makers about the appropriate forage species and prescribed grazing practices needed to meet specific goals at the farm and the broader ecosystem level.

STOCKING METHOD Achieving Purposes of Prescribed Grazing through Managing Stocking Method

The pastureland literature supports a conclusion that rotational stocking increases forage quantity-related responses relative to continuous



Critical thresholds for grazing intensity, above which lead to occurrences of substantial environmental impacts, have not been established...for pasturelands.”



...stocking method (is) an important prescribed grazing practice, but one that is secondary...to grazing intensity”

stocking. The effect of stocking method on forage nutritive value is inconclusive, and although the literature indicates that stocking method affects pasture botanical composition and persistence, interactions with other factors, especially grazing intensity, make it impossible to generalize about which stocking method is best across situations. The literature supports a conclusion that rest periods between grazing events provide greater flexibility in choice of grazing intensity. The literature also supports that grazed grasslands maintain greater plant species richness than non-grazed areas and that prescribed grazing is a key component in sustaining species diversity of grassland communities.

Daily animal production is generally not affected by stocking method, with an exception being when species composition of the pasture changes over time due to stocking method. The effect on gain per ha is less clear, but when differences occur, they generally favor rotational stocking. Conclusions from this pastureland review are in general agreement with those of Briske et al. (2008) for rangeland, with the exception that there appears to be greater likelihood of an advantage in pasturelands for higher gain per ha for rotationally stocking over continuous stocking than there is for rotationally stocked rangeland. This could be due to the plant species used, amount of inputs, differences in rainfall, and potential for greater plant growth.

The majority of studies on stocking method effects on water quality, hydrology, and stream morphology indicate that rotational stocking has less negative effect than continuous stocking. Accumulation of additional forage mass and ground cover during regrowth periods accounts for some of the benefits attributed to rotational stocking. In total, the literature supports stocking method as an important prescribed grazing practice, but one that is secondary in importance to grazing intensity.

Gaps in the Published Literature regarding Stocking Method

Briske et al. (2008) concluded that “a continuation of costly grazing experiments adhering to conventional research protocols will yield little additional information.” However, based on the current literature

assessment for humid pastures, the most compelling justification for additional stocking method studies is to assess their impact on responses beyond pasture plants and domestic animals, specifically soil, water, and wildlife. The lack of information regarding the influence of stocking method on soil, water, and wildlife responses suggests need for such comparisons at strategically selected sites throughout the humid pastureland regions of the USA. Multidisciplinary teams of the best scientists nationally should be assembled to coordinate these studies, so that treatment selection and response measurements are done in a manner that will generate conclusive results and support potential modeling efforts. This work would serve as an authoritative guide to future prescribed grazing recommendations.

In agreement with Briske et al. (2008), more consistent or standardized research protocols are needed for stocking method comparisons of forage mass, accumulation, nutritive value, and species composition. Based on the preliminary data available, more measurements are needed on plant and soil factors that contribute to wildlife habitat and food sources. The studies need to be multidisciplinary and long term to capture responses along the way to ecosystem stabilization and for evaluating the treatments while at steady state.

SEASON OF GRAZING AND DEFERMENT Achieving Purposes of Prescribed Grazing through Season of Grazing and Deferral

Stockpiling is the most common deferred stocking practice and is useful for extending the grazing season, reducing reliance on stored feed, and improving animal health and performance. Timing of initiation, termination, and deferral of grazing, along with inclusion of complementary cool- and warm-season forages in the production system are important prescribed grazing practices for maintaining forage cover and desired sward botanical composition.

Ground cover is critical because the largest negative effects on water quality typically occur when cover is compromised, particularly $\text{NO}_3\text{-N}$ leaching and sediment loss. Highest runoff rates occur during dormant seasons

when evapotranspiration is lowest; thus winter feeding on grassland can impact water quality significantly.

Animals grazing on unstable or wet soil can increase soil bulk density and penetration resistance and decrease aggregation, all of which will negatively affect productivity and environmental quality. Research supports the removal of livestock from riparian areas during periods of high soil saturation.

Most wildlife studies relate to the effect of timing of grazing on vegetation characteristics at potential avian nesting sites or on nesting success. For many avian species, deferral of grazing is critical for nesting success. Incorporating additional pastureland species is a practice that provides variation in sward structure and differences in seasons of growth, making it relatively easy to vary the timing of grazing.

Gaps in the Published Literature regarding Season of Grazing and Deferment

As need increases for high-quality forage in pastures, additional research into optimal timing of initiation, termination, and deferral of grazing will be critical. Relatively little of this work has been done in the USA. Effects of timing of initiation of grazing on subsequent forage production and nutritive value, and the effect of timing of termination on persistence and regrowth suggest that this is an area that would benefit from increased research.

There remains a need for comprehensive studies to understand the multitude of soil changes in response to season of grazing and deferment. For example, it is unclear whether season of grazing or deferment might affect long-term soil organic matter accumulation and how, in turn, this affects soil quality and forage and animal productivity. Questions

Excessive stocking rates can reduce herbage mass and vegetative cover and increase occurrence of soil erosion. Photo by Lynn Betts, USDA NRCS.





Distance to water is more important than paddock size with respect to optimizing grazing distribution and animal performance.”

remain regarding exclusion of livestock from riparian areas, including the level and timing of such disturbances and their effect on plant, mammalian, avian, and benthic species. Obtaining this knowledge would allow for improved management of pasturelands and their riparian areas to support livestock production while improving diversity and numbers of nonlivestock species.

TYPE AND CLASS OF LIVESTOCK **Achieving Purposes of Prescribed Grazing through Type and Class of Livestock**

Within a livestock species, no evidence was found that breed or age has significant effects on pasture characteristics or ecosystem services. The literature supports a conclusion that co-grazing or grazing by particular species can be used effectively as a prescribed grazing tool to manipulate botanical composition of pastures and to decrease abundance of invasive, unwanted, or potentially toxic plants. Relative to animal health and production, the consensus of the literature is that choice of animal species is less critical than grazing intensity. Little comparative evidence exists in the humid USA to assess the effects of livestock type and class on soil erosion and condition. Only two papers were found that addressed the role of type and class of livestock on wildlife, and both focused on the impact of livestock species on sward structural diversity and arthropod abundance. Grazing by cattle or cattle plus sheep, instead of sheep alone, created greater variation or patchiness in sward height favoring spiders, an important food source of some birds.

Gaps in the Published Literature regarding Type and Class of Livestock

Further research on plant response to grazing by type and class of livestock is needed because studies to date have been limited both geographically and in the forage species tested. The interaction between livestock species and stocking rate is not well understood in terms of plant and animal response, but especially on wildlife and soil and water responses, and is an important area for future research. Little research has assessed the effect of various livestock species on water quality, hydrology, riparian health, and watershed function. Research into the environmental responses

from differing grazing livestock is needed as age, physical characteristics, and grazing behavior vary among species. Particularly lacking is research on the effects of horses and sheep.

Better understanding of the effects of different types of livestock on the environment will help develop best management practices such as riparian buffers and refine grazing techniques to mitigate problems such as overgrazing. A great need exists to determine the differential effects of single-species, single-age, mixed-species, and mixed-age livestock effects on soil erosion and soil condition in the humid USA.

DISTRIBUTION OF LIVESTOCK IN THE LANDSCAPE **Achieving Purposes of Prescribed Grazing through Distribution of Livestock in the Landscape**

Sloping areas often have shorter livestock grazing time and are associated with greater species richness and legume proportion, but lower rates of herbage accumulation than summit or toeslope areas. Shade has a greater impact on livestock distribution than does location of water source during warm seasons or in warm climates. Distance to water is more important than paddock size with respect to optimizing grazing distribution and animal performance. This suggests that increasing the number of shade and watering points in conjunction with decreasing paddock size minimizes spot grazing and reduces associated stand deterioration. From an animal health and production standpoint, key management factors include minimizing distance to water, increasing quality of drinking water by providing alternatives to surface water, and providing shade. These prescribed grazing practices should be considered as part of an overall management plan.

Distribution of livestock throughout the landscape can provide important niches for particular wildlife species and the diverse landscape features required by other species. The majority of the literature pertaining to livestock distribution effects on water and wildlife addresses exclusion fencing and riparian buffers. Restricting livestock access to surface waters is justified by the current literature

because changes in water quality occur quickly and affect wildlife populations. Livestock restriction from riparian areas has resulted in relatively rapid increases in abundance and richness of small mammal populations. Restoring richness and abundance of reptiles, amphibians, and fish is a longer-term process, but one that appears to be achievable.

Gaps in the Published Literature regarding Distribution of Livestock in the Landscape

The literature describing plant and animal responses to livestock distribution is limited. Greater research efforts are also needed to understand the effects of livestock distribution management systems on shallow groundwater quality and recharge. Livestock distribution is a research area where scientists evaluating soil, water, and wildlife responses could collaborate more closely with pasture and animal scientists.

Final Synopsis

The NRCS has developed conservation practice standards to provide guidance for applying conservation technology on the land and setting the minimum acceptable level for application of the technology. The goal of this literature synthesis was to determine if practices defined in the Prescribed Grazing Practice Standard (Code 528) meet the purposes and criteria that were established for their implementation. The assessment was organized around five purposes or desired outcomes that arise from imposing prescribed grazing. Prescribed grazing strategies evaluated include grazing intensity, stocking method, season of grazing and deferment from grazing, type and class of livestock, and livestock distribution on the landscape. Summation assessments were made of the literature support for each purpose and their criteria in Code 528 (Table 3.1).

Specific details regarding these strategies and their impacts on plant, livestock, water, soil, and wildlife were presented and summarized throughout this chapter. Prescribed grazing practices clearly have major influence on plant, livestock, water, soil, and wildlife. Proper grazing intensity is the most important prescribed grazing strategy on pastureland ecosystems, and conservation plans should

prioritize its implementation. Stocking method is useful for fine-tuning the overall production system once an appropriate grazing intensity is imposed. Choice of rotational over continuous stocking has been shown to positively affect forage accumulation rate and forage utilization efficiency on pastureland as well as important measures of water quality. Season of grazing affects forage ground cover, which in turn influences water infiltration, runoff into surface water bodies, and availability of wildlife habitat, avian nesting sites, and food supply for wildlife and livestock. The literature describing effects of type and class of livestock was limited primarily to studies of effects of mixed-species grazing on plant communities. Most literature on distribution of livestock in the landscape has assessed the effects of shade, water, and fence placement on components of the pastureland ecosystem.

Although societal interest and emphasis on soil, water, and wildlife is increasing, a paucity of literature addressing these ecosystem components is seen. This leads to a recommendation that future grazing studies on pastureland be more comprehensive in scope, including soil, water, and wildlife responses in addition to plant and livestock measures, and be carried out over longer time periods to allow the full impact of prescribed grazing to be quantified. These data would then provide the basis for development of effective pastureland ecosystem models.

Last, there appears to be a significant future role for emphases, including 1) use of prescribed grazing to correct undesirable trends in pastureland response and restore desired grassland condition, 2) better education of end users regarding implementation of prescribed grazing technology, 3) detailed monitoring and reporting of the impacts of implementation of prescribed grazing practices to more effectively use adaptive management to adjust the system to meet goals, and 4) quantifying effects and interactions to guiding future assessments of their merit.

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