CHAPTER

4

Forage Harvest Management

C. Jerry Nelson[1], Daren D. Redfearn[2], and Jerry H. Cherney[3]

Authors are [1]Curators' Professor Emeritus, Plant Sciences, University of Missouri; [2]Associate Professor, Plant and Soil Sciences, Oklahoma State University; and [3]E. V. Baker Professor, Crop and Soil Sciences, Cornell University.

Correspondence: C. Jerry Nelson, 205 Curtis Hall, University of Missouri, Columbia, MO 65211
nelsoncj@missouri.edu

"management to provide ecosystem benefits and the economic return can be complementary, but in many cases the desired outcomes are competitive."

Forage Harvest Management

4

C. Jerry Nelson, Daren D. Redfearn, and Jerry H. Cherney

INTRODUCTION

The NRCS Conservation Practice Standard Code 511 (see Appendix I) addresses timely cutting and removal of forages from the field as hay, green-chop, or silage to optimize yield and quality of the product while maintaining stands for the desired length of time. In addition, there are implied and stated criteria for environmental and wildlife benefits, respectively. However, achieving these benefits may require altering management to accept some reduction of yield or quality to maintain or enhance abundance and diversity of wildlife, reduce soil erosion, and reduce contaminants such as fertilizer elements and pesticides from entering surface and groundwater. Code 511 contains a series of prescribed purposes and criteria or guides for achieving each purpose. A team of respected forage specialists was formed to determine the science base for the practice standard (Table 4.1).

The primary goal of the harvest manager is to obtain a good yield of a quality product that allows for stand persistence. Until recently economic returns to the land owner/client have been assumed to include the basic foundation for meeting conservation goals and providing other desired ecosystem services. In some cases the management to provide ecosystem benefits and the economic return can be complementary, but in many cases the desired outcomes are competitive.

This shows the need for literature assessments to determine what management changes would improve the provision of these long-term services with the least effect on economic value of the forage harvested. The literature assessment will also expose deficiencies in research information (Table 4.1).

The evaluation team recognizes that Conservation Practice Standards are written as the base for meeting national priorities, so by design they are broad and more general to form the foundation. The purposes and criteria are then adapted to state and even local conditions for planning, education, and implementation of practices. In that way, proposed use of the forage, species of forage harvested, soil resources, and local environmental and wildlife concerns need to be considered during implementation. In most cases, research is focused on basic principles that need to be interpreted to fit the situation on each specific landscape where the practice is being applied. States can utilize research to build on the national standard to address specific situations and needs. Further, local knowledge and experience of agency personnel are needed to fine-tune applications of the practice for specific sites and goals.

With the above broad perspective we considered the major forage species according to region of adaption. This mostly led to conclusions regarding tolerance to low and high temperatures and to drought stress, which primarily affect competitiveness and persistence. We then evaluated general plant growth habits that are desirable for one or more mechanical harvests during the growing season. Growth habits give insight to the yield potentials, forage quality, regrowth processes, and their potential effects on environmental concerns and wildlife. Thus, most of the assessment effort was focused on perennials and how management decisions would interact with environmental conservation. Management considerations included use of chemical fertilizers and manures, potentials for soil erosion, effects on water quality, and provision of habitat and food supplies for wildlife.

Chopping wilted forage for ensilage in Missouri. NRCS photo by Charlie Rahm.

TABLE 4.1. Purposes of the Forage Harvest Management Practice Standard and the criteria used for assessment. The degree of research support for the each criterion is given in the last column.

Purpose of the Practice Standard	Criteria used for assessing achievement of the purpose	Support by research
Optimize yield and quality of forage at the desired levels	Harvest at frequency and height to maintain a healthy plant community as recommended by State Extension Service	Strong support on major species, limited on minor species or forbs used in special situations
	Harvest forage at stage of maturity for desired quality and quantity	Strong support on major species to optimize yield and quality
	Delay harvest if prolonged or heavy precipitation is forecast that would damage the cut forage	Moderate, need comparative data on rate of yield and quality change due to weather or to later maturity
	Harvest silage/haylage crops within the optimum moisture range for the storage structure(s) being utilized	Strong support for haylage and silage crops over a range of moisture contents
	Use State Extension Service recommendations for optimum and how to determine moisture content	Strong support for optimum content, but methods for field measurement need research
	Treat direct cut hay crop silage (moisture content > 70%) with chemical preservatives or add dry feedstuffs	Generally supported, research is variable on consistency of results achieved; cost effectiveness needs more research
	Invert swaths when moisture content is above 40% and rake hay at 30–40% moisture to maintain hay quality	Inverting assists the drying process, but leaf loss on some species can be high, need research on different methods and cost effectiveness
	Bale field-cured hay at 15–20% moisture; bale at 20–35% moisture if it is to be dried by forced air	Strong support, but need more research on quality losses from field drying vs. costs for water transport and costs for forced-air drying
	Chop ensilage to a size appropriate for the storage structure that allows adequate packing	Strong support for packing to exclude oxygen and maintain anaerobic conditions
Manage for desired species composition	Harvest at the proper height and frequency to maintain desired species composition	Strong research on height and frequency of cut can affect in short term, would be useful for use as an adaptive management method
	Fertilize with appropriate minerals at the correct time in the growing season	Strong support for use of N, P, and K and timing during the season to alter the botanical composition
Use forage plant biomass as a soil nutrient uptake tool	Use a harvest regime that utilizes the maximum amount of available or targeted nutrients	Moderate support for use of forages to utilize excess nutrients in cropping systems
	When desired, select species that can maximize nutrient uptake	Variation in nutrient uptake among species is known, but balance is more critical than uptake of a single nutrient
	Use proper balance of nutrients such as nitrogen to avoid toxic plant material for animals	Strong research support on NO_3 and HCN challenges in grasses, some research on N effects on alkaloids in some cool-season grasses

TABLE 4.1. continued.

Purpose of the Practice Standard	Criteria used for assessing achievement of the purpose	Support by research
Control insects, diseases, and weeds	Select harvest periods to control disease, insect, and weed infestations	Minimal research support except for insects on alfalfa (weevils and potato leafhoppers)
	Evaluate pest management options by planning conservation practice standard Pest Management (595)	Strong IPM research for alfalfa insects, but weak for other species, need research on loss economics
	Lessen incidence of disease, insect damage, and weed infestation by managing for desirable plant vigor	Strong support for maintaining plant vigor and high competition to reduce biotic challenges
Maintain or improve wildlife habitat	If suitable habitat is desired for wildlife species, appropriate harvest schedules(s), cover patterns, and plant height should be maintained to provide suitable habitat	Good support for delayed harvest of first cut for ground nesters and leaving stubble for winter cover and food source; most data on birds; raise cut height for some turtles
	Avoid harvest and other disturbances during nesting, fawning, and other critical times	Some research indicates biomass crops will be harvested late and will provide habitat in summer and winter for some forms of wildlife

Finally, we considered the purposes and criteria of standard Code 511 in terms of potential trade-offs in management to provide desired conservation and ecosystem services to the landowner and the public. Published US research literature was emphasized, but in some cases extension publications were used if based on literature and professional experience. In general, extension publications were based on sound scientific principles that were interpreted and adapted for state and regional conditions. This was expected since management research for local conditions is rarely published in national journals unless there is a unique feature that has regional or national application. Assessments of literature support for purposes and criteria of Code 511 were summarized (Table 4.1).

REGIONAL ADAPTATION OF FORAGE PLANTS

Scores of annual, biennial and perennial species are used as forages in humid areas of the eastern USA (Barker et al., Chapter 2, this volume). Some species are native, but most are introduced, and many of those introduced have become naturalized because of their long-term use (West and Nelson, 2003). Our assessments are also affected by regions due to increases in precipitation from the west, near the 100th meridian, eastward to the Atlantic Ocean, and to increases in average temperature and length of the growing season going from the Canadian border to the Gulf of Mexico. These climatic variations form a matrix of temperature and precipitation that affect the forage species grown (see Figs. 1.1 and 1.2, Chapter 1, this volume), the number of times it is harvested, and the dominant livestock enterprises of the region that use the forage (Allen et al., 2007). Pest, pathogen, and wildlife populations also differ among regions to give an array of variables that affect adaptation of each forage species and its optimum harvest management for economic return and conservation.

Species differ in morphology and forage quality that help define their management use for growing or milking livestock in defined geographic areas of adaptation (see Fig. 1.1; Baron and Belanger, 2007). Nearly all State Agricultural Experiment Stations conduct extensive applied research to determine the major species and mixtures that are best adapted to the specific climate and meet yield, quality, and persistence needs for major livestock enterprises of the state. Yield, quality, and stand longevity are emphasized to determine the optimal harvest management regimes for economic return. These recommendations may include more specific

“

Fortunately most states define optimum harvest times of forage crops according to growth stages based on flowering”

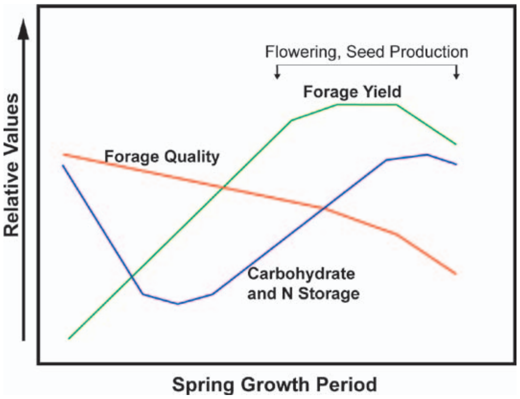


FIGURE 4.1. Relative changes in forage yield, forage quality, and content of carbohydrate and nitrogen reserves during the spring growth period. Data are generalized from several sources for legumes and the spring growth of most grasses.

management systems when the primary goal is yield, quality, or stand persistence. Cultivars within a species differ in maturity, seasonality of growth, yield potential, and quality of forage produced, thereby allowing some fine-tuning of management on a within-species basis for specific sites.

Fortunately most states define optimum harvest times of forage crops according to growth stages based on flowering of a monoculture or flowering of the most desired species in a mixture. This allows neighboring states to share performance data based on plant development such that recommendations for harvest management tend to have some similarity and transferability within geographic regions. Unfortunately there is little research on minor-use species or the latest “hot introduction,” which can lead to management decisions based on unreliable information, often based on promotional hype and testimonials. Eventually these factors are evaluated scientifically and documented in the literature, but by then there may be another generation of “wonder grasses” that needs scientific evaluation.

GROWTH HABIT AFFECTS YIELD AND QUALITY

Since there are many species to consider they were divided into groups based on adaptation to climatic regions and then to morphological features that favor mechanical harvests for conservation as hay, silage, or biomass.

Legumes like alfalfa (scientific names for all species mentioned are given in Appendix III), red clover, and upright-growing types of birdsfoot trefoil have erect stems and regrow from the plant base, that is, the crown that exists at the top of the root near soil level (Beuselinck et al., 1994; McGraw and Nelson, 2003). In general, these characters, especially upright growth, provide adaptation to repeated but infrequent harvest for hay or silage through the season. In contrast, low, prostrate growing legumes such as white clover and prostrate birdsfoot trefoil retain leaf area near the soil surface and are usually better adapted to pastures where plants may not have long rest periods between defoliations.

During spring growth the yield of a grass or legume gradually increases and quality decreases through the flowering stage (Buxton and Casler, 1993; Nelson and Moser, 1994), after which plant parts senesce and yield gradually decreases while the forage quality decreases more rapidly (Fig. 4.1). Upright growing legumes also differ in time to maturity; e.g., alfalfa reaches the desired cutting stage earlier than red clover, which is earlier than upright birdsfoot trefoil. This range of maturity among species allows staggered harvest times, which also affect growth of associated plant species and provision of environmental services and biodiversity.

Upright growing legumes have morphological development during each regrowth similar to that during spring growth. Thus, in general, early spring harvest and shorter durations between subsequent harvests reduce yield but increase forage quality (Kallenbach et al., 2002). The actual relationships between increase in yield and decrease in quality of alfalfa differ for each harvest depending on environmental factors (Brink et al., 2010). In Pennsylvania and Wisconsin the daily rate of decrease in alfalfa quality was greater during the spring growth and first regrowth periods than during later regrowths. Thus, in the eastern USA the timing of harvest for alfalfa and other legumes is most sensitive during the early growth periods of the growing season.

Summer annual legumes including common lespedeza and soybean are also used in hayfields (Sollenberger and Collins, 2003). In southern latitudes summer annual legumes such as smooth-seeded wild bean (Butler and Muir, 2010), and soybean, cowpea and pigeon pea (Foster et al., 2009; Rao and Northup, 2009) show potential. In the south, winter annual legumes can be planted into warm-season perennial grasses in autumn to extend the grazing season or to be harvested for hay in spring (Muir et al., 2007; Hancock et al., 2011). The legumes provide environmental and ecosystem value by providing winter cover and fixing atmospheric nitrogen. Some produce a seed bank for reseeding (Muir et al., 2005) and food for wildlife.

Legumes such as sweetclover and some other forbs are biennials that germinate in spring, grow through the summer, and overwinter to produce spring growth that can be harvested. Most will produce some regrowth after cutting then die. Nonlegume forbs in hayfields are usually managed as opportunists and are beneficial to wildlife, but often are low yielding and not valued highly for preserved forage. More assessments are needed on the overall benefits from these forbs.

Perennial grasses differ markedly in growth responses to temperature and are usually divided into cool-season and warm-season species based on their photosynthetic system and optimum temperatures for growth (Table 4.2; MacAdam and Nelson, 2003). Photosynthetic rates of warm-season grasses are as much as 50% higher than cool-season grasses, and this is reflected in faster growth rates, especially at high temperatures. All legumes have a photosynthetic system that is similar to cool-season grasses, but they exhibit greater concentrations of protein and most minerals. Many legumes, such as red clover, have temperature optima similar to cool-season grasses, but others, such as alfalfa, perennial peanut and lespedezas, have growth temperature optima that are intermediate between cool- and warm-season grasses.

Similar to legumes, most cool-season grasses harvested for hay or silage, like orchardgrass, tall fescue, smooth bromegrass, reed canarygrass and timothy, are upright growing and adapted to repeated but not frequent mechanical harvests. Except for timothy these grasses flower only one time in spring with optimum trade-off between forage yield and quality occurring between inflorescence emergence and anthesis (Fig. 4.1). Also, optimum dates differ among species to allow spread of harvest dates; for example, orchardgrass is several days earlier in maturity than is tall fescue, followed in order

"All legumes have a photosynthetic system that is similar to cool-season grasses, but they exhibit greater concentrations of protein and most minerals."

TABLE 4.2. Perennial grasses can be classified as warm-season or cool-season based on their photosynthetic process. The C_4 photosynthetic system is more efficient in light use than the C_3 system and is associated with high production and other characteristics. Adapted from several sources.

	Cool season	Warm season
Photosynthetic process, first product	C_3	C_4
Photosynthetic rate, g CO_2 m^{-2} leaf area h^{-1}	2.0–3.0	>3.5
Light saturation, % of full sun	50–60%	>100%
N content of young leaves, % of dry wt	2.5–4.0%	1.5–2.5%
Water use efficiency, g dry wt g water used^{-1}	Low	High
Optimum temperature range, °C	18–27°C	30–40°C
Daily growth rate, kg day^{-1}	Medium	High
Major representative species	Smooth bromegrass	Bahiagrass
	Kentucky bluegrass	Bermudagrass
	Orchardgrass	Big bluestem
	Reed canarygrass	Caucasian bluestem
	Tall fescue	Indiangrass
	Timothy	Switchgrass

“Switchgrass, big bluestem, and indiangrass are tall, upright growing grasses that are the main native warm-season perennials suitable for conserving forage as hay.”

by perennial ryegrass, smooth bromegrass, and timothy (Balasko and Nelson, 2003). Further, late cultivars within a species matured 4, 8, 9, and 14 d later than did early cultivars for tall fescue, orchardgrass, timothy, and ryegrass, respectively (Hall et al., 2009), providing another way to obtain a range of first harvest dates.

Regrowths of most cool-season grasses consist mainly of leaves causing forage quality to decline at a slow rate (Brink et al., 2010). Hay made from leafy regrowth of grasses, especially orchardgrass, is prized for certain niche uses such as for young dairy calves, horses, and perhaps sheep, in part because it dries rapidly, is unlikely to mold if managed properly, and is very soft in texture. In most cases, however, the leafy regrowths of grass stands are grazed instead of being harvested mechanically.

Switchgrass, big bluestem, and indiangrass are tall, upright growing grasses that are the main native warm-season perennials suitable for conserving forage as hay. Optimum time of harvest for these grasses is later in the season than cool-season species in the same area, which again allows spread in harvest dates. Switchgrass is generally 4 or more wk earlier in maturity than big bluestem (Fig. 4.2), which is 2 to 3 wk earlier than indiangrass. These upright growing warm-season grasses, including some old world bluestems, have stiff stems that provide good habitat for wildlife, even during winter, and serve well as grass barriers for riparian areas (Karlen et al., 2007). These warm-season grasses are better adapted to drought and cold winters and grow much taller than bermudagrass, bahiagrass, or caucasian bluestem. The latter three grasses are introduced warm-season perennials that exhibit considerable prostrate growth and can be grazed or cut and preserved as hay. Napiergrass is a tall, upright warm-season grass that is adapted to subtropical areas.

Summer annuals (e.g., oat, corn, and pearl millet) or winter annuals (e.g., wheat, rye, or triticale) can be harvested for forage (Moser and Nelson, 2003). Annual grain crops decrease in forage quality as they grow until flowering but, in contrast to perennial forage grasses, may increase again in quality as the grain develops. True annuals are usually harvested only one time, near anthesis, because of poor regrowth. Forage sorghums are perennials that have some regrowth after cutting, but they lack cold hardiness and are managed like annuals throughout most of the USA. Annual forages were not reviewed in detail for our analysis of conservation benefits because many of the environmental and ecosystem relationships are similar to those resulting from grain harvest (Schnepf and Cox, 2006).

In summary, forage stands for hay or silage harvest consist mainly of upright growing plants with emphasis on the first cuttings, which have the highest potential for yield and quality. The yield of regrowths is usually lower and has a slower rate of decrease in quality, and the forage value is less sensitive to timing of harvest. Thus, most landowners are less flexible for adopting conservation practices that would lower economic return during the first harvest compared with later harvests. Unfortunately, most water management and erosion challenges from short stubble occur during the high rainfall period that also coincides with the dominant time of bird nesting and fledgling. As described there are alternative species that match with earlier or later harvests. And height of cut will also affect the amount of vegetation remaining for water management and certain wildlife. These details are considered in the analysis.

HARVEST MANAGEMENT FOR STAND PERSISTENCE

Delayed harvest usually allows more carbohydrate and nitrogen storage in roots of upright-growing legumes or in the lower plant parts of grasses, which can be used to support regrowth vigor and persistence (MacAdam and Nelson, 2003). Vigorous plants are more competitive with weeds and other species resulting in better plant persistence, especially the proportion of desirable legume plants within mixed swards. Depending on livestock requirements, or for nonlivestock purposes, harvest management requires compromises to produce the largest quantity of a quality product for the desired number of years.

Strategies for plant persistence of perennial legumes are based on whether they are crown formers using a single taproot (e.g., alfalfa)

TABLE 4.3. Legumes differ in their persistence strategies depending on whether they are crown formers that retain the original root or if they are clone formers that spread laterally by stolons or rhizomes and take root. Annuals, biennials, and short-lived perennials must reseed naturally or have seed applied at a regular interval. Adapted from Beuselinck et al. (1994).

Species name	Persistence strategy			Life cycle		
	Crown former	Clone former	Reseeder	Annual	Perennial	Biennial
Alfalfa	X				X	
Arrowleaf clover			X	X		
Barrel medic			X	X		
Berseem clover			X	X		
Big trefoil	X		X		X	
Birdsfoot trefoil	X		X		X	
Black medic			X	X		
Burr medic			X	X		
Cicer milkvetch	X	X			X	
Common lespedeza			X	X		
Crimson clover			X	X		
Crownvetch		X			X	
Hairy vetch			X	X		
Korean lespedeza			X	X		
Kura clover		X			X	
Leucaena	X				X	
Persian clover			X	X		
Red clover	X		X		X	
Rose clover			X	X		
Sanfoin	X				X	
Sericea lespedeza	X		X		X	
Subterranean clover			X	X		
Sweetclover (white)	X		X			X
Sweetclover (yellow)	X		X			X
White clover		X	X		X	

or clone formers that can form new plants by spreading laterally using stolons (e.g., white clover) or rhizomes (e.g., crown vetch; see Table 4.3). Crown formers depend on longevity of individual plants and rarely reseed (Fig. 4.3). Clone formers must have a low canopy density at certain times to allow light penetration to stimulate shoot development from stolons and rhizomes, but this also allows annual weeds to invade. In addition, canopy density has to be extensive enough during summer to shade the soil to maintain low soil temperatures and restrict germination and development of annual weeds.

Plant persistence of alfalfa in Missouri was reduced by frequent harvest since plants were weakened and died allowing weeds to invade the stand (Kallenbach et al., 2002). There was little difference in persistence among cultivars. In Kentucky new alfalfa cultivars differed only slightly in yield and persistence under a

“Most managers want to reduce risk of winter kill of legumes, which can result in complete loss of a stand.”

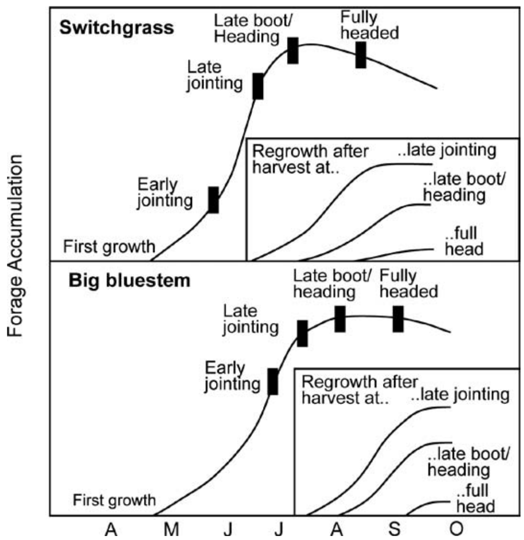


FIGURE 4.2. Switchgrass in Nebraska goes through various growth stages earlier in the season than does big bluestem. Harvest at earlier stages of maturity of both species increases duration and amount of regrowth. Adapted from Mitchell et al. (1994).

range of harvest frequencies, but all cultivars were best when cut at early bloom and 35-d intervals compared to intervals of 25, 30, or 40 d (Probst and Smith, 2011). Lodging occurred more frequently at the 40-d interval. Many dairy farmers elect to harvest alfalfa more frequently, before blooms appear, knowing stand life will be reduced which is compatible when grown in rotation with row crops.

Most managers want to reduce risk of winter kill of legumes, which can result in complete loss of a stand. Thus, management strategies have been researched to ensure the plants in northern areas have 4 to 6 wk of growth in autumn to become winter hardy (Volenec and Nelson, 2003). In most areas it is critical to provide a canopy through winter to reduce soil freezing and thawing that causes heaving and death of plants (Fig. 4.4). Research in Missouri indicates alfalfa yield in late fall is low and rarely economic to harvest, even when plants are cut infrequently during the season (Kallenbach et al., 2005). In southern areas perennial legume plants are managed carefully during summer to ensure the plants are not cut or grazed too closely. High soil temperatures can weaken plants to be less competitive with weeds and less tolerant of insect damage and diseases. Perennial grasses are less sensitive to fall management than are upright legumes.

Reseeding is not common with upright-growing legumes because plants are harvested before seed development occurs with the result that stand persistence depends mainly on individual plant persistence (Fig. 4.3). If encouraged to reseed naturally, harvest must be delayed to allow seed to be produced, dropped to the soil, have adequate seed-soil contact, and be able to germinate at the proper time. When germinated, the seedlings need to emerge with minimal competition from species already present, whether they are desirable or weedlike (Barker et al., Chapter 2, this volume). Alfalfa plants are unique in that autotoxic compounds released to the soil inhibit germination and root growth of alfalfa seedlings for 6 mo or more (Jennings and Nelson, 2002).

Stand persistence of annual legumes like striate lespedeza (Davis et al., 1994) or several winter annual legumes (Muir et al., 2005) depend on natural reseeding. Needs for reseeding also occur with biennials and short-lived perennials like red clover and birdsfoot trefoil that succumb to diseases (Beuselinck et al., 1994). Plants need to be managed to produce seed naturally, which works for birdsfoot trefoil and lespedeza (Redfearn and

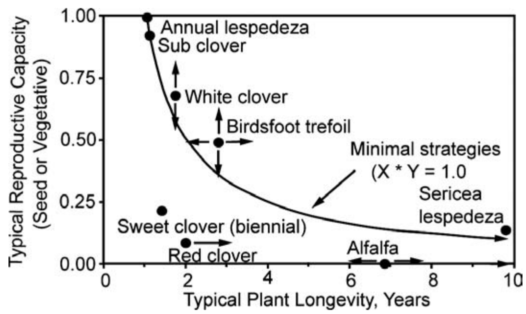


FIGURE 4.3. Annual legumes maintain the stand by reseeding themselves whereas long-lived perennials maintain the stand by plant longevity. Perennial plants differ in their reproductive capacity from seed or vegetative spread to form new plants. The solid line (X × Y = 1.0) is the minimal capacity from each process needed to maintain the stand indefinitely. Arrows associated with each data point indicate how management can alter the longevity or reproductive capacity. Adapted from Beuselinck et al. (1994).

Grassland specialist discusses pasture condition with farmer in Missouri. NRCS photo by Charlie Rahm.

Nelson, 2003). Red clover is well known for its good seedling vigor (Gist and Mott, 1958), but managing for seed production and natural reseeding has not been consistently reliable. Instead it is reseeded regularly, usually in late winter, and the existing canopy needs to be controlled (Barker et al., Chapter 2, this volume). In addition, proper fertilization regimes are critical to stimulate vigor of seedlings and not the competing canopy.

Aside from crabgrass, few annual forage grasses are used for hay or silage, and there are no important biennial grasses, so emphasis is usually on perennials. Perennial grasses also can be classified as bunch formers or sod formers. Bunch formers such as big bluestem and orchardgrass are somewhat similar to crown-forming legumes in that the lateral buds near the soil level develop into upright tillers that contribute limited lateral growth (Moser and Nelson, 2003). This usually leaves open areas of soil between plants. Other grasses such as smooth bromegrass, reed canarygrass, bahiagrass, and bermudagrass are sod formers that spread by lateral tillers, rhizomes, or stolons to fill in open spaces. Compared with upright bunch grasses, sod formers have smaller tillers, thinner stems, more leaf area near the soil surface, and are more tolerant of frequent cutting to short stubble heights. Tall fescue produces short rhizomes and is flexible; it is bunchy when cut infrequently and sod forming when cut or grazed frequently.

Grass plants cut during reproductive growth of the first harvest depend on carbohydrate and nitrogen reserves stored in the plant for vigorous regrowth (Fig. 4.1). Vegetative regrowths of cool-season grasses during summer and fall depend largely on photosynthesis from residual leaf area. As described above, associated legumes tend to repeat the canopy shape and flower in each growth period, whereas the dramatic shift in grass morphology changes the competitiveness

“Some managers emphasize grazing as the preferred harvest method but still use a single mechanical harvest for hay or silage as a tool to prepare hayfields or pasture areas for grazing.”

FIGURE 4.4. Alfalfa plants lifted from the soil by freezing and thawing of the surface soil in Iowa. The root is broken, and the plants will be weak and die. Photo courtesy of Steve Barnhart.

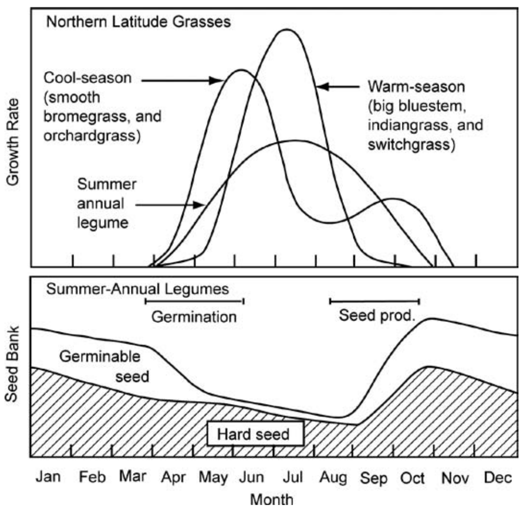


FIGURE 4.5. Annual growth curves for perennial cool-season grasses (top) and annual warm-season legumes (bottom). Cool-season grasses have reproductive growth during spring followed by vegetative growth for the rest of the year. Summer-annual legumes germinate in spring when competition is low and produce seed in autumn.

of the canopy. This difference in canopy structure during regrowths needs to be understood to effectively manage fertilization and cutting management of forage mixtures to maintain desired proportions of grasses and legumes (Fig. 4.5). In contrast with cool-season grasses, introduced warm-season perennial grasses (e.g., bermudagrass and bahiagrass) tend to flower repeatedly during summer, so production is not as cyclical (Fig. 4.6). The grasses regrow from buds that are supported by current photosynthesis of residual leaf area and some carbohydrate stored in stem bases.

REASONS FOR FORAGE HARVEST

Some managers emphasize grazing as the preferred harvest method but still use a single mechanical harvest for hay or silage as a tool to prepare hay fields or pasture areas for grazing. In this case, timing of the single harvest, being early or late, and proper height of cutting are based on stimulating vigorous regrowth for pasture. Seed harvest of cool-season grasses is another option that occurs very late when stems are mature and provides nonforage income and prepares the stand for grazing. In this case, residual herbage after seed harvest that consists of basal parts of stems and old leaves should be harvested, packaged, and stored as low-quality forage. Removing residue after seed harvest opens the canopy to stimulate new tillers and regrowth, which shortens the time needed before leafy regrowth can be grazed later during summer or accumulated for autumn or winter grazing (Sollenberger et al., Chapter 3, this volume).

Since the spring growth period is usually the most productive, especially with cool-season grasses, it is the most desired stage for hay or silage production. Under these circumstances, other animals are needed or selected pastures of the forage area on a farm may be harvested once while other areas are grazed during spring. Then, during summer and fall when growth is slower, the entire area is grazed, either continuously or rotationally (Sollenberger et al., Chapter 3, this volume). This allows the manger to “rotate” the areas cut for hay or silage such that any one area is mechanically harvested about 1 yr in 3. Fertilizer timing and allowing plants to grow to near maturity for mechanical harvest are adaptive management practices that can revitalize the stand by reducing weed problems, altering insect cycles, reducing disease pressures, and restoring a better balance of legumes and grasses in the mixture. It may also be more wildlife friendly.

SUMMARY

The Practice Code requires conservation practices be a part of the total management strategy for hay and silage crops. Most conservation practices include reducing soil erosion, maintaining water quality of runoff or flow through, and providing wildlife food supplies and habitat that all depend largely on maintaining groundcover. Achieving the multiple objectives of yield, quality, and species composition while controlling insects, diseases, and weeds, being an effective nutrient uptake tool, and maintaining or improving wildlife habitat will require compromises in management. How that is achieved will depend on balancing priorities and incentives.

As pointed out above, most forage species used for hay or silage are upright growing grasses and legumes that can be grown in monoculture, especially alfalfa, or in legume-grass mixtures. For the latter the maturities need to be matched so components are compatible when harvested at appropriate times. Harvest management and species selection also affect winter ground cover, rate of regrowth after harvest to reestablish adequate ground cover, appropriate cutting heights, and optimal timing of fertilizer or manure applications. Fortunately there is flexibility among options like species selection, harvest stages, cutting heights, cutting frequency, and potentials for providing ground cover throughout the year. The literature review is focused on achieving the multiple purposes and criteria described in the Conservation Practice Code 511 (Table 4.1).

THE CEAP ASSESSMENT OF FORAGE HARVEST MANAGEMENT

To determine if prescribed practices are effective in meeting the purposes, a series of questions were framed to focus on each purpose (Table 4.1). Then US scientific literature, especially peer-reviewed literature, was reviewed to determine if the practice, in fact, did provide the production goals, desired ecosystem services, or both. As discussed above, general principles of harvest management have been researched by scientists at Agricultural Experiment Stations within each state to know when forages can be harvested to obtain maximum economic return to the producer. But the standard also has primary challenges of evaluating if and how forages could be managed more flexibly to obtain forage yield and quality at some acceptable level, while promoting vigorous plant regrowth, maintaining stand life, and providing desired ecosystem services.

Special attention was given to whether the prescribed practice maintains desired species composition over time, whether biomass produced is effective in soil nutrient uptake, and if management can be flexible enough to help control insects, diseases, and weeds while maintaining and/or improving the environment and biodiversity of wildlife. This approach by purposes helped organize the assessment for each criterion, after which an overall assessment of research support was made and deficiencies noted in Table 4.1.

PURPOSE 1: OPTIMIZE YIELD AND QUALITY AT DESIRED LEVELS

With increasing costs of concentrate feed supplements there is more emphasis on high protein and generally higher quality forage to help offset concentrate use for dairy and beef production. This emphasis can affect species selection, as well as harvest time and frequency. Mixed grass-legume stands are more likely to provide higher quality forage than pure grass stands (Merry et al., 2000). Increased desire for higher quality forage often results in harvesting more frequently, which may reduce stand life and potential benefits for wildlife.

Harvest Time and Frequency

Land-grant universities and other agencies in the eastern USA have done a good job of

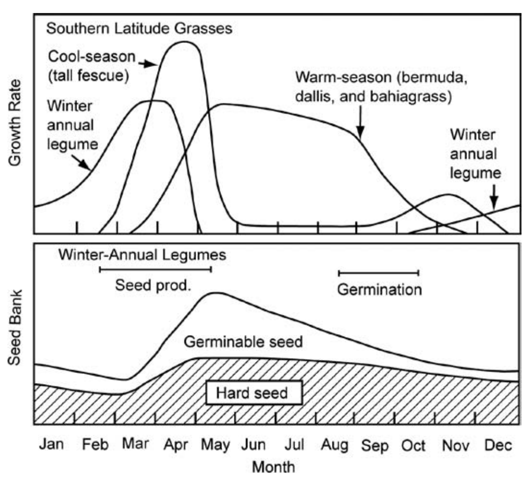


FIGURE 4.6. Warm-season grasses like bermudagrass have an extended period of high production that slows as days get shorter and cooler in autumn. Winter annual legumes provide additional forage and N fixation. Adapted from Bueselinck et al. (1994).

> "desire for higher quality forage often results in harvesting more frequently, which may reduce stand life and potential benefits for wildlife."

“Overall, State Experiment Stations and Cooperative Extension Services have effectively provided adaptation and sound management recommendations for the major species and cultivars grown in their area.”

researching harvest management for major species grown in various geographic areas. Emphasis, however, has usually been on monocultures or legume-grass mixtures with goals of optimizing economic return to the producer in terms of yield, quality, and stand persistence. For example, recommended management of alfalfa for North Dakota focuses on winter hardy cultivars and good fall cutting management to allow development of winter hardiness. Cultivars with high winter dormancy (Group 2) are recommended, and stands are harvested two or three times at early bloom stages before 25 August (Meyer and Helm, 1994). Yields are similar, but quality is higher with three cuts. Another cutting can be made after plants stop growing in October, but strips should be left uncut to catch snow for insulation to reduce winter kill.

In Iowa, with a longer growing season and less severe winters, moderately dormant cultivars of alfalfa (Group 4) are recommended. They can be cut four times at early flowering with the last cutting by 1 September (Smith, 2008). Winter damage was increased when final cutting was delayed from mid-September to mid-October, and yield of first cutting the following year was reduced by 1.4 Mg ha^{-1}. Removing late growth (cut 5) is cautioned on poorly drained soils since the standing regrowth provides insulation against cold and reduces freezing and thawing of the surface soil that may lead to frost heaving of plants (Fig. 4.4). In Kentucky, Group 5 alfalfa is adapted, and the crop is cut five times at early bloom. A late harvest or a late fall grazing is acceptable after growth has stopped. With milder winters the importance of fall management is lessened.

In general first cutting of alfalfa should be made at early bloom stage, but high temperatures are known to hasten maturity and flowering, so intervals between harvests are longer at northern locations. All states recommend cultivars with appropriate winter dormancy rating and prescribe P and K applications to improve persistence and yield. There is more emphasis on insects and diseases at southern locations. In all cases, management recommendations are based on the same basic principles that have been adapted for the environment, soil conditions, and length of growing season using local research.

These basic observations on management changes based on latitude are consistent for all major species of legumes and grasses. In general, plant adaptation principles can be transferred longitudinally more easily than across latitudes. Thus, similar to hardiness groups of alfalfa, different ecotypes of most perennial grasses have become naturalized over time for specific latitudes, especially native warm-season grasses. Cultivar differences within species of cool-season grasses allow adaptation across broader latitudes than do cultivar differences for many legumes (Baron and Belanger, 2007; Hall et al., 2009). Alfalfa is a marked exception since cultivar differences in fall dormancy and winter hardiness allow adaption in nearly all areas of the USA from California to Maine and from Florida to Alaska.

Loosely defined areas of geographic adaptation hold for other legume and grass species (Barnes et al., 2003; Hannaway et al., 2005). Good data are available for most species showing forage quality at harvest is inversely related to growing temperature. High temperatures are associated with lower concentrations of easily digested sugars in leaves and stems, a shift toward more cell wall and lignin formation, and a tendency to have smaller and shorter leaf blades (Buxton and Casler, 1993; Nelson and Moser, 1994). Thus, on average, quality of forage at the same growth stage is higher in northern locations than in southern locations (Matches et al., 1970). There is considerable indirect evidence that plant persistence is related more closely to winter temperatures in the north and to disease and weed pressures in the south. Overall, State Experiment Stations and Cooperative Extension Services have effectively provided adaptation and sound management recommendations for the major species and cultivars grown in their area.

A major contribution of USDA-ARS to geographic adaptation has been the revised Plant Hardiness Map (Fig. 4.7) that is based on average minimum winter temperature and is interactive with GPS and other tools to assist in determining adaptation of species to geographic areas. The revised map has a stronger base than the 1990 version, and zone boundaries in the map have shifted in many areas. The new map is generally one half-zone warmer than the previous map throughout much of the USA, as a result of a longer and more recent averaging period (1976–2005). Some changes in zones are due to use of new, more sophisticated mapping methods and a greater number of observation stations. Thus, the revised map has greatly improved accuracy, especially in mountainous regions. Because of the way the map is constructed, using data for only 30 yr, it is not an indicator of global change which requires longer durations. Nevertheless, it provides an updated and interactive tool that could have value for species selection and management in various areas of the USA.

The hardiness map is used diligently by scientists and others in the horticultural community, yet is rarely mentioned in forage management literature (Baron and Belanger, 2007). Instead, ecoregions for adaptation of grasslands and forage species are usually focused on energy balance (Gates, 1980), growing degree days (Hall et al., 2009), precipitation balance including evaporation (Bailey, 1996), and soil and climate effects (Hannaway et al., 2005). These adaptation regions are less familiar with the forage and grassland community than the hardiness map is with horticulturalists. Seemingly the Plant Hardiness Zone Map could be made more practical for forage and pasture applications if upgraded to include some aspect of precipitation efficiency and/or perhaps soil issues like erosion potential. This approach and understanding will become more critical for adaptation as climate change occurs, which will lead to greater public concern about conservation and sustainability.

Further, more research information is needed on minor forage species or those species, including forbs, that may have potential as forage crops in an area. The USDA-ARS Plant Introduction Stations, especially the North Central Regional Plant Introduction Station in Ames, Iowa, and the Western Regional Plant Introduction Station in Pullman, Washington, play significant roles in evaluation of introduced legumes and cool-season grasses. Each site has primary responsibility for appropriate genera to acquire and evaluate new plant germplasm and to establish a maintenance program. These stations play significant roles in assessing areas of potential adaptation of introduced species for forage and assist with initial seed supplies of adapted species that may fit niche areas or have values that go beyond forage production.

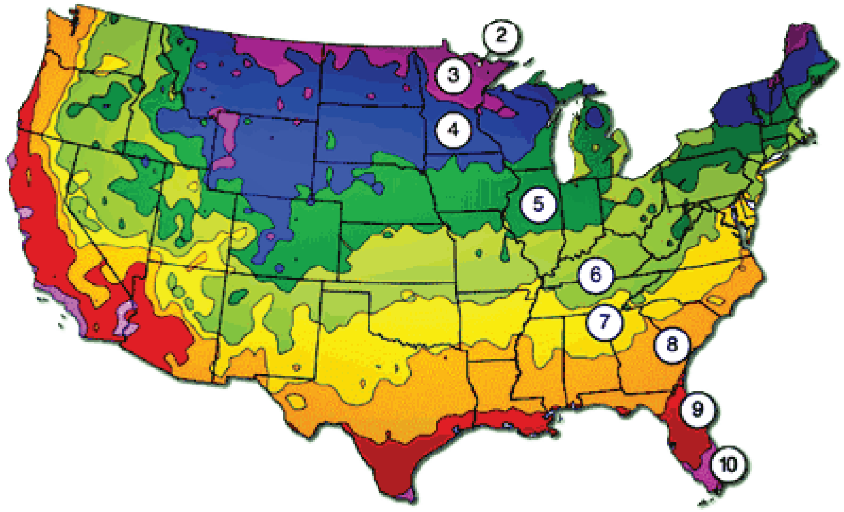


FIGURE 4.7. The 2012 version of the USDA Plant Hardiness Map shows revision of the adaptation zones over previous maps due to a stronger database. Note temperature isolines are generally oriented east-west except near water bodies. Zone 10 is down to −1°C, Zone 8 is down to −12°C, Zone 6 is down to −23°C, Zone 4 is down to −34°C, and Zone 2 is down to −46°C. Image courtesy of USDA.

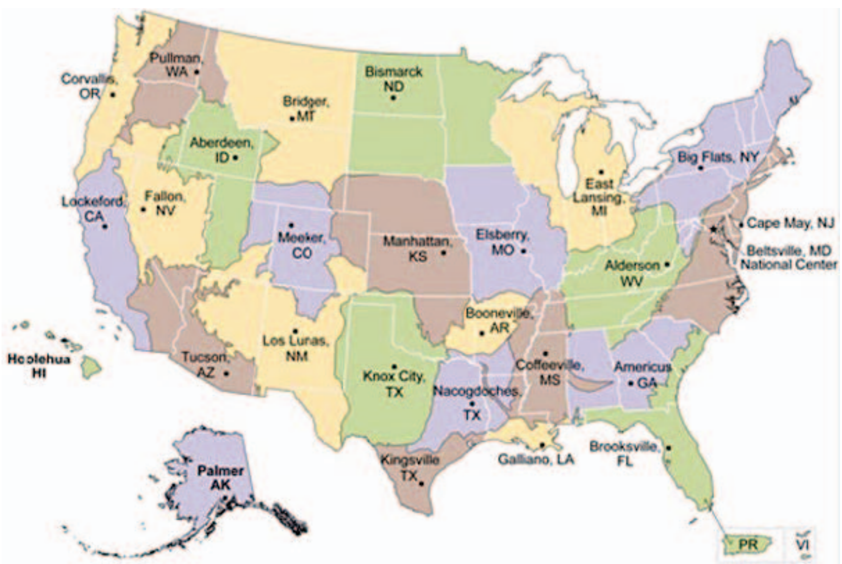


FIGURE 4.8. Locations of the 27 USDA-NRCS Plant Material Centers that evaluate new plants for adaptation and basic management principles for conservation purposes. Centers also provide seed to commercial seed growers who increase the supply for use by landowners. Image courtesy of USDA-NRCS.

In addition, USDA-NRCS maintains a network of 27 regional Plant Materials Centers that help meet the growing interest in use of native plants and some introductions, especially those unique plants that may help solve conservation problems (Fig. 4.8). The centers locate and evaluate plants for conservation traits and make these materials available

“Cost-effective solutions for conservation objectives require coordinated approaches that involve NRCS, other federal and state government agencies, agricultural experiment stations, cooperative extension service, private groups, and individuals.”

to commercial growers who provide plant materials to the public. Evaluations involve some research and result in application-oriented technology for the region including technical publications, fact sheets, identification, and release of conservation plants for further research and land restoration. The Centers have released over 600 grasses, legumes, forbs, shrubs, and trees for conservation purposes.

It is clear that plants offer versatility and a cost-effective tool for long-term protection and improvement of the environment. It would be helpful to the total effort if there was more applied research to determine best management practices for these new conservation plants. Cost-effective solutions for conservation objectives require coordinated approaches that involve NRCS, other federal and state government agencies, agricultural experiment stations, cooperative extension service, private groups, and individuals. As conservation issues and ecosystem services increase in importance, there will be even greater needs for education and evaluation of management options to maintain credibility and meet the growing demand.

Cooperative extension, NRCS field staff, and private organizations have direct connection to provide timely and appropriate information to landowners, managers, and the public about conservation issues. In addition, Plant Materials Centers provide vital plant data to support decision-making tools such as the Revised Universal Soil Loss Equation (RUSLE 2), Wind Erosion Prediction System (WEPS), and Grazingland Spatial Analysis Tool (GSAT). These tools are used in NRCS field offices to assist landowners conserve the nation's natural resources. It is critical that effective linkages among the key players are maintained so messages transferred are consistent and based on available research.

Harvest Intervals and Stubble Height

Considerable literature documents how general principles of growth, regrowth, cutting frequency, residual leaf area, and reserves of carbohydrate and nitrogen affect regrowth of most major forage species (Fig. 4.1; MacAdam and Nelson, 2003). Implications from water stress (leaf growth is reduced more than root growth), inundation (roots are deprived of oxygen), temperature stresses (too cold or too hot affects metabolic processes and growth), and fertilization regimes (nitrogen usually stimulates growth of grasses at the expense of reserve storage and reduces N fixation by legumes) on regrowth have been well developed for the major species. And these basic principles can be applied directly to their management. In addition, understanding local soils and climates helps determine the best management to be used. Local knowledge can be based on field demonstrations, especially those not novel enough to be published in refereed journals, or on broad experience of professionals.

Basic principles of forage management have been assembled into good extension publications that are based on published science and observations. For example, Rayburn (1993), in West Virginia, discusses growth and development of cool-season grasses and legumes to explain how these processes can be managed to optimize production and utilization. He emphasizes allowing reserves to be restored during spring growth before harvesting alfalfa, red clover, orchardgrass, and tall fescue for hay or silage. At this stage the yield advantage occurs by leaving a short stubble (5 to 8 cm), and regrowth is rapid. But quality of forage may be lower as cutting height is reduced since the lower canopy is mainly stem. Subsequent regrowths of alfalfa or red clover can be cut infrequently to leave a short stubble because they are able to restore reserves and depend very little on leaf area. This knowledge was further supported in research-based extension recommendations for stubble height of alfalfa in Wisconsin (Wiersma et al., 2007).

In contrast with alfalfa and red clover, cool-season grasses shift in growth habit after first cutting. Vegetative regrowths in West Virginia should have about 10 cm of stubble to ensure adequate leaf area to support regrowth (Rayburn, 1993). This recommendation is consistent with extension recommendations from Minnesota (Peterson and Thomas, 2008) in which they suggest grasses cut infrequently, especially during summer, should retain a stubble height of about 10 cm. In addition to providing sufficient leaf area to support regrowth, they emphasize the value of leaf area for shading to reduce soil temperatures,

Grassed waterway is part of the conservation plan in Iowa. NRCS photo by Lynn Betts.

reduce soil moisture evaporation, and provide competition with weed seedlings.

Peterson and Thomas (2008) gave further guidance on how cutting height could be used to maintain desired alfalfa-grass proportions in hay fields by leaving shorter stubble in summer to favor the legume or a longer stubble to favor grass. Further, they ranked grasses according to sensitivity to leave 3.5-cm of stubble compared with 10 cm citing research data from Wisconsin. Smooth bromegrass and timothy were more sensitive to close cutting than were orchardgrass, reed canarygrass, and tall fescue. The effect of increasing stubble height on forage quality of both alfalfa and grasses has been found to be minimal (Parsons et al., 2009; Parsons et al. 2011). In Georgia tall fescue that was endophyte infected was not affected by cutting at 3-wk intervals at 3.8 cm or 7.6 cm. But yields of the same cultivars without endophyte were about 25% lower when cut at 3.8 cm (Hoveland et al., 1997). It is clear that extension specialists are aware of research in surrounding areas and can effectively apply the principles to the local condition. For example, use of disc mowers and short cutting heights can shift bermudagrass–tall fescue mixtures rather quickly to a bermudagrass monoculture.

Leaving a tall stubble height is generally considered to be more important for upright-growing warm-season grasses than for cool-season grasses, especially with frequent defoliation (Anderson and Matches, 1983). Responses to stubble height and frequency of cutting have been well documented for most upright warm-season grass species, and information is available in extension publications. But there is a shortage of emphasis on how environments affect responses and delivery of ecosystem services. For example, proper cutting height and frequency are critical for maintenance of native warm-season grasses in dryer areas of the eastern Great Plains (Owensby et al., 1974; Mitchell et al., 1994) and for bermudagrass in warmer areas of the South (Ethredge et al., 1973). But there is evidence from eastern states that these native warm-season grasses can tolerate closer and more frequent cutting in cooler areas with more rainfall (e.g., Forwood and Magai, 1992). Thus, similar to other studies with a range of forage plants (Balasko and Nelson, 2003; McGraw and Nelson, 2003; Redfearn and Nelson, 2003; Sollenberger and Collins, 2003), plants grown in lower stress environments, due to either biotic or abiotic challenges, are better able to tolerate close and frequent harvest.

Moisture Management for Curing and Storing

A major goal of forage and silage management is to harvest when the crop is at the optimum stage for economic return, but this goal is further affected by need to preserve as much yield and quality as possible during drying, packaging, and storage periods. Rapid drying is the most important factor to achieve proper moisture content for storage with least loss in dry matter, especially leaves. Standing forage is typically 75–85% moisture and needs to be dried quickly to less than 70% moisture for silage, 50–60% for haylage, and about 20% for baling as hay (Rotz and Muck, 1994).

About 25–30% of the total water from stems and leaves is lost rapidly through stomata for the first hr after cutting; after this time stomata close as plants wilt. Loss of remaining water through waxy layers on the stem and leaves is hastened if stems are crushed by a roll conditioner, which is better for legumes than crimping, which breaks the stem every few cm (Rotz, 1995), or scratched mechanically by a flail mower or a tine conditioner, which is better for grasses (Klinner, 1976; Digman et al., 2011). A thick forage mass going through the roller or flail mower decreases amount of conditioning received so operational speed is a factor. Final drying from 30–40% moisture to 15–20% for baling is slowest, during which time forage is most subject to damage from rain or high humidity. While reducing probability of weather damage, conditioning may lead to increased handling losses later.

In general, flail mower conditioners have greater power requirements than sickle-mower roll-type conditioners because of the need to accelerate and convey cut forage by blade force, which leads to greater field losses of small pieces (McRandal and McNulty, 1978; Rotz and Sprott, 1984). Minimum blade velocity for cutting grass or oat straw was 20 m s^{-1}, and power required for cutting actually decreased when blade velocity was increased to 60 m s^{-1} (McRandal and McNulty, 1978). In their field evaluations with eight grasses and oat straw, at a blade velocity of 78 m s^{-1} and forward velocity of 5.5 km h^{-1}, total power consumption increased linearly as crop density increased from 0.95 to 5.4 kg m^{-2}. Throughout, energy to cut stems was minimal (3%) compared with that needed to accelerate and propel forage out of the machine (> 50%). Using a disc rotary cutter, actual stubble height increased from near the fixed height of 5.0 cm at forward velocity of 5.5 km h^{-1} up to 6.3 cm of nonharvested stubble (1.8% field loss) at 14.2 km h^{-1} (Ponican and Lichar, 2004). Losses of small pieces and other breakage due to swathing of forage cut with a disc rotary mower also increased from about 1.5% up to 6.4% as raking velocity increased.

Solar radiation is the most important factor affecting drying in the swath followed in order by air temperature, relative humidity, wind speed, and soil moisture (Rotz and Chen, 1985). Therefore, the upper surface of the swath dries most rapidly indicating the

Conservationist teaching landowners about grasses for buffer strips. NRCS photo by Bob Nichols.

advantage of having wide windrows that are not thick. It also indicates why tedding or turning the windrow increases rate of drying. Forage may increase in moisture content due to absorption of water vapor from air during times of high humidity, mainly during the night, or from dew formation when liquid form is absorbed into dry inner parts of leaves and stems (Rotz, 1995). Thereafter, drying needs to resume, and it takes more time before forage reaches proper moisture content for storage.

Rainfall on the windrow is particularly challenging because it can move into tissues as liquid, like dew, and if duration and intensity are great enough some rain will pass through the forage swath to increase soil water content. Surface water on the plants can dry rather rapidly after rain ceases depending on solar radiation and relative humidity. Water absorbed by plant tissue dries slower, and high humidity due to evaporation within the swath will be a further deterrent. With light rain of short duration a wide swath will retain a higher amount of water on plant surfaces than a narrow swath and will dry quickly. With a heavy rain the swath width makes little difference (Rotz, 1995). Conditioned forage may absorb more water into plant tissue than nonconditioned forage during rain events (Rotz, 1995).

Swath manipulation by tedding, inversion, or raking can speed drying since the top of the swath dries faster than the bottom. But there is leaf loss that depends on moisture content (Fig. 4.9). Further, each field operation increases fuel, labor, and machinery costs and increases leaf loss. Leaf loss of grasses from tedding is only about 25% that of alfalfa (Savoie, 1987). Routine tedding or inverting is rarely cost effective for legumes due to high leaf loss (Rotz and Savoie, 1991) but may be cost effective with grass crops for hay (McGechan, 1990).

Based on summary data from Rotz and Muck (1994), harvest losses of legumes averaged 1% for mowing, 2% for mowing and conditioning, 3% for tedding, 1% for swath inversion, 5% for raking, and about 4% for baling. With grasses losses from cutting and conditioning and from tedding were slightly lower than for legumes, whereas losses from other operations were similar. But the literature is consistent

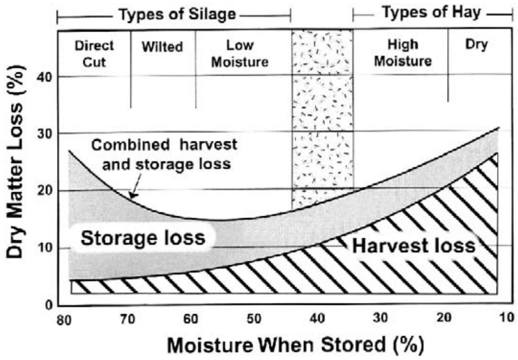


FIGURE 4.9. Typical losses in dry matter when legume-grass forage is stored at various moisture levels. Note losses in haymaking are due mainly to field situations, whereas those for silage making are due mainly to storage conditions. Adapted from Collins and Owens (1993).

“Some dry matter loss during handling and storage is unavoidable; it usually affects leaf loss, so proportional loss in quality is greater than loss in yield”

that moisture content for both should be above 30% for raking.

Some dry matter loss during handling and storage is unavoidable; it usually affects leaf loss, so proportional loss in quality is greater than loss in yield and depends largely on moisture content of forage (Fig. 4.9). Losses are primarily during storage for silage that is preserved at 60% moisture, whereas losses are mostly field losses for hay that is baled at 15% moisture (Fig. 4.9). Comprehensive research reviews conclude the most important factors leading to loss are respiration, leaf shatter, microbial activity, and color bleaching (Rotz and Muck, 1994; Collins and Coblentz, 2007). Minimal loss with near perfect conditions is about 15% of total dry matter and should be a goal (Rotz and Abrams, 1988). Based on five research reports, Rotz and Muck (1994) concluded average losses in hay making are between 24% and 28%. This suggests there is room for improvement.

Several research studies support baling hay at 20% moisture or less for long-term storage. Most published studies showed losses during indoor storage are about 5% for both legumes and grasses, but are about 15% for legume bales stored outdoors and about 12% for grass bales when both are stored off the ground on rocks or a platform. These summations support the NRCS practice standard for forage handling and storage.

Conservationist and landowner discuss a management plan. Photo by Paul Fusco, NRCS.

Weather-induced losses are a major consideration in harvest management. Short intervals between rain events and the resulting high humidity require critical harvest timing to minimize losses due to weathering and to reduce soil compaction from heavy equipment on wet soils. During first harvest in spring the time required between cutting and forage removal from the field can be a few hours for preservation of silage, about 2 d for packaging and storing as haylage and 3 to 4 d when baled and stored as hay. Spring weather patterns in much of the eastern USA do not have sufficient dry periods to cut at the proper harvest stage and store quality hay. For these reasons, many producers accept loss of hay quality by delaying harvest, which allows plants to become more mature but coincides with less weather risk. However, harvest delay may provide some wildlife and environmental benefits.

Estimating Moisture Content of the Forage

Measuring moisture content of windrows is the best way to assure forage is the correct moisture for storage as silage or hay. There are many electronic moisture meters available commercially for field use, but accuracy is questionable with errors often being 5 or more percentage units of moisture, which is too high for hay. Most meters are based on measures of capacitance or conductance and are not acceptable for assessing forage suitability for ensiling. Meters using electrical resistance are also not useful for silage (Prairie Agricultural Machinery Institute, 1993). There are several good laboratory methods for measuring moisture content, but they are time consuming and not suitable for field applications. An intermediate method that may have some merit would be to take a sample from the entire depth of the windrow, weigh the fresh sample, place it in a microwave to dry, and then weigh the sample again. This method requires experience to remove all water without charring the sample.

Most methods used are nonscientific and based on farmer experience; for example, they may involve holding a sample of parallel stems and leaves that is about 5 cm in diameter in both hands, and then twisting the sample back and forth. If stems break after a few twists, the forage is dry enough to bale. For silage, a sample of cut forage can be squeezed into a ball that is allowed to expand on the open hand. If the ball gradually opens, the moisture content is acceptable for silage. If it is too wet, the ball will not expand very much. In both cases experience is helpful, but not quantitative, as stage of maturity and species of plants will cause samples to react differently. Unfortunately there are no defined methods for ease and accuracy for estimating moisture content in the field. This would be a good research contribution.

Conserving Carbohydrates in the Forage

Carbohydrates in forage should be conserved as much as possible during drying and handling processes. Respiration of cut forage continues rapid use of carbohydrates for 5 to10 hr after cutting, which extends beyond closure of stomata (Collins and Coblentz, 2007) and continues until moisture content is reduced to about 40% (Klinner, 1976). Respiration requires sugars and reduces rapidly digestible carbohydrate in forage, especially from leaves with their superior forage quality; sugars are needed for bacterial fermentation during silage making (Muck and Kung, 2007). Due to high buffering capacity of proteins and mineral compounds in forage, both of which are higher in concentration in legumes, it requires more carbohydrate to make quality silage from legumes than grasses.

Plant carbohydrates are higher in concentration at low temperatures than high temperatures due to reduced respiration, are higher in the afternoon than in the morning due to photosynthesis, are higher in leaves than stems, and are generally higher in cool-season grasses than legumes or warm-season grasses (Moore and Hatfield, 1994; Collins and Coblentz, 2007). Some research, especially in the West, suggests forage should be cut in late afternoon when carbohydrate concentrations are elevated to improve forage quality (Burns et al., 2005). Diurnal variation in carbohydrate concentrations also occurs in the East (e.g., Morin et al., 2011) but appears to have less practical value since there is more cloud cover and lower photosynthesis, and initial drying occurs in late afternoon when humidity increases, especially during night. Lower carbohydrate concentrations and slower drying likely offset the potential advantage.

Use of Drying Aids and Preservatives

Chemical treatments have been used to increase rate of drying, particularly application of a water solution of potassium carbonate at mowing (Rotz, 1995). The chemical reduces cuticle resistance to facilitate faster moisture loss from the plant. Other chemicals are reputed to open stomata or disrupt the cuticle but have not worked as effectively. The mechanics for applying potassium carbonate have been worked out for alfalfa, and when used properly on days with high solar radiation, drying time for baling hay can be reduced by 1 d. Economic assessment is not consistent. The chemical also works to improve drying rates for grasses but is much less effective than for alfalfa, which has higher forage value and is more subject to weather damage and bleaching in the field.

Moist hay can be preserved by use of a range of compounds, mainly those that inhibit microbial activity (Collins, 1995). Chemicals that are effective include organic acids such as propionic acid and ammonium propionate that control molding and heating of moist hay by preventing growth of fungi. In general, hay with higher moisture requires a higher acid concentration to inhibit microbial growth. In most cases with chemical treatment, storage losses are reduced and forage quality is retained. Animal acceptance of treated hay is generally not a problem. Using correct rates can be a challenge since moisture content of forage is variable across a field. In addition, application usually occurs as the windrow enters the baler, and distribution of the chemical should be uniform within the bale. Further, most organic acid treatments are now buffered, so they are less corrosive to equipment.

“Chemical treatments have been used to increase rate of drying, particularly application of a water solution of potassium carbonate at mowing.”

> "There were insufficient data on minor forage species to be confident about having the scientific base for management."

Ammonia compounds reduce microbial growth (Woolford and Tetlow, 1984) to be effective preservatives for moist hay under plastic (Moore et al., 1985). Urea added at 7 g kg^{-1} to high-moisture tall fescue hay reduced mold and yeasts to about 15% of the control (Henning et al., 1990). Ammonia treatment also improved fiber digestibility and nitrogen content of low-quality grass hays like mature orchardgrass (Moore and Lechtenberg, 1987). Similar results occurred with urea-treated tall fescue hay. The treated orchardgrass hay also had higher forage intake and dry matter digestibility. Treatment of hay bales with anhydrous ammonia under plastic, especially bales with high moisture content, has been an effective way to preserve forage and also to increase protein content and digestibility of fiber fractions. Urea is an easy and effective way to treat hay since plant tissue naturally contains adequate activity of urease enzyme to convert urea to ammonia. These ammonia treatments improved digestibility of grass hays more than legume hays (Knapp et al., 1975).

In summary, good research data are available for most practices to harvest, cure, and store major forage species. Fortunately most harvest practices are based on plant development and are transferable to nearby states. A gradient in temperature exists that leads to species shifts in adaptation according to latitude from north to south that are based largely on winter and summer temperatures (e.g., Fig. 4.7). Likewise, a rainfall gradient occurs primarily from west to east according to latitude. In general adaptation is affected more by latitude than longitude. But water stress levels tend to be different from west to east and may alter the management needed to offset stresses for plant persistence and for various types of wildlife. The plant hardiness map (Fig. 4.7) could be enhanced by adding information on soil types and erosion potentials to better consider adaptation of forage species and offer guidelines to manage soil erosion and water quality.

There were insufficient data on minor forage species to be confident about having the scientific base for management. This will be critical because of growing interest in using native species and other minor-use species, especially in niche areas and for specific purposes. For example, several native legumes are known to have potential in hay and silage systems, and may offer better potential for wildlife, yet there are few data.

PURPOSE 2: PROMOTE VIGOROUS PLANT REGROWTH

Stored Reserves and Leaf Area

Vigorous regrowth is desired for regaining maximum light interception by forage leaves to shade the soil and provide competition with weedy species. Vigorous regrowth of both legumes and grasses depends on the status of carbohydrate and nitrogen that are stored in plant parts that remain after cutting (Volenec et al., 1996; Volenec and Nelson, 2007). Carbohydrate, mainly starch, and nitrogen, usually as vegetative storage proteins, are stored in taproots of legumes and in stolons and rhizomes. Cool-season grasses store carbohydrate as fructan, a polymer of fructose, and vegetative storage proteins in stem bases and lower internodes. Warm-season perennial grasses store starch and nitrogen compounds in the lower stem. In general, the upright-growing grasses contain a larger supply of carbohydrate reserves when cut to leave tall stubble (Risser and Parton, 1982). Locations and roles of nitrogen storage in more prostrate growing warm-season grasses such as bermudagrass and bahiagrass are less understood.

Cutting forage plants removes leaf area and reduces photosynthesis, immediately placing plants in a negative carbon and nitrogen balance (Volenec and Nelson, 2007). Root growth of grasses slows within a few hours after cutting and may stop temporarily or even die depending on the amount of leaf area removed. Similarly, cutting causes nitrogen fixation by legumes to slow dramatically or even stop. The reserves are used to develop new leaf area and support respiration of the nonphotosynthetic parts. The negative balance continues for up to 14 d after cutting, until leaf area is sufficient to support the carbohydrate requirements, roots grow again, and nitrogen fixation again becomes active. Reserve levels will be low at cutting if the duration from the previous cutting is short or if temperatures are high. In these cases, taller stubble should be left that has live leaf area. Residual leaf area provides photosynthate so plants regain a positive balance sooner, some root growth can continue, soil is shaded to reduce air and soil temperature, and plant respiration rate is slowed.

Regrowths originate from axillary meristems near soil level (Nelson, 1996; Moser and Nelson, 2003; Skinner and Moore, 2007). After cutting, buds of most legumes arise from the crown area or from lateral stems, stolons, or rhizomes. Leaves of cool-season grasses regrow from intercalary meristems located at bases of each leaf sheath. In addition, some grasses such as smooth bromegrass, reed canarygrass, and switchgrass have rhizomes with axillary buds that lead to lateral spread. Since leaf area is reduced after cutting, especially with grasses with an upright growth habit that are harvested mechanically, these meristems depend largely on carbohydrate and nitrogen reserves (Volenec and Nelson, 2007). Grasses with high tiller density and substantial leaf area near ground level such as Kentucky bluegrass depend less on stored reserves and mainly on leaf area for carbohydrate supply during regrowth.

In summation, the principles discussed above are well known and have been researched for most major species, and appropriate management practices have emerged (Moser and Nelson, 2003; Skinner and Moore, 2007). Practice Standard 511 recognizes these principles and appropriately gives them emphasis. There is concern, however, that less-used forage species, mainly legumes and forbs, have potential for commercial use, but regrowth processes and adaptation are not clearly understood from research. This weakness can lead to lack of success in practical situations when managers know the potentials, but not the best options for management.

PURPOSE 3: MANAGE TO MAINTAIN DESIRED SPECIES

Hay and silage are usually made from single-species fields of a perennial grass or alfalfa, or from mixtures of two or three species that often include a legume. Management to retain monocultures is generally associated with weed management to maintain a vigorous condition for a high-quality forage species such as alfalfa for dairy cattle. In most cases the legume component of a legume-grass mixture is used as the management guideline since legume persistence and production are more sensitive than grasses to management treatments. Particularly in the case of variable soils within a field, increased species diversity can lead to increased productivity, due to niche partitioning and other factors (Hector and Loreau, 2005).

Interseeding native grasses into a cool-season grass field in Iowa. NRCS photo by Lynn Betts.

Cutting height is a critical management decision since it affects yield and quality of forage harvested, but it also affects persistence of many species and environmental services provided. Proper cutting height should be used to promote vigor and health of desired species. Fortunately this has been researched for major forage legumes (e.g., Buxton et al., 1985; Buxton and Hornstein, 1986) and grasses (Buxton and Marten, 1989; Buxton, 1990). For example, alfalfa uses stored reserves almost exclusively in early regrowth; if reserves are high it is not critical to leave leaf area at cutting (Monson, 1966; Sheaffer et al., 1988). In contrast, half or more of the energy for regrowth of cool-season grasses can be from photosynthesis of residual leaf area (Ward and Blaser, 1961; Booysen and Nelson, 1975). Thus, cutting height can be used to maintain or regain species balance in a mixture.

Several studies show leaving only 3 to 5 cm of stubble gives good regrowth of alfalfa when an

“Soil temperatures can increase markedly if stubble does not provide shade.”

interval of 30 to 40 d occurs between cuttings. A taller cutting height for alfalfa was beneficial only when plants were cut frequently (Smith and Nelson, 1967), but leaving 8 to 10 cm of leafy stubble is recommended for birdsfoot trefoil. In contrast with alfalfa, birdsfoot trefoil stores only small amounts of reserves during the summer, and regrowth depends nearly exclusively on photosynthesis of residual leaf area. In general, reserves in red clover roots respond similar to the pattern observed for alfalfa (Smith, 1962), and those of crown vetch (Langville and McKee, 1968) respond much like birdsfoot trefoil. Kura clover had higher forage yield with 4-cm stubble height than with 10-cm stubble height (Kim and Albrecht, 2011). Annual legumes such as korean and kobe lepedezas store very little reserve in the roots and depend on leaf area remaining after cutting to support regrowth (Davis et al., 1994, 1995).

Soil temperatures can increase markedly if stubble does not provide shade. In Massachusetts, when spring growth of orchardgrass was cut and removed, leaving 5 cm of stubble, soil temperature the next day increased by 14°C (Colby et al., 1966). High temperatures increase respiration and heat stress on young tillers of cool-season grasses. In contrast, Kentucky bluegrass is a sod former that retains leaf area near the soil surface and can be cut shorter. There is evidence that leaving a tall stubble in late fall cuttings of upright-growing grasses and legumes helps catch snow and reduces soil freezing and thawing that leads to frost heaving and winter kill. Most of these relationships have been researched for major species, and practical results are published in extension outlets for a state or region.

Stem tissue is lower in quality than leaf tissue, so whereas forage yield of alfalfa and upright grasses is greater when cut shorter, the added amount of stem tissue generally reduces quality of hay or silage (Buxton, 1990). Further, the lowest sections of stems are lower in quality than upper sections, and they support the oldest, lowest quality leaves of forage legumes (e.g., Buxton et al., 1985: Buxton and Hornstein, 1986) and grasses (Buxton and Marten, 1989; Buxton, 1990). In West Virginia, monocultures of bermudagrass and caucasian bluestem with somewhat prostrate growth had higher forage yield than did upright growing switchgrass when cutting began early in the season (Belesky and Fedders, 1995). However, growth rates for all were higher when 75% of the canopy was removed compared with 50% removal. They concluded that bermudagrass and caucasian bluestem were better adapted to frequent defoliation, whereas switchgrass would be better for conserved forage. Thus, cutting to shorter stubble heights usually increases forage yield, but may reduce forage quality (Burger et al., 1962). This economic relationship needs to be understood while managing legume-grass mixtures.

In addition, since forage grasses store reserves in lower stem internodes and stem bases, more reserves are removed by close cutting which reduces regrowth vigor of cool-season (Matches, 1969) and warm-season grasses (Rains et al., 1975). Close cutting also opens the canopy, which allows shifts in legume-grass proportions (Fales et al., 1996) and greater invasion of weeds in monocultures of alfalfa (Peters and Linscott, 1988). It also shifts the proportions of cool- and warm-season grasses growing in mixture.

Managing for the Desired Species Mix

Matching maturity times of legume and grass components is critical since management is easier when both types of plants are at the appropriate growth stage when harvested, especially spring growth. Morphological and physiological relationships are important, but recent research on mixtures has been minimal. Exceptions relate to the endophyte status of tall fescue, which has very little effect on compatibility with some legume species (e.g., alfalfa; Hoveland et al. 1997), and the quest for legumes that are compatible with native warm-season perennial grasses in the Midwest and with a range of grass species in the South.

Review of several extension publications show a sound scientific basis for management of mixtures of most major species (e.g., Koenig et al., 2002, in Utah; Rayburn, 2002, in West Virginia; Johnson, 2007, in Indiana; Barnhart and Sternweis, 2009, in Iowa; Hancock et al., 2011, in Georgia). Over a period of years, legume-grass mixtures are often higher yielding than monocultures of any of the components, more persistent, better adapted to variable soils in the field, more resistant to weed encroachment, have better erosion control, and compared with a monoculture of legume are easier to harvest and cure.

Most research has been on alfalfa-grass mixtures with coalescence around use of orchardgrass that matches alfalfa in stages of maturity, improves seasonal distribution of production, gives good regrowth and competition with weeds in summer, and improves ground cover during winter (Wolf and Smith, 1963). Compared with grass monocultures in Iowa, binary mixtures of alfalfa, birdsfoot trefoil, and kura clover all improved seasonal growth distribution with smooth bromegrass, orchardgrass, and intermediate wheatgrass (Sleugh et al., 2000). In contrast, tall fescue and timothy tend to match best with red clover, whereas studies with Kentucky bluegrass tend to focus on white clover, which is also low growing. Using appropriate cutting management, yield of an alfalfa-reed canary grass mixture in Minnesota was greater than reed canarygrass in mixture with birdsfoot trefoil or red clover, while yields with ladino clover were lowest (Heichel and Henjum, 1991). Nitrogen fixation by legumes was closely related to their yield in the mixture. In mixture with reed canarygrass, alfalfa fixed 175 kg N ha^{-1}, whereas birdsfoot trefoil fixed 77 kg N ha^{-1}, red clover fixed 63 kg N ha^{-1}, and ladino clover fixed only 9 kg N ha^{-1}.

Several extension publications suggest a threshold of about 25–30% legume in mixtures to gain the benefits of legumes in a mixture. Grass monocultures fertilized with high N rates have higher yield potential than legume-grass mixtures without N (Wolf and Smith, 1963; Sleugh et al., 2000), whereas legume-grass mixtures have higher forage quality, better weed control, and improved stand persistence. But mixtures are more difficult to maintain because of species differences in growth habits and in carbohydrate reserves at cutting (Kust and Smith, 1961). Shorter stubble usually favors alfalfa, whereas taller stubble heights tend to favor the grass component. Fortunately, good educational information is available on the basic principles of management of mixtures of legumes and cool-season grasses that include effects of light interception and N nutrition. These are also regulated by liming that favors the legume, K nutrition that favors legumes that are less competitive for K at low rates, cutting height, cutting frequency, timing of fertilization, and reseeding practices.

Nutrient management is an important tool for maintaining desired proportions of legume and grass species in the field. Nearly all experiment stations recommend no N fertilizer be used on mixes including at least 25% legumes since N tends to stimulate grasses making them too competitive. Conversely, fertilization with K improves tolerance of environmental stresses; grasses benefit most at low rates, while legumes

“mixtures are more difficult to maintain because of species differences in growth habits and in carbohydrate reserves at cutting.”

Native grasses are part of a buffer system to aid wildlife and the environment. NRCS photo by Lynn Betts.

Discussion about pasture management in Louisiana. NRCS photo by Bob Nichols.

benefit most at high rates. Most experiment stations suggest fertilization of legume-grass hayfields with K after first harvest to improve tolerance to drought and heat or in early autumn to improve winter survival (Meyer and Helm, 1994). These recommendations are based on good science and are effective. Dealing with manures as nutrient sources is more challenging and is discussed later in this chapter.

In summary, there is good research on the importance of legume-grass mixtures and management strategies to maintain both types of plants in the stand. Legumes are the most sensitive component, and, if they cannot be managed to persist or naturally reseed, they are usually overseeded periodically to increase stand density. Due to autotoxicity, alfalfa cannot be overseeded to increase stand density (Jennings and Nelson, 2002). Unfortunately there are few herbicides that can be used to control weeds in legume-grass mixtures.

PURPOSE 4: MANAGE FORAGES FOR EFFECTIVE SOIL NUTRIENT UPTAKE

Fields devoted to harvested forage lack the inherent nutrient recycling found in pasture systems (Brown, 1996). Replacement of nutrients removed is required for a sustainable system, and soil testing is essential for documenting nutrient changes in soil over time (Wood et al., Chapter 5, this volume). Fertility management, including rates and timing, for mixed perennial forages can have dramatic effects on the species balance. Removal of nutrients by harvested forages can be estimated using published forage composition tables; however, forage composition of a particular field may deviate greatly from average values. Since both yield estimates and forage analysis are essential for using precision feed management, these data can also be used to help assess fertilizer needs for the crop.

While nutrient removal by forage is critical for economic returns to the producer, fate of applied nutrients that are not taken up is of environmental concern and needs to be minimized. This is covered to a great extent by Wood et al. (Chapter 5, this volume) and is supplemented here considering removal of forage to be stored for use as an animal feed.

Nutrient Management for Yield and Persistence

Lime. Soil nutrient levels must be assessed prior to establishment of perennial forages (Barker et al., Chapter 2, this volume). Natural soil pH is usually acidic in the eastern USA that was dominated by forest, but tends to be closer to neutral (pH = 7.0) in the dryer areas to the west that were dominated by prairie. Availability of nutrients in the soil is affected by pH, and it should be corrected to optimum for the species to be planted. If soil pH is too low for the sown species, lime should be applied and worked into soil prior to seeding. Appropriate soil pH (in water suspension) in northern states is approximately 6.5 to 7.0 for alfalfa, slightly lower for red clover and birdsfoot trefoil, and 5.8 to 6.5 for grasses (Brown, 1996). Recommended amounts of liming material are quantified using estimates of neutralizable activity in the surface soil. Actual recommendations based on local research may vary from state to state due to use of different calibration techniques.

Nitrogen. Nitrogen has the greatest effect on forage yield of all nutrients, and the most influence on forage quality and balance of a legume-grass mixture. Legumes fix most of the N that they require without need for added external N. Most studies on alfalfa have concluded there is a reduction in N fixation with addition of readily available sources of N, but responses have been variable. For example, Shuler and Hannaway (1993) concluded biological N fixation can be completely inhibited by available soil nitrate, while other studies suggest that significant N fixation occurs in alfalfa, even when fertilizer N is applied at high rates (Cherney and Duxbury, 1994; Lamb et al., 1995). Reasons are unknown.

Rarely is N fertilizer (beyond N fixation) recommended for mixtures if the stand is at least 40% legume (Ketterings et al., 2007). Such estimates are based on experience, as there is no good soil test for N on which to base these recommendations. Once the legume component is reduced to less than 20% in a mixed legume-grass stand, the field is usually managed as a grass using N applications to increase yield, putting the legume at a competitive disadvantage and the grass component dominates.

Grass monocultures can respond to high levels of N fertilization (over 335 kg ha^{-1} annually) under adequate moisture conditions (Hall et al., 2003). Rates above 250 kg ha^{-1} annually, even with split applications, increase risks of nitrate leaching, and high forage nitrate concentrations that can affect animal health. Some grass species have lower yields and lower forage-N content, making them less efficient at removing soil nitrate. There are few species-specific N recommendations for cool-season grasses harvested for stored forage. Some states base N recommendations for grasses on average soil moisture availability (Anderson and Shapiro, 1990). Some Midwestern states base recommendations on projected yields of a specific species, ranging from 5.5 to 18 kg N Mg^{-1} of forage in the Midwest (Brown, 1996). The economic optimum N rate is considerably higher in the Northeast, exceeding 27 kg N Mg^{-1} of forage (Hall et al., 2003).

Potential environmental effects of N fertilization of grasses can be estimated by the amount of applied N that is not recovered in the harvested forage. The calculation is based on N recovered in fertilizer treatments minus N recovered by unfertilized controls. But the fate of the nonrecovered N is not known. Apparent-N recovery by perennial grasses at fertilization rates of 225 to 270 kg N ha^{-1} was variable and generally ranged between 50% and 70% (Vetsch and Russelle, 1999; Hall et al., 2003; Cherney and Cherney, 2006). Timothy typically has a significantly lower apparent-N recovery than other cool-season species (George et al., 1973; Hall et al., 2003). Increasing number of harvests per season will increase recovery (Hall et al., 2003), but splitting applications of N has not increased total N recovered or apparent N recovery (Vetsch and Russelle, 1999; Cherney and Cherney, 2006). Applying N just before rapid growth need is usually considered a good way to maximize recovery, but there are few studies that have evaluated this topic.

Phosphorus. Phosphorus recommendations are based on soil test results, although several different P extractants are used to test for soil-P depending on the state. Phosphorus recommendations also are based partly on whether soils were leached of P during formation (Brown, 1996), resulting in a wide range of recommended amounts. From a soil perspective, timing of P fertilization during the season does not appear important, but forage species differ in response. Phosphorus is important for N fixation in legumes, impacting both yield and persistence (Berg et al., 2007), and legumes are less efficient at extracting P from soils compared with grasses (Barker and Collins, 2003). Significant yield responses of grasses have been noted (Ludwick and Rumberg, 1976; Christians et al., 1979). Phosphorus has a greater effect on yield than on persistence in grasses.

Programs for gradually increasing soil-P should be reevaluated in this era of increased environmental concerns. Phosphorus content of forages does not fluctuate greatly, averaging approximately 0.33% of dry weight in grass silage and 0.34% in legume silage (DairyOne Forage Laboratory, Ithaca, NY). Phosphorus typically has been overfed to dairy cattle (Harris et al., 1990). The excess P usually ends up in the manure creating a disposal problem. This serious P-management problem should not be solved by limiting P availability and yield of plants but can be dealt with effectively by limiting P content of supplementary feeds in the diet (Van Horn et al., 1991; Esser et al., 2009; Bjelland et al., 2011).

“excess P usually ends up in the manure creating a disposal problem.”

"Priority fields for manure application should be those fields with nonlegume crops that could most benefit from manure nutrients."

Potassium. Potassium has the same issues with extractants as those mentioned for P above. Unlike P, which has low water solubility, K is soluble so timing of applications on forage crops is important. Soil K is released naturally over winter so is relatively high in spring, indicating application of K to forage crops should be delayed until after first hay harvest. Potassium is essential for maintaining yields, reducing disease susceptibility, and increasing winter hardiness and stand survival. For alfalfa, an application of K later in the season will help ensure that K is available to enhance plant survival over winter. For grasses, potassium fertilizer regimes should be controlled by K-supplying power of the soil and by total K removed per season (Cherney et al., 1998). Yield and persistence of alfalfa are strongly influenced by available soil K, while grasses are less dramatically affected (Cherney and Cherney, 2005). Yet K fertilization of grasses is critical for winter hardiness, especially for bermudagrass that receives high rates of N fertilizer.

Potassium concentration in forage crops is relatively high, is related to available soil K and can be higher in the crop than needed for high yield, resulting in significant removal by the crop. Potassium content of forages is considerably more variable than P, averaging 2.4% in grass silage and 2.8% in legumes (DairyOne Forage Laboratory, Ithaca, NY). In addition to amount of available K in the soil, concentration of K in grasses is influenced by grass species, forage age, and time of season, and also interacts strongly with N fertilization. Variability occurs in grasses because they exhibit luxury consumption at high rates of K, yet they also can tolerate lower levels of soil-test K than legumes (Joern and Volenec, 1996; Cherney et al., 2003).

Use of Animal Manures for Yield, Persistence, and Nutrient Management

Animal manures supply both nutrients and organic matter to soil which are assets. Yet they can affect harvested forage negatively through excessive nutrient concentrations or through contamination of the soil surface. Type of animal generating the manure, amount of excreta versus bedding or litter, and manure storage system all affect application and use of manure (Simpson, 1991). Manure use for establishment of perennial grasses, legumes, or legume-grass mixtures may increase yields if soil is deficient in P, K, S, or B (Ketterings et al., 2008). Inclusion of an annual companion crop is suggested to minimize N losses while perennial crops are slowly becoming established.

Established alfalfa and alfalfa-grass hayfields can be topdressed with cattle manure without loss of yield or quality; however, there may be risk of heavy metal accumulation in soils treated with poultry or swine manure (Nicholson et al., 1999; Wood et al., Chapter 5, this volume). Additional risks involved in manure applications to alfalfa include salt damage to new growth, pathogen contamination, and soil compaction and damage to plant crowns during application. The ratio of N to P in manures differs from the needs of forage plants. Therefore, manure application to meet N requirements of forage crops results in excess P application, with the additional disadvantage of N volatilization losses. Partial incorporation of manure using an aerator/tillage tool can reduce volatilization losses (Fuchs, 2002). Even though alfalfa has a deep rooting zone to capture nitrates low in the soil profile, high application rates of liquid manure (23,000 L ha^{-1}) resulted in significant leaching (Daliparthy et al., 1994).

From a nutrient-use-efficiency standpoint, corn and forage grass fields tend to be preferred sites for manure application. Forage grasses have a high N requirement while minimizing nitrate leaching due to a fibrous root system. After two to four seasons of manure application, forage yields of perennial grasses were equal or higher than those fertilized with commercial N (Cherney et al., 2002; Cherney et al., 2010). Different times of manure application during the season did not affect yield or forage quality of cool-season grasses (Cherney et al., 2010). Alfalfa typically meets its nitrogen requirement through biological N fixation, so N from other sources such as manure is unnecessary if conditions for N fixation are satisfactory. Priority fields for manure application should be those fields with nonlegume crops that could most benefit from manure nutrients.

Current nutrient management plans for many states require that manure application to corn and forage grasses be limited to crop-N needs, increasing the likelihood that some manure will need to be applied to forage legumes such as alfalfa or legume-grass fields. At some times these fields may be the only ones available and accessible for manure application. If legume monocultures continue to fix N in the presence of readily available N sources, uptake of manure N will be reduced, and the manure application could increase risk of N leaching. The risk is reduced if manure is applied to alfalfa-grass mixtures, in which case the grasses will use the manure N. The practice of applying manure shortly before plowing alfalfa or alfalfa-grass stands designated for rotation to corn or other crops should be strongly discouraged. Breakdown of alfalfa or alfalfa-grass by soil microorganisms alone supplies sufficient N for a corn crop under most conditions (Lawrence et al., 2008a).

The vast majority of broiler chickens in the USA are produced in southern states, resulting in a large broiler litter manure source for potential application on forage fields (Wood et al., Chapter 5, this volume). Mechanically harvested forage will reduce buildup of nutrients from poultry litter applications, and limited N fertilization will encourage mineral uptake of P, K, Cu, and Zn that would otherwise build up in soils (Evers, 2002; Pederson et al., 2002). Depending on rate and frequency of applications, poultry litter may increase levels of soil nutrients enough to adversely affect health of animals consuming harvested forage. Off-farm alternative uses for manures such as compost, mulch, or substrate for mushroom growing should be considered if forage fields are the only alternative and they already have excessively high nutrient levels.

Manure or Soil Contamination of Forage

Manure carries a variety of pathogens that can live in soil for up to 1 yr (Stabel, 1998). *Salmonella*, *Listeria, Campylobacter,* and *E. coli* bacteria can be found in manure, along with the pathogenic protozoa *Cryptosporidium* and *Giardia*. There is risk of direct leakage from manure in buildings, in storage, or following spreading on land (Mawdsley et al., 1995). Manure pathogens may move laterally via surface or subsurface runoff and downward through sandy soils, cracking clay soils, or tile-drained soils (Geohring et al., 2001).

Some soil-borne pathogens will proliferate in improperly stored forage and be exposed to animals. Unpasteurized or raw milk can potentially carry a variety of serious pathogens including *Salmonella*, *Listeria,* and *E. coli*, and cheese made from raw milk can contain these same pathogens (CDC, 2007; Omicciole et al., 2009). Ensiled forage that does not achieve a low pH can result in proliferation of *Clostridium botulinum*, a secondary fermentation, particularly if the stored forage is greater than 70% moisture. Botulism in stored hay is rare but possible if wet, anaerobic conditions exist.

Aerobic molding of hay or silage from *Aspergillus* and other aerobic fungi reduces palatability, but generally causes significant animal disorders only in horses. An exception occurs when mycotoxins are produced. *Aspergillus*, *Fusarium*, *Penicillium,* and *Alternaria* are all capable of producing mycotoxins in silage and haylage (Kuldau and Mansfield, 2006). Toxins from *Aspergillus* species are the most common in warmer climates, and aflatoxins and cyclopiazonic acid produced by *Aspergillus* species are passed in milk. *Fusarium* species generate toxins most efficiently at relatively cool temperatures, and these toxins are not reduced by ensiling (Gotlieb, 1997). Soil contamination and/or aerobic deterioration of silage also can result in proliferation of *Listeria* (Collins and Hannaway, 2003), a serious condition more commonly found in bale silage.

The most common pathogen in manure affecting animal health is *Mycobacterium paratuberculosis*, the causative agent of Johne's disease, which is an incurable, progressive disease in cattle. Research is underway to determine if it can spread to humans as Crohn's disease. Approximately 22% of US dairy herds contain animals infected with Johne's disease, although very few animals show clinical signs of the disease (Collins and Manning, 2005). Infected, subclinical animals can infect other animals for up to 10 yr before showing clinical symptoms, often following significant stress such as calving (Jansen and Godkin, 2005). Calves can become infected by ingesting a small amount of infected manure or milk. Regular monitoring of the herd for Johne's disease is strongly suggested.

“Manure carries a variety of pathogens that can live in soil for up to 1 yr.”

“Forage plant growth habit and rooting architecture significantly affect the balance between runoff and infiltration.”

There are several methods to control spread of *M. paratuberculosis*. The bacterium is sensitive to pH; a surface lime application on fields receiving manure applications will reduce its survival. Young animals should not come in contact with pastures or stored forage that is potentially contaminated with manure. The bacteria survive on dry hay, but proper ensiling appears to greatly reduce populations (Katayama et al., 2001). If animals with Johne's disease are known to be present in the herd, the manure should be applied on nonforage fields to minimize forage contamination. Spread of Johne's disease is minimized if manure applications are delayed until after final forage harvest of the season. Manure contamination of harvested forage during the season is minimized if manure is applied during spring greenup or immediately after harvesting, before forage regrowth has accumulated. Manure or soil contaminating the surface of forage tissue increases risk of Johne's disease or clostridial silage fermentation.

In summary, harvesting forage at the proper stage of maturity and moisture level for the storage system is a key practice to minimize pathogens and toxins in forage. Rapid harvest, tight packing, and oxygen exclusion for silage making are also essential (Collins and Owens, 2003). Feedout of forage, especially from bunker silos, must be at a rate per day that is rapid enough to avoid surface spoilage.

Management Effects to Reduce Nutrient Runoff

Surface runoff and erosion may contaminate surface waters with P as well as manure pathogens (Sharpley et al., 1994). In general, forage crops reduce soil erosion by protecting the soil surface from raindrops (Karlen et al., 2007). The energy from raindrops is dissipated, preventing them from dispersing soil aggregates, thus increasing filtration and minimizing runoff. Forage plant growth habit and rooting architecture significantly affect the balance between runoff and infiltration. Sod-forming vegetation, particularly species with rhizomes such as reed canarygrass, reduces velocity of runoff and protects soil surfaces from erosion (Karlen et al., 2007).

Forages may serve a dual purpose as a forage crop and as a conservation buffer. Buffer strips of perennial forages can play a major role in minimizing nutrient flow into surface waterways (Clausen et al., 2000; Liu et al., 2008). Contour buffer strips, field borders, filter strips, and grassed waterways may all be used for forage production (Karlen et al., 2007). Care should be taken when harvesting conservation buffers such as filter strips and waterways that are more likely to have wet soils. Heavy forage harvesting equipment can compact or produce ruts in the forage field, depending on soil moisture and soil type. Soil compaction decreases infiltration and can increase runoff. Ruts can also increase runoff by providing channels for water flow, depending on field slope and channel orientation.

If possible, manure applications should be timed to minimize the potential for a rain event soon after the application. Applications in summer and early fall are more likely to meet this criterion, when soils tend to be relatively dry. Precipitation directly following manure application will maximize chances for nutrient and pathogen runoff, as well as chances for leaching, macropore flow, and effluent losses through tile drains (Geohring et al., 2001). Partially incorporating manure into soil is a good manure management practice that reduces potential runoff losses from perennial forage fields (Fuchs, 2002; Lawrence et al., 2008b). Manure application, as well as harvest for hay or silage, should be restricted to fields with a slope that is less than 15%. Forage land with steeper slopes may be used for pasture, where runoff concerns exceed leaching issues. Leaching potential is greater in pastures compared to mechanically harvested forage fields (Karlen et al., 2007).

Nutrient Imbalances and Effects on Livestock

Proper timing and rates of fertilization for forage crops will maximize yield and persistence and will result in high nutrient uptake. Just as overfertilization of field crops was common in the past, overfeeding of cattle also was viewed as cheap insurance for maximizing productivity. Forage crops can be managed and harvested to produce optimum quality forage for a given class of livestock. Ration balancing for each class of livestock can eliminate nutrient deficiencies, but nutrient excesses in forages are most effectively controlled by soil fertility and harvest management.

Some forage crops contain toxic compounds in sufficiently high concentrations to harm animals. Examples are hydrocyanic acid in sorghums, ergot alkaloids in tall fescue, indole alkaloids in reed canarygrass, and phytoestrogens and coumarin in legumes. Harvesting plants at more advanced stages of growth for hay or silage greatly reduces the cyanide potential in sorghums (Collins and Hannaway, 2003). Alkaloids in tall fescue can be reduced to safe levels by use of endophyte-free seed (Sleper and West, 1996), although endophyte infection increases plant tolerance to water stress, insects, and disease. Nontoxic endophytes have been developed that increase plant persistence in tall fescue with minimal or no effect on livestock performance (Bouton et al., 2002). Growing infected tall fescue in mixture with a legume such as white or red clover or other grasses dilutes the toxicity level. Livestock disorders due to alkaloids in reed canarygrass can be minimized by use of low-alkaloid cultivars (Marten, 1989). Negative effects of most toxins can be minimized by dilution of the toxin source in the animal diet with other forage sources. Proper ensiling minimizes effects of most toxins except for cyanide potential and phytoestrogens (Collins and Hannaway, 2003).

Nutrient imbalances, such as grass tetany (hypomagnesaemia), and bloat are typically seasonal and most often associated with ingestion of fresh forage on pasture. Nitrate toxicity in grasses can be generated by high N fertilization, coupled with drought, frost, or prolonged cloudy conditions that slow growth. Under normal conditions nitrates accumulate rapidly in forage after fertilizer application, but with moderate rates are metabolized to other compounds within 3 wk (Fig. 4.10). Forage growth during drought is reduced, and nitrates can accumulate to high levels since they are not used to increase yield. These nitrates are stable and remain high if plants are harvested and stored as hay, but concentrations are reduced by about 50% when forage is ensiled. Alternative solutions include allowing plants to mature further or to cut higher to leave lower stem material.

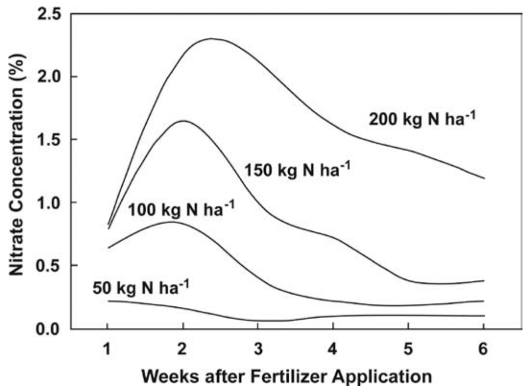


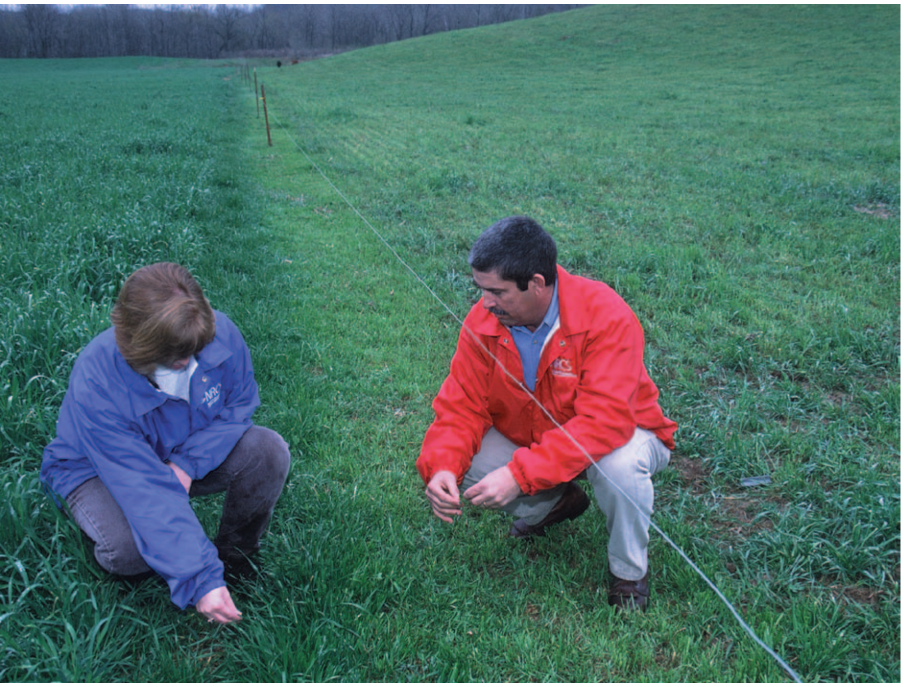
FIGURE 4.10. Nitrogen fertilization effects on forage nitrate patterns in tall fescue depend on application rate and ability of growth processes to utilize accumulated nitrate compounds. From Collins and Hannaway (2003).

The primary nutrient imbalance associated with stored forage is high K content leading to potentially severe post-partum maladies in dairy cattle. As discussed above, K is subject to luxury consumption in grasses, which is aggravated by high N fertilization (Cherney et al., 1998). Controlling K inputs to a field of cool-season grasses utilized as dry cow forage, along with delayed harvest, can minimize K content of forage and potentially avoid milk fever and associated post-partum problems (Cherney et al., 2003; Cherney and Cherney, 2005). Warm-season grasses are usually lower in K concentration and have less risk.

PURPOSE 5: MANAGE FORAGES TO CONTROL INSECTS, DISEASES, AND WEEDS

Control of insects, diseases, and weeds is most economic and usually based on maintaining a vigorous stand to provide a strong degree of biological control through healthy plants. Most forage cultivars are seeded and are highly heterogeneous in nature; therefore they have genotypic plasticity that allows adaptation to environmental or management conditions. Recognizing this, plant breeders have been primary contributors to disease control through selection and use of disease-resistant cultivars (Nelson and Burns, 2005; Lamb et al., 2006), although yield or quality may be only marginally changed. Most genetic progress has been made in disease resistance that may also favor persistence (Lamb et al., 2006). In only

"Some forage crops contain toxic compounds in sufficiently high concentrations to harm animals."



Conservation specialists evaluate a prescribed grazing practice in Arkansas. NRCS photo by Jeff Vanuga.

a few cases is it economic to use fungicides, bactericides, or nematicides in hay or silage plantings. Instead, the crop is usually harvested to remove the infected material with the expectation the regrowth will be less infected and the plants will survive. Conversely there is good evidence that leaf diseases can cause leaf death and loss, which reduces the digestibility and intake of the forage.

Principles of integrated pest management are most frequently used to control biotic stresses. These principles depend on knowledge of life cycles and management guidelines for the forage and life cycle of the specific disease, insect pest, or weed (Sulc and Lamp, 2007). Management can be altered by cutting at times in life cycles when plants are vigorous and the pathogen, pest, or weed is in a vulnerable stage. But this interaction also changes with time as new cultivars are introduced and management practices are changed. In some cases release of exotic insects or pathogens helped reduce pest or weed populations to near or below threshold levels. For example, several exotic parasites and some pathogens from Europe have been released to control alfalfa weevil. In some cases a forest or other crop must be nearby to provide habitat for survival of the parasite or pathogen. Desired long-term ecosystem solutions are based on a mix of biological control and resistant cultivars. Most genetic progress has been made with alfalfa, due to private industry leadership and a very specialized seed industry that provides protection of proprietary cultivars (Lamb et al., 2006).

Potato leafhopper, another major insect pest of alfalfa, releases toxins as nymphs feed on leaves. Plants are stunted, and protein content of forage is reduced. This problem was less serious when harvests were made at late maturities (Graber and Sprague, 1935). Adults overwinter in the Deep South and move northward on wind currents to lay eggs in alfalfa fields. Harvest at near full bloom removed the forage before eggs hatched and nymphs developed. When better cultivars were introduced to allow earlier and more frequent harvest, eggs were laid in regrowth after first harvest and nymphs damaged plants before second harvest. Some damage also occurred in the third harvest. Use of insecticides was the first response, but this has been largely replaced by use of glandular-haired cultivars that deter egg laying (Sulc et al., 2002). Genetic resistance was increased such that today there is no economic damage on new glandular-haired cultivars.

In eastern states the egg hatch of alfalfa weevil in early spring allowed larval damage before the first harvest. It was too early to cut alfalfa, so insecticides were needed. Early regrowth after first harvest can be damaged, but little if any damage occurs in later harvests because adults leave the field. The weevils reduce yield some, with most effect being loss of forage quality since larva feed on young leaf blades. Several attempts were made to develop genetic resistance with very little success (Lamb et al., 2006), so other alternatives were researched. Gradually other insects were introduced and became established that parasitized the larval stages of the weevil (Sulc and Lamp, 2007). Biocontrol methods for weevil control usually are effective enough in much of the northern USA that insecticides are not needed on a regular basis (Radcliffe and Flanders, 1998).

Survival of fall-laid eggs of alfalfa weevil in basal parts of the stem leads to the early spring infestation the following year, especially in the geographic transition zone with milder winters. This major feeding comes early, ahead of the biocontrol agents, and requires some intervention. Burning the stubble in winter or a late fall harvest increases winter kill of the eggs and delays major damage until spring-laid eggs hatch. But these management treatments open the canopy in fall and winter, which allows greater infestations of winter annual weeds and/or potential for plant heaving. Winter annual weeds such as henbit and chickweed tend to be prostrate and cover buds on crowns of alfalfa to reduce shoot number, yield, and competiveness during spring. Farm managers in this zone must decide whether to harvest in late autumn and monitor winter annual weeds or not harvest in late autumn and monitor early hatch of weevils (Caddel et al., 1995).

Other insect problems occur infrequently or mainly in certain areas. Alfalfa snout beetle occurs near the St. Lawrence Seaway in northern New York and southern Canada, presumably introduced from Europe by ship traffic. Snout beetle larvae destroy alfalfa tap roots, and there is no practical control through management or pesticides. Fortunately the insect is flightless. Clover root curculio affects younger clover and alfalfa plants by girdling outer layers of root tissue to get food. Feeding reduces storage of carbohydrates and regrowth vigor and opens root tissue to pathogens that cause diseases and plant death. Fall armyworm infestations occur intermittently in forage crops in northern areas, and more routinely in southern areas where they can be very damaging to yield and plant vigor if not controlled, usually requiring an insecticide. State Agricultural Experiment Stations and Extension Services provide information on identification of insect pests and the array of ways they can be controlled. Invariably information focuses first on plant management to reduce the problem, with use of an insecticide as a last resort. Information generally cautions users about application of chemicals and restrictions on subsequent use of the forage.

Weeds are plants that compete strongly with desired forage plants to reduce yield, quality, or stand persistence, through competition for light, space, water, and nutrients. Weeds are more likely to be a problem during establishment, and again later in the life of the stand when the forage crop begins to decline. In these terms weeds in hayfields are being redefined since nonplanted species like many forbs have good quality and contribute to yield. However, rarely will these species have the same degree of value as the planted forage, yet are major parts of the soil seed bank. Weed management of haylands starts during establishment, after which plant competition is the major method used to reduce encroachment, seed production, and survival of weeds. Vigorous regrowth of the forage is critical since many weeds that have germinated before cutting become established in thin stands during the forage regrowth period. Weeds in monocultures can be controlled by an array of chemical herbicides (Barker et al., Chapter 2, this volume).

Weeds are rarely controlled by chemicals in established stands except in alfalfa because weeds reduce yield and quality of this superior forage species (Doll, 1994). Foxtails, quackgrass, Canada thistle, pigweed, lambsquarters, mustard, and volunteer grains compete aggressively with alfalfa in summer and reduce forage quality and acceptance. Winter annual weeds such as henbit and chickweed shade the crowns overwinter and reduce plant vigor in spring, weakening the stand and allowing summer weeds to increase. Some weeds have good forage quality but will still reduce yield (Marten and Andersen, 1975). An example is dandelion, which is an opportunist to become established and has upright leaves in thicker stands that extend more horizontally to remain very competitive as the alfalfa stand thins (Sheaffer and Wyse, 1982). However, dandelion populations in alfalfa are associated positively with populations of *Coleomegilla maculate,* an insect that feeds on pea aphids to reduce their damage to alfalfa (Harmon et al., 2000).

Weeds in either grass or legume monocultures can be effectively controlled with herbicides, while there are essentially no herbicides labeled for use on legume-grass mixtures. The primary and most cost-effective method of weed control in perennial forages is managing the forage crop to provide maximum competition against weeds. In the northern USA, weed encroachment in an established perennial forage stand is often only a side effect of a declining forage stand and can be used to help determine timing of crop rotation. Thinning

“Weed management of haylands starts during establishment, after which plant competition is the major method used to reduce encroachment”

> “Recently alfalfa cultivars with glyphosate resistance have been made available by private industry.”

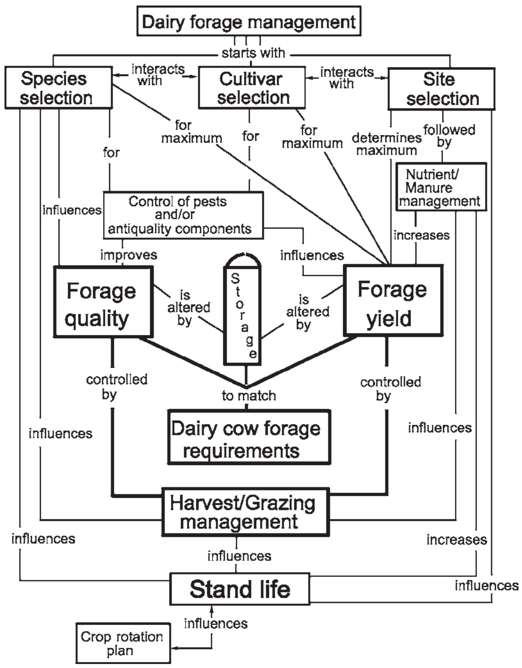


FIGURE 4.11. Major linkages in a dairy-forage system focused on management for economic production of quality forage and stand life to meet nutritional requirements of lactating cows. Note nutrient management has a major effect on yield whereas harvest management affects yield, quality, and stand life. From Cherney and Cherney (1993).

usually does not reach this stage in the first 2 or 3 yr, so weed control is usually not used for short rotations. Weeds tend to be more effective competitors in southern regions where longer stand durations are preferred.

Gaining maximum competition from forage crops begins with site selection, preferably one that has appropriate soil drainage, pH, and fertility for the forage crops involved (Fig. 4.11). Soil pH and soil fertility can be adjusted in advance of seeding to be optimal for the forages to be planted. Well-adapted cultivars should be selected. This is the most cost-effective method of weed control in established stands of perennial forages. Mowing is typically not very effective for reducing weed competition in established perennial forage stands not used as pastures. Weeds generally have a shorter development cycle than perennial forages, making it difficult to reduce seed production. Many perennial weeds require repeated mowing to weaken the plants, but this is not compatible with good forage harvest management schemes. A vigorous, healthy stand with an aggressive harvest management for high-quality forage will be beneficial for weed control.

Recently alfalfa cultivars with glyphosate resistance have been made available by private industry. A small percentage of the individual plants in the cultivar will not be resistant because of the genetic nature of alfalfa, which does not allow pure lines to be developed like for annual crops. Even so, glyphosate-resistant cultivars can be an alternative tool for weed control during establishment of pure stands, and later to control weeds that increase during the life of the stand. Experiments in several states showed seeding-year yields were slightly lower at 6.7 kg ha^{-1} than seeding rates of 11.2, 15.7, or 20.2 kg ha^{-1} (Hall et al., 2010). Alfalfa plant density was similar, but more weed mass was in the control treatment without a commercial herbicide. Competition was the key control for the next year with little difference among control and herbicide treatments. Forage quality was not affected by the glyphosate cultivar or herbicide treatment. This suggested that lower seeding rates may be feasible with glyphosate-resistant cultivars.

In other short-term experiments, with seeding rates as low as 4.5 kg ha^{-1} in Missouri, glyphosate gave more consistent weed control because of its broad spectrum and had little direct effect on yield or quality of glyphosate-resistant alfalfa (Bradley et al., 2010). Alternatively, a long-term study in Michigan considered potential for extending stand life by controlling weeds as the alfalfa stand thinned in a natural pattern from 236 to only 27 plants m^{-2} over the period of 8 yr (Min et al., 2012). Forage quality was affected by cutting frequency but most years was not affected by weed removal by herbicide treatments. The stand thinned at a similar rate with and without herbicide treatment. Understanding economic value of using glyphosate-resistant cultivars in terms of lower seeding rates and extended stand longevity is warranted (Bradley et al., 2010).

Overall, Agricultural Experiment Stations and the Cooperative Extension Service have done a good job of determining harvest schedules that optimize economic return and stand longevity for major forage crops in the state or region. This includes research on timing of first harvest, frequency of harvests, optimal stubble height left after harvest, timing and rates of fertilizer regimens, managing for drought and winter stress, and determining effects of major weeds, diseases, and insect pests. In most cases, however, research evaluations are focused primarily on the yield, quality, and persistence of major species harvested for use as livestock feed. Further, most studies were conducted on flat sites with average or better soils. Except for some studies on erosion control and nutrient use, there has been little research attention given to environmental conservation and provision of other ecosystem services.

Therefore, the question was addressed, "How much change occurs in economic returns when management goals are extended beyond yield, quality and persistence of monocultures or mixtures to incorporate the other purposes of the Practice Standard?" Focus was on those purposes associated with management decisions to improve the environment or provide more ecosystem services such as plant diversity and enhanced conditions for wildlife. Concurrently, issues of reduced production were considered while the forage serves as a soil nutrient uptake tool, improves control of insects, diseases, and weeds, and maintains or improves wildlife habitat.

PURPOSE 6: MANAGE FORAGES TO MAINTAIN AND/OR IMPROVE WILDLIFE HABITAT

Many options exist for landowners who need a stored forage supply but also want to provide habitat and food supplies for wildlife. Some US literature from the wildlife perspective supports alternative management practices, mainly time of cutting, and is usually focused on ground-nesting birds. Limited literature has caused several states to develop recommendations partly based on the combination of plant and wildlife research focused on food chains, nesting times, and desirable habitat. Minimal amounts of research are usually supplemented by intuition and experiential knowledge. This is clearly a stop-gap method, is usually focused on one or two wildlife species, and usually does not include effects on nonfocused wildlife or determining rational balances between production economics and providing habitat or food supplies for wildlife.

Alfalfa

Many worms, insects, rodents, and other animals live in or are attracted to hay fields for some of much of their life cycle. The most studied situation is alfalfa that is being cut for quality hay or silage. California studies show alfalfa provides good protection and supports varied food sources, especially insects, for hundreds of species of songbirds, swallows, bats, and many types of migratory birds including waterfowl (Putnam et al., 2001). This includes more than 150 resident species of amphibians, birds, mammals, and reptiles. The high palatability of alfalfa, which makes it such a good dairy feed, also makes it desirable to many herbivores, including many species of insects, rodents, and grazing animals. It also provides protection and food for herbage consumers such as rabbits, voles, mice, and gophers. In turn, these birds and small mammals provide food for predators such as fox, hawks, and vultures.

In the southern USA, alfalfa is being evaluated for wildlife plantings based on its high N fixation, good forage quality, and desirable canopy structure (Ball, 2010). Hardy plants can be grown in the South with occasional cutting to support regrowth and young forage for deer, birds, and other wild animals. Ball indicates the value of alfalfa used by wildlife is almost certainly underestimated by most farmers and the public. Until a few years ago conservation plantings focused on food grains, mainly annuals, in recommended planting mixes for food and habitat. Advances in disease resistance and introduction of grazing-tolerant cultivars of alfalfa have improved potentials for large herbivores. High forage quality helps milk production and reproduction of deer and other small mammals. Ball (2010) also points out the vast number of insects that reside in alfalfa fields that provide support for birds and other animals in the food chain.

Thus, the alfalfa environment in many geographic regions supports a multiplicity of wildlife species in harmony with the growing canopy. The challenge, however, is that first harvest of alfalfa grown primarily for high yield

"Many options exist for landowners who need a stored forage supply but also want to provide habitat and food supplies for wildlife."

Wild turkeys do well within managed areas. NRCS photo.

Conservationist conducting a habitat survey for birds in Connecticut. NRCS photo by Paul Fusco.

of high-quality feed occurs at early flower stages which coincide with nesting periods of many wildlife species in the Midwest and eastern states. The main disrupter is close and frequent harvests that rapidly change the habitat and food chain. This situation has become a greater problem following major genetic increases in winter hardiness and plant persistence that has led to earlier and more frequent harvests during the growing season.

Research conducted several years ago in several Midwestern states, for example Leopold et al. (1943) in Wisconsin, Leedy and Hicks (1945) in Ohio, Baskett (1947) in Iowa, Trautman (1982) in South Dakota, and Warner (1981) in Illinois, pointed out first harvest of alfalfa destroys nests of ringnecked pheasants. In South Dakota the normal first cutting in mid-June killed 32% to 39% of the incubating hens and destroyed 86% to 91% of the nests (Trautman, 1982). In contrast, a more recent long-term multistate evaluation including Illinois indicates if the trend toward earlier harvest of alfalfa continues, it will benefit pheasant, since first harvest will occur before the peak nesting period (Warner and Etter, 1989).

Researchers in South Dakota evaluated yellow-flowered alfalfa (falcata types), which has tall growth, lodging resistance, and flowers over a longer period of time than sativa types, until 1 July or later (Boe et al., 1988). It was hypothesized that late maturity of falcata would help farmers stagger harvest dates for production in semiarid areas where one or two-cut systems are common and improve success of ground-nesting birds, especially pheasants, that attract hunters to the state. Synthetics that included falcata genetics were high yielding when harvested in mid- to late July, but quality was lower even though falcata types tended to have better resistance to potato leafhopper. Regrowth of falcata types was less than that of conventional cultivars and could be grazed. Although falcata types have superior winter hardiness, they need to have improved quality for both wildlife and harvested forage. The major deterrent to use of falcata types is very poor seed production.

Nesting water fowl were monitored in south-central North Dakota where about 57% of duck nests would hatch by 10 July, 78% by 20 July, and 85% by 25 July. Other evidence indicated later maturity and harvest would maintain habitat for several species of grassland songbirds, allowing them to fledge at least one brood (Berdahl et al., 2004).

Other Forage Species

Other legumes are being considered for wildlife benefits, including native legumes, but little is known about their production and management. For example, native legumes such as wild bean are being evaluated in Texas and Oklahoma (Butler and Muir, 2010) for agronomic characters that need to be understood before there is further evaluation for wildlife benefits (Butler et al., 2006). Specific studies needed include rhizobia requirement, soil pH, P and K needs, forage and seed yield potentials, responses to cutting, and herbicide tolerance. These are critical since many of the native legumes have indeterminate flowering and seed pods that dehisce, which leads to poor seed harvest. The specific rhizobia also may be unknown or not available (Barker et al., Chapter 2, this volume)

All 15 native legumes evaluated in Missouri had higher protein and lower neutral detergent fiber concentrations than did switchgrass, big bluestem, and indiangrass (McGraw et al., 2004). Legumes were inoculated by use of soil from areas with dense plant populations. Based on forage yield, quality, and seed production, Illinois bundleflower had the greatest potential for use in mixtures with native warm-season grasses. In Kansas, Posler et al. (1993) evaluated yield and quality of binary mixtures of five native legumes and three native warm-season grasses. Addition of legumes increased yield and protein concentration of the mixture, but not digestibility. Once agronomic characteristics are known, legume-grass mixtures can be tested in management systems with potential to favor wildlife.

A modeling effort in Mississippi considered preferences of white-tailed deer for soil resources and forage quality (species not reported) (Jones et al., 2010). Principle component analysis showed deer abundance increased as soil fertility and forage quality increased, with these two variables contributing 58% of the variation in body mass and 52% in antler score. Further, based on general linear models the soil resource components explained 78% and 61% of the variation, respectively. Greater forage availability and quality likely provide a better nutritional plane for herbivores (Strickland and Demarais, 2008). Calcium may have also been important. Most studies on wildlife evaluate plant density and an estimate of quality without documenting the soil resource that likely has both direct and indirect effects on structure of habitat and quality of the food supply.

A detailed review of relationships between modern agricultural practices in Europe and decline in wildlife species gives insight to key principles (Wilson et al., 2005). The authors concluded that agricultural practices have negatively affected diversity of birds, mammals, arthropods and flowering plants. The major effect of intensification has been on crop structure that is now based on a few plant species. Forages are harvested more frequently or grazed more intensively; grain crops are shorter, but have dense structure after harvest due to N fertilization. The authors focused mainly on birds and indicate protection, food sources, and amount of intercepted solar insolation for temperature control of wildlife are critical.

In general, grazing is favored by many wildlife species over cutting because it leaves a heterogeneous sward of vegetation mosaics (Wilson et al., 2005). These swards, especially if somewhat sparse, have bare ground and seed abundance. Some birds depend on nearby trees or shrubs for protection. In one study 15 of the 20 key "farmland bird species" benefited more from shorter heterogeneous swards for foraging and detection of predators. Each bird species reacts differently, however, indicating one crop management system will not favor all. They concluded that structure should be emphasized in crop management with adjacent areas set aside to be managed for food supplies.

> "The main disrupter is close and frequent harvests that rapidly change the habitat and food chain."

“Wildlife biologists for most states in the USA have substantial research data for nesting dates, food sources, and desirable habitats for a range of bird species”

A similar conclusion was reached by Roth et al. (2005) in Wisconsin after their evaluation of a biomass harvest of switchgrass in August. Interestingly, they focused on the population of grassland birds the following year. Harvested plants had shorter vegetation and lower density the next year than did areas that were not harvested. The shorter areas were preferred by grassland birds whereas tall material was preferred by tall-grass bird species. They suggest it would be advantageous for bird populations to not harvest some field areas each year so they could provide habitat for a wider range of available structure and to increase local diversity of grassland birds.

Wildlife biologists for most states in the USA have substantial research data for nesting dates, food sources, and desirable habitats for a range of bird species (see Table 4.4). Thus, recommendations for forage harvest are based primarily on needs of wildlife, mostly on habitat associated with nesting times, with few data on concomitant influences on forage yield and quality. Several state conservation departments have published guidelines for farmers who desire forage species that are more compatible or can be managed as hay and silage crops in ways that are least disruptive to wildlife (e.g., Ochterski, 2006, in New York; Anon, 2010, in Pennsylvania; Anon., 2012, in Missouri).

General recommendations for hay harvests to support wildlife are usually based on birds and are quite similar to the representative one for nesting habits from Pennsylvania (Table 4.4), with emphasis on life cycles of prevalent wildlife for each particular state. Using Pennsylvania recommendations as a general template, the emphases on species and preferred harvest management include the following:

1. Cutting some forage grasses or legumes for hay or silage at the peak of production may be compatible with habitat value of some wildlife, but the best mowing times and heights depend on forage species and desired wildlife.
2. Some areas of forage legumes should be cut very early, before nesting begins, or late, after nesting ends. These mowing strategies may be beneficial since most forage is harvested in a timely way for forage value, while other areas are left to favor wildlife.
3. Mowing cool-season grasses at the boot stage in May minimizes effects of mowing on most nesting wildlife by allowing some regrowth prior to peak nesting season (June–July). Sensitive periods for major wildlife have been defined (see Table 4.4 for Pennsylvania).
4. Cutting cool-season grasses late, for example, first cut during June and July, may destroy nests and kill young wildlife, and hay quality will be lower than when cut at early heading.
5. Native warm-season grasses (e.g., indiangrass, switchgrass, big bluestem, Eastern gamagrass) mature later than most cool-season grasses (Fig. 4.10) and should be cut during the early seedhead stage, when their nutritional yield is greatest. These grasses usually have peak growth during mid- to late summer after the main nesting periods. Thus, cutting time of warm-season grasses is usually less of an issue for wildlife but should occur between 1 and 15 Aug.
6. Native warm-season grasses provide excellent food and year-round cover for wildlife. Forage should be cut to leave 25 cm of stubble, and subsequent use should allow regrowth of 25–30 cm before the first killing frost to provide adequate winter cover for grassland wildlife (Fig. 4.2. in Nebraska).
7. Occasional disturbance from mowing, burning, spraying, or disking is needed to maintain a native grass field. Without disturbances, succession will cause the grassland to be replaced by woody vegetation causing wildlife that require grassland or meadow habitat to be replaced by more common woodland wildlife.
8. Mowing to control “weeds” may not be beneficial for some wildlife. Controlling plants such as thistles is important, but many “weeds” such as nettles, foxtail, and ragweed are palatable to wildlife or attract insects needed to meet diet requirements of many bird species. The goal is to provide a balance between volunteer forbs (weeds) and other desirable forage plants to provide diversity.
9. Field borders are valuable to wildlife and can be simulated by squaring off the

inner portion of irregular-shaped fields for regular harvests. Delaying mowing the angled spaces until August or leaving a 10-m border along wooded areas or fence rows helps provide habitat and food. These outer areas are often less productive for hay, dry slowly, or have fallen branches that can damage haying equipment.

Types of Mowing Patterns

Many state agencies that are responsible for wildlife conservation recommend considering three main types of mowing: 1) Block mowing involves dividing fields into three or four blocks that are mowed on a rotational schedule. This allows different growth stages of forage to exist within a large field. 2) Strip mowing involves dividing a field into strips with fixed or variable widths. A proportion of strips should be harvested each year, but switched annually such that a given strip is not mowed in consecutive years. 3) Random-pattern mowing involves dividing a field into several irregularly shaped patterns assigned to provide cut and not-cut vegetation cover. Each area should be harvested rotationally over years to have a 3–5 yr harvest cycle, primarily to reduce encroachment of woody vegetation.

Regardless of the type or pattern used for mowing, the not-mowed areas or strips should be at least 30 m wide and consist of at least 0.25 ha. Blocks or strips that are too small or too narrow can serve as "habitat sinks," making it easier for predators to hunt the small animals that the land manager desires as outcomes from the habitat management objectives.

Most of these practices have not been researched using established methods to gain supporting data for the forage resource or other ecosystem services, yet they can be considered as "logical uses" of the technology based on life cycles of forage species, desirable wildlife species, food chains, and predators. This focus tends to promote managing the forage resource less intensively, which may be acceptable to landowners who are willing to sacrifice income to accommodate increased plant and wildlife diversity.

Alternatives to Mowing

An acceptable alternative to mowing is spot spraying grass stands with selective herbicides to control noxious weeds and woody plant invasion. This is most critical during the establishment period of grass stands when competition is low and outbreaks can be treated at first detection. Use of selective herbicides before and after grass/legume plantings helps control noxious weeds to establish a successful stand, but there are few herbicides for grass/legume fields. Random or strip spraying may be performed throughout the year taking care to not damage the established forage stand. Herbicide spraying can be used on random patches or fixed strips within a field.

TABLE 4.4. Common nesting periods in Pennsylvania for a range of wildlife species (Anon., 2010).

Wildlife:	Nesting period
White-tailed deer	15 May to 15 July
Eastern cottontail rabbit	1 Feb. to 30 Sept.
Wild turkey	15 April to 31 July
Bobwhite quail	15 April to 31 July
Ring-necked pheasant	15 April to 30 June
Grassland songbirds:	
Eastern meadowlark	15 May to 31 July
Grasshopper sparrow	1 June to 15 Aug.
Field sparrow	15 May to 15 Aug.
Bobolink	15 May to 30 June
Dickcissel	1 June to 31 July

Strip or rotational disking is a simple, effective, and inexpensive tool to manage wildlife habitat. In strip disking, a disk or harrow is used to create ground disturbance in strips to reduce natural succession by breaking up grassy vegetation. Disking opens up grass stands, reduces thick mats of thatch, stimulates germination of seed-producing plants, and increases insect populations as a wildlife food source. But even light tillage will increase loss of organic carbon from the soil.

Prescribed burning is an alternative to mowing, especially when managing many larger fields of native perennial warm-season grasses. Controlled fire using approved methods and safety precautions sets back natural succession and releases nutrients to stimulate growth of valuable grasses and legumes. Prescribed

“Few US studies have evaluated both forage and wildlife in the same experiment.”

burning is less expensive and time consuming than mowing and produces many wildlife and forage benefits. However, prescribed burning requires careful planning and controlled conditions to be an effective management tool. An early season burn works well for perennial warm-season grasses. Improved technologies are needed, especially those addressing timing of burning, which is not well defined for cool-season grasses.

Few US studies have evaluated both forage and wildlife in the same experiment. In Quebec, 20% of North American wood turtles in a mixed-species hayfield were killed by mechanical harvest of first growth with a disc mower (Saumure et al., 2007). In addition, 90% of adults that survived and 57% of juveniles were mutilated. The turtles leave the grassland area before second harvest. They recommend that cutting height of disc mowers be increased to 100 mm since most turtles are < 87 mm high. Sickle-bar mowers cause less death and damage since sickle guards tend to move turtles away from the sickle, albeit with some injury. The authors cite data that a higher cutting height would also reduce wear on the harvester, result in higher quality forage with less stem, and provide more rapid regrowth. Also, the taller stubble would reduce runoff and soil erosion. Understanding interactions among these socioeconomic values in the same experiment is needed (Warner and Brady, 1996).

More emphasis has been placed on assessment of wildlife needs in areas with large tracts of public lands, where grazing predominates. On most public lands, and many private lands, there is direct competition between livestock and wildlife (Cory and Martin, 1985). Loomis et al. (1989) derived a demand curve using a regional travel cost model to statistically estimate marginal value of land for either livestock or wildlife use. Estimates of economic values of forage for elk and deer in Idaho were generated with this method. Loomis et al. found that marginal forage values of deer and elk sometimes exceed livestock forage values. They suggested that wildlife habitat issues should play a major role in determining seasons of use and optimal stocking levels for ranges. Similar methods could be used to assess the relative cost effectiveness of modifying forage harvest regimes to benefit wildlife.

In Nova Scotia a holistic approach to ecosystem services involved fledgling success of ground-nesting birds and forage quality of first harvest of a mixture of timothy, meadow foxtail, several bluegrasses, and reed canarygrass. Delaying cutting from 20 June to 1 July increased fledgling from 0 up to 20% for bobolink, 56% for savannah sparrow, and 44% for Nelson’s sharp-tailed sparrow. Delaying cutting to 7 July allowed maximum fledgling rates for all species. Protein concentration of forage on 20 June had decreased by 2.1 percentage units by 1 July and by 3.5 percentage units by 7 July, whereas acid detergent fiber gradually increased. Calcium and phosphorus remained rather constant. They concluded forage quality decreased when cutting was delayed but was still sufficient for many classes of livestock. Unfortunately they did not report changes in forage yields that would help in economic assessments.

In summary, despite growing public interest and implied responsibility of land owners to support wildlife, there are very few data for specific practices. In most cases the practice that would support one or a few species of wildlife could be to the detriment of other species. The literature tends to show habitat may be the most critical factor regarding harvest management compared with food supplies (Wilson et al., 2005). Timing of harvest to avoid the nesting period, especially the first harvest each year, is critical for most grassland birds. Since landowner goals are a major part of selection of conservation practices to be implemented, landowners should be aware of effects of a management practice on various types or forms of desired wildlife. In some cases, managing stubble height for water management and erosion control may be beneficial to some wildlife and detrimental to other types (Sollenberger et al., Chapter 3, this volume). An overriding challenge is the need to evaluate forage production issues and wildlife systems in the same experiment. Overall, there will be no easy answers; wildlife species that are most desired need to be identified early and given appropriate priority in management decisions.

Fortunately most states have rather good data on life cycles, especially nesting habits, of birds that frequent hayfields in the region. That information, and needs for structure and habitat at certain times of the year, e.g., winter, should allow wildlife biologists, agronomists, and animal scientists to develop experiments to validate the observations. Soils should not be overlooked since production capacity and environmental stability, especially on low-productivity and sloping sites, may be key areas where multiple functions of haylands are best accomplished. Above all, one or more common denominators for forage value and ecosystem services need to be developed that allow objective as well as subjective assessments of desired outcomes from implementation of a conservation practice.

ACHIEVING MULTIPLE GOALS BY FORAGE HARVEST MANAGEMENT

There is movement among the public and policy makers that forages and other land management systems need to achieve multiple goals that contribute to sustainability and resilience of ecosystems and efficient use of natural resources. This context goes well beyond production and extends to broader and long-term food system goals. In this case, roles and management of forages for hay and silage play a critical part in the matrix of activities on the landscape that help facilitate these goals. Future practice standards will need to address these multiple objectives as they grow in importance, and as new research points the way for solutions and compromises among competitive goals. This requires scaling up to whole-farm systems, and beyond, to integrate the land used for hay and silage production into the larger picture involving economic returns, conservation of resources, and providing other services for the public.

Nutrient Balance for Livestock

Nutrient balance within a livestock farm is essential for sustainable, economically feasible livestock production where hay and silage are often important components of the system. Home-grown forages benefit nutrient balance by removing excess nutrients from the soil and serving as a repository for manures to minimize import of nutrients from off-farm. Grazing can be utilized as an efficient forage harvesting system; however, most farms require some forage be harvested and stored for later use. Harvest management controls both forage yield and quality and has a strong influence on stand life (Fig. 4.11). It also affects outputs of ecosystem services such as water quality and wildlife diversity.

Regardless of harvest time, two primary methods of storage are silage (Buxton et al., 2003) and dry hay (Hall et al., 2007). Management prior to harvest is similar for forage that is to be stored as silage or hay, but harvest and storage losses of nutrients are greatly affected by forage composition and the specific details of the harvest and storage processes (Fig. 4.9). Agricultural Experiment Stations have developed good management recommendations for harvest of hay or silage for major forage species and popular mixtures that are adapted and used in that respective state. Invariably recommendations are based on basic principles of forage management and are supported by field research that is often published in semitechnical outlets for practitioners. Guidelines for reducing storage losses are not common among all states, yet these losses affect feed quantity and quality in negative ways and need to be managed to minimize losses.

Forage Contributions to Precision Feed Management

Recently attempts have been made to combine environmental and economic sustainability with feeding management, referred to as either precision feeding or precision feed management (Ghebremichael et al., 2007). The two primary concepts involved are 1) use diets that maximize forage and homegrown feeds diets and 2) ensure nutrient contents for optimum production without overfeeding. Goals are to 1) improve nutrient efficiency and economic returns, 2) optimize the balance between purchased feed nutrient imports and on-farm feed production, and 3) minimize nutrient overfeeding and nutrient excretion (Cerosaletti and Dewing, 2008) (Fig. 4.11). Nutrients must be fed slightly above requirements to accommodate daily variations, but any excess N or P in the diet is excreted by the animal.

Precision feeding is based on measurable characteristics and requires monitoring and effective record keeping (Fig. 4.12). A cropping plan is designed to match available land resources, output needs of the farm, and the farm's conservation plan. Available machinery, labor, and storage facilities are evaluated to

“Recently attempts have been made to combine environmental and economic sustainability with feeding management”

“

monitoring and record keeping involved with precision feed management will minimize nutrient losses in the system.”

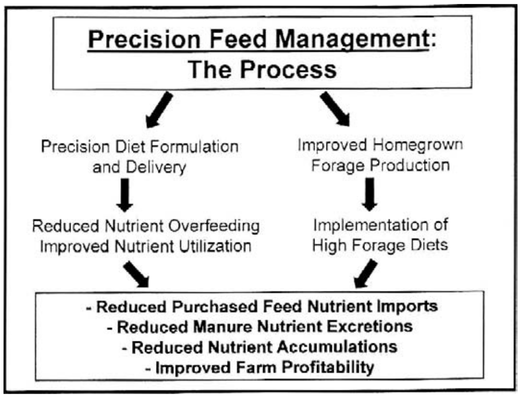


FIGURE 4.12. Precision feed management helps balance nutrient supply from forages to prevent overfeeding and to maximize use of on-farm forages in the diet. The end result is high efficiency of forage use and provision of areas where manures can be recycled on the farm. From Cerosaletti and Dewing (2008).

determine if the farm has the capacity to harvest the desired quantity and quality of forage in a timely manner and allow for proper storage and allocation of feeds (see next section on modeling). Benchmarks for forages to be successful with dairy cattle (Cerosaletti and Dewing, 2008) are the following:

1. Neutral detergent fiber intake > 0.9% of body weight
2. Forage goal > 60% of the diet dry matter
3. Homegrown feed goal > 60% of the diet
4. Phosphorus in ration < 105% of animal P requirement
5. Crude protein in diet < 16.5%
6. Urea N in milk produced, 8–12 mg dL^{-1}
7. Calving interval < 13 months
8. Less than 5% of cows die or culled at < 60 days in milk.

Compared to conventional ways, precision feeding of lactating dairy cows reduced P concentrations in manure by 33%, showing potential for a major impact on P imports in watersheds where dairy farming is the primary agricultural activity (Cerosaletti et al., 2004). A primary requirement for precision feed management is harvest of high-quality forage, coupled with nutrient management (Cherney and Kallenbach, 2007). Hay and haylage quality goals for grasses are approximately 50–55% NDF and 38–40% NDF for alfalfa. Goals for alfalfa-grass mixtures are intermediate and a function of the proportion of grass in the stand (Cherney et al., 2006). Nutrient management is an integral component of this process, leading to high yields of highly digestible forage that is free of toxins and severe mineral imbalances.

Forage mixtures (e.g., alfalfa-grass) can provide high-quality forage for dairy cattle while eliminating or minimizing fertilizer N inputs and maximizing protection from both runoff and leaching. Grass species that are sod forming with robust root systems, such as reed canarygrass, will minimize runoff. Species such as timothy, with much lower apparent N recovery (ANR) and lower CP content, require more supplemental N in cattle diets and should be avoided. Strict guidelines for manure applications on forage crops will minimize environmental concerns and animal pathogen issues. Partial incorporation of manure on forage lands will minimize surface runoff risk. Increased number of harvests will increase ANR and increase forage quality for precision feed management. The monitoring and record keeping involved with precision feed management will minimize nutrient losses in the system. A harvest management that provides high-quality forage is essential.

Special attempts need to be added to precision feed management strategies on dairy farms to meet the purposes and criteria. Environmental and wildlife goals implied in conservation Standard Code 511 should include practices for fields harvested for hay and/or silage. Each field is expected to contribute these services and be managed to realize them. The flexible harvest/grazing management strategy can be adjusted to meet multiple objectives including soil erosion, manure management, other nutrient management, water quality, and wildlife. Each of these needs a balance sheet or diagram to show the various interactions that could occur due to the management system employed. This would also allow the planner to understand if yield, quality, or stand life would be the major factor altered. Thus, there is a need for modeling efforts to help understand the interactions. Research efforts in combination with other data such as rainfall, temperature, and soil properties are critical (Nelson, Chapter 6, this volume).

Similar guidelines for having successful whole farm systems have been considered for beef production (Allen et al., 1992, 2000; Allen and Collins, 2003). Components for beef cattle differ from those for dairy cattle since grazing is a larger part of forage use (Sanderson et al., Chapter 1, this volume), but some hay or silage is required causing the need for another set of data inputs for integration of practices and desired outcomes. For example, compared with a dairy farm, primary forage and livestock breeds on a beef farm are different; pastures are the dominant feed source, priority for high forage quality may be lower, the soil resource may have lower inherent yield potential, the primary focus is on weight gain, most manure is deposited nonuniformly on pastures, and areas used for hay or silage production may also be grazed part of the year. Further, provisions of desired ecosystem outputs by the beef producer may involve priorities that differ from those of dairy farmers.

These interactions among different goals and the methods to achieve them indicate a need for broad education over a range of outputs and strategies. Once goals are defined, application of models that evaluate interactions among major inputs and outputs would be valuable. Education programs should be put into place to help landowners prioritize desired outputs and ways to best achieve them. This should then be followed with periodic monitoring to determine if the practice is working and to assist the landowner apply adaptive management practices to sustain effectiveness of the installed practice.

Use of Comprehensive Models

Modeling was introduced to forage management several years ago with the primary focus on a single component of the entire system even though it had limitations (Debertin and Pagoulatos, 1985). They used a model to focus on alfalfa and crop management within the context of a total farm plan for west-central Kentucky when alfalfa was harvested 3, 4, or 5 times annually. They found the five-harvest system competed with crop production for time and equipment at the desired planting period, especially in a wheat-soybean double crop situation, which could lead to harvest delay and reduced forage quality. It was clear that the best management for alfalfa could not be realized when the entire farm was considered. In fact, in some scenarios, due to challenges with time management, some of the forage could not be harvested. They found tradeoffs would be necessary to achieve most of the goals.

More recently Rotz et al. (1989) have led efforts to develop models that integrate numerous aspects of forage management on a whole farm as a comprehensive system. Examples include manure application methods (Rotz et al., 2011), carbon footprints (Rotz et al., 2010), greenhouse gas emissions (Chianese et al., 2009), and phosphorus losses (Sedorovich et al., 2007). This research also shows it may be very difficult to achieve and maintain high forage productivity and quality simultaneously with needs of other enterprises on the farm. Therefore, these models allow some economic analyses of competing enterprises such as row crops within a whole farm comparison. Computer capabilities and better programs have added to potentials of models for planning and evaluation of conservation practices. Integrated crop-livestock systems for the future may occur within a farm and more likely among farms that occupy watersheds or other basal units. These complex systems will require sophisticated computer programs to enhance both profitability and environmental sustainability (Russelle et al., 2007).

“Once goals are defined, application of models that evaluate interactions among major inputs and outputs would be valuable.”

CONCLUSIONS

For assessment of each purpose the various criteria and goals were listed and then evaluated according to amount and comprehensiveness of published data. In some cases there are ample data for national standards and thus summarized as being adequate (Table 4.1). In other cases there were few or no data available, in which case the summation indicates a specific need and in some cases for specific types of data. Some criteria had intermediate levels of support, and the strengths and deficiencies were pointed out. Overall, the evaluation team felt most production purposes on major species were supported strongly by the published research data. At the same time it was recognized and noted that most local applications of basic principles were developed from local experiments that were published in nonrefereed publications, yet were consistent with the basic literature.

“Assessing goals is even more critical during monitoring of the installed practice to ensure it is working as planned.”

In all cases it was clear that the published data would not answer all the questions that could arise as the field site was evaluated and a structure or practice was proposed and implemented. While species differences were apparent, the most notable factor was harvest practices to address environmental concerns such as soil erosion, water quality, and climate change. In these cases, the experience and intuition of the professional would need to play a larger role by adjusting for local soils, climates, and the local public interests. There was very little research on the roles of harvest management on wildlife, except for nesting patterns, and often the research was on success of only the target species. Little data were presented on habitat, competition among wildlife for food sources, and effects of management on predators. Comprehensive, large-scale research studies utilizing diverse scientists are needed to obtain the correct data to fully evaluate the ecosystem and its outputs.

More technical understanding can play a large role in evaluation and planning even if research is not available. Specialization is needed for evaluation and implementing practices, but broad education is needed to evaluate how the practice will affect the physical environment and local wildlife. Discussions are needed among scientists and professionals to discuss the implications of the program goals based on simple studies and experience-based knowledge, and the landowner needs to be involved. Assessing goals is even more critical during monitoring of the installed practice to ensure it is working as planned. Some results may be achieved quickly, while other outcomes may take several years to become fully credible. Unfortunately nearly all the research is short term, whereas most conservation practices should be long term and have measurable outcomes. Monitoring will be a great asset to the understanding of the practice and what happens over time after the practice is installed (Easton et al., 2008).

There is a gap in the research between those interested in production and those scientists interested in environmental issues or wildlife issues. Too many research papers focus on one aspect with little consideration of the others. For example, we saw many papers addressing major forage management issues with good plant data without enough environmental or wildlife data to document treatment effects. Conversely, there were detailed studies of bird populations and nesting without quantitative data to describe the forage and soil condition. Incentives are needed to ensure the research is comprehensive and of sufficient duration to fully document the responses.

Further, the management effects appear to be somewhat specific relative to optimal environmental results and/or wildlife results. There are other interactions that may offset environmental and wildlife goals of the landowner. In that sense, there is a need to construct practical models to evaluate the interactions and determine the cost-benefit relationships of competing outcomes. Clearly the landowners may differ in their expected “returns” from implementing a conservation practice. These are dealt with in more detail in the synthesis chapter (Nelson, Chapter 6, this volume).

Literature Cited

Allen, V.G., and M. Collins. 2003. Grazing management systems. p. 473–501. *In* R.F Barnes et al. (ed.) Forages: An introduction to grassland agriculture. 6th ed. Iowa State Press, Ames, IA.

Allen, V.G., J.P. Fontenot, and R.A. Brock. 2000. Forage systems for production of stocker steers in the upper South. *J. Anim. Sci.* 78:1973–1982.

Allen, V.G., J.P. Fontenot, D.R. Notter, and R.C. Hammes. 1992. Forage systems for beef production from conception to slaughter: I. Cow-calf production. *J. Anim. Sci.* 70:576–587.

Allen, V.G., R.K. Heitschmidt, and L.E. Sollenberger. 2007. Grazing systems and strategies. p. 709–729. *In* R.F Barnes et al. (ed.) Forages: The science of grassland agriculture. 6th ed. Blackwell, Ames, IA.

Anderson, B., and A.G. Matches. 1983. Forage yield, quality and persistence of switchgrass and Caucasian bluestem. *Agron. J.* 75:119–124.

Anderson, B., and C.A. Shapiro. 1990. Fertilizing grass pastures and haylands. Coop. Ext. NebGuide G78-406. University of Nebraska–Lincoln, NE.

Anon. 2010. Mowing and wildlife: Managing open space for wildlife species. Pennsylvania Game Commission, Harrisburg, PA.

Anon. 2012. Native warm-season grasses for wildlife. Missouri Department of Conservation, Jefferson City, MO.

Bailey, R.G. 1996. Ecosystem geography. Springer-Verlag, New York.

Balasko, J.A., and C.J. Nelson. 2003. Grasses for northern areas. p. 125–148. *In* R.F Barnes et al. (ed.) Forages: An introduction to grassland agriculture. 6th ed. Iowa State Press, Ames, IA.

Ball, D. 2010. Growing alfalfa for wildlife. p. 31–34. *In* G. Lacefield and C. Forsythe (ed.) Kentucky Alfalfa Conf. Proc. 30 (2). University of Kentucky, Lexington, KY.

Barker, D.J., and M. Collins. 2003. Forage fertilization and nutrient management. p. 263–293. *In* R.F Barnes et al. (ed.) Forages: An introduction to grassland agriculture. 6th ed. Iowa State Press, Ames, IA.

Barnes, R.F, C.J. Nelson, M. Collins, and K.J. Moore (ed.) 2003. Forages: An introduction to grassland agriculture. 6th ed. Iowa State Press, Ames, IA.

Barnhart, S.K. 2004. Steps to establish and maintain legume-grass pastures. Iowa State University Extension, Agronomy 3-3. Ames, IA.

Barnhart, S.K., and L. Sternweis. 2009. Converting to pasture or hay—Forage seeding mixtures. Iowa State University, University Extension CRP-13.

Baron, V.S., and G. Belanger. 2007. Climate and forage adaptation. p. 83–104. *In* R.F Barnes et al. (ed.) Forages: The science of grassland agriculture. 6th ed. Blackwell, Ames, IA.

Baskett, T.S. 1947. Nesting and production of the ring-necked pheasant in north-central Iowa. *Ecol. Monogr.* 17:1–30.

Belesky, D.P., and J.M. Fedders. 1995. Warm-season grass productivity and growth rate as influenced by canopy management. *Agron. J.* 87:42–48.

Berdahl, J.D., J.F. Karn, and J.R. Hendrickson. 2004. Nutritive quality of cool-season grass monocultures and binary grass-alfalfa mixtures at late harvest. *Agron. J.* 96:951–955.

Berg, W.K., S.M. Cunningham, S.M. Brouder, B.C. Joern, et al. 2007. The long-term impact of phosphorus and potassium fertilization on alfalfa yield and yield components. *Crop Sci.* 47:2198–2209.

Beuselinck, P.R., J.H. Bouton, W.O. Lamp, A.G. Matches, et al. 1994. Improving legume persistence in forage crop systems. *J. Prod. Agric.* 7:311–322.

Bjelland, D.W., K.A. Weigel, P.C. Hoffman, N.M. Esser, et al. 2011. Production, reproduction, health, and growth traits in backcross Holstein x Jersey cows and their Holstein contemporaries. *J. Dairy Sci.* 94:5194–5203.

Boe, A., R. Bortman, K.F. Higgins, A.R. Kruse, et al. 1988. Breeding yellow-flowered alfalfa for combined wildlife habitat and forage purposes. South Dakota Agric. Exp. Stn. Bull. 727.

Booysen, P. de V., and C.J. Nelson. 1975. Leaf area and carbohydrate reserves in regrowth of tall fescue. *Crop Sci.* 15:262–266.

Bouton, J.H., G.C.M. Latch, N.S. Hill, C.S. Hoveland, et al. 2002. Reinfection of tall fescue cultivars with non-ergot alkaloid-producing endophytes. *Agron. J.* 94:567–574.

Bradley, K., R. Kallenbach, and C.A. Roberts. 2010. Influence of seeding rate and herbicide treatments on weed control, yield and quality of spring-seeded glyphosate-resistant alfalfa. *Agron. J.* 102:751–758.

Brink, G., M. Hall, G. Shewmaker, D. Undersander, et al. 2010. Changes in alfalfa yield and nutritive value within individual harvest periods. *Agron. J.* 102:1274–1282.

Brown, J.R. 1996. Fertility management of harvested forages in the northern states. p. 93–112. *In* Proc. Symp. Nutrient Cycling in Forage Systems, Columbia, MO. 7–8 March 1996. Foundation for Agronomic Research, Manhattan, KS.

Burger, A.W., J.A. Jacobs, and C.N. Hittle. 1962. The effect of height and frequency of cutting on the yield and botanical composition of smooth bromegrass and orchardgrass mixtures. *Agron. J.* 54:23–26.

Burns, J.C., H.F. Mayland, and D.S. Fisher. 2005. Dry matter intake and digestion of alfalfa harvested at sunset and sunrise. *J. Anim. Sci.* 83:262–270.

Butler, T., M.D. Porter, L. Stevens, and J.P. Muir. 2006. Utilization of forages by wildlife. *Agron. Abstr.* 71–75.

Butler, T.J., and J.P. Muir. 2010. 'Rio Rojo' smooth seeded wild bean, a native annual forage legume. *J. Plant Reg.* 4:103–105.

Butler, T.J., J.P. Muir, M.A. Islam, and J.R. Bow. 2007. Rhizoma peanut yield and nutritive value are influenced by harvest technique and timing. *Agron. J.* 99:1559–1563.

Buxton, D.R. 1990. Cell-wall components in divergent germplasm of four perennial forage grass species. *Crop Sci.* 30:402–408.

Buxton, D.R., and M.D. Casler. 1993. Environmental and genetic effects on cell-wall composition and digestibility. p. 685–714. *In* H.G. Jung et al. (ed.) Forage cell wall structure and digestibility. ASA, CSSA and SSSA, Madison, WI.

Buxton, D.R., and J.S. Hornstein. 1986. Cell wall concentration and components in stratified canopies of alfalfa, birdsfoot trefoil, and red clover. *Crop Sci.* 26:180–184.

Buxton, D.R., J.S. Hornstein, W.F. Wedin, and G.C. Narten. 1985. Forage quality in stratified canopies of alfalfa, birdsfoot trefoil, and red clover. *Crop Sci.* 25:273–279.

Buxton, D.R., and G.C. Marten. 1989. Forage quality of plant parts of perennial grasses and relationships to phenology. *Crop Sci.* 29:429–435.

Buxton, D.R., R.E. Muck, and J.H. Harrison. 2003. Silage science and technology. Agron. Mono. 42. ASA, CSSA, SSSA. Madison, WI.

Caddel, J., J. Stritzke, P. Mulder, R. Huhnke, et al. 1995. Alfalfa harvest management: Discussions with cost-benefit analysis. Oklahoma Coop. Ext. Serv. Circ. E-943.

CDC (Centers for Disease Control). 2007. Salmonella typhimurium infection associated with raw milk and cheese consumption—Pennsylvania. *MMWR Morb. Mortal. Wkly. Rep.* 56:1161–1164.

Cerosaletti, P., and D. Dewing. 2008. What is precision feed management? *Northeast Dairy Bus.,* Dec. 2008, p. 15.

Cerosaletti, P.E., D.G. Fox, and L.E. Chase. 2004. Phosphorus reduction through precision feeding of dairy cattle. *J. Dairy Sci.* 87:2314–2323.

Cherney, D.J.R., and J.H. Cherney. 1993. Annual and perennial grass production for silage. p. 9–17. *In* Silage production: From seed to animal. Proc. Natl. Silage Prod. Conf. NRAES-67, Syracuse, NY. Northeast Region. Agric. Eng. Serv., Ithaca, NY.

Cherney, D.J.R., and J.H. Cherney. 2006. Split application of nitrogen on temperate perennial grasses in the Northeast USA. Available at doi: 10.1094/FG-2006-1211-01-RS (verified 10 Nov. 2011)

Cherney, D.J.R., J.H. Cherney, and E.A. Mikhailova. 2002. Nitrogen utilization by orchardgrass and tall fescue from dairy manure or commercial fertilizer nitrogen. *Agron. J.* 94:405–412.

Cherney, J.H., and D.J.R. Cherney. 2005. Agronomic response of cool-season grasses to low intensity harvest management and low potassium fertility. *Agron. J.* 97:1216–1221.

Cherney, J.H., D.J.R. Cherney, and T.W. Bruulesma. 1998. Potassium management. p.137–160. *In* J.H. Cherney and D.J.R. Cherney (ed.) Grass for dairy cattle. CAB Intl., Wallingford, UK.

Cherney, J.H., D.J.R. Cherney, and M.D. Casler. 2003. Low intensity harvest management of reed canarygrass. *Agron. J.* 95:627–634.

Cherney, J.H., D.J.R. Cherney, and D. Parsons. 2006. Grass silage management issues. p. 37–49. *In* Silage for dairy farms: Growing, harvesting, storing, and feeding, Harrisburg, PA. 23–25 Jan. 2006. NRAES-181. Nat. Resour., Agric., and Eng. Serv., Ithaca, NY.

Cherney, J.H., and J.M. Duxbury. 1994. Inorganic nitrogen supply and symbiotic dinitrogen fixation in alfalfa. *J. Plant Nutr.* 17: 2053–2067.

Cherney, J.H., and R.L. Kallenbach. 2007. Forage systems in the temperate humid zone. p. 277–290. *In* R.F Barnes et al. (ed.) Forages: The science of grassland agriculture. 6th ed. Blackwell, Ames, IA.

Cherney, J.H., Q.M. Ketterings, D.J. Cherney, and M.H. Davis. 2010. Timing of semisolid dairy manure applications does not affect yield and quality of orchardgrass. *Agron. J.* 102:553–558.

Chianese, D.S., C.A. Rotz, and T.L. Richard. 2009. Simulation of nitrous oxide emissions from dairy farms to assess greenhouse gas reduction strategies. *Trans. ASABE* 52:1325–1335.

Christians, N.E., D.P. Marten, and J.F. Wilkinson. 1979. Nitrogen, phosphorus, and potassium effects on quality and growth of Kentucky bluegrass and creeping bentgrass. *Agron. J.* 71:564–567.

Clausen, J.C., K. Guillard, C.M. Sigmund, and K. Martin Dors. 2000. Water quality changes from riparian buffer restoration in Connecticut. *J. Environ. Qual.* 29:1751–1761.

Colby, M.G., M. Drake, H. Oohara, and N. Yoshida. 1966. Carbohydrate reserves in orchardgrass. p. 151–155. Proc. Int. Grassl. Congr., Helsinki, Finland. 7–16 July 1983.

Collins, D.M., and D.E. Manning. 2005. Johne's Information Center, School of Veterinary Medicine, Univ. of Wisconsin, Madison, WI.

Collins, M. 1995. Hay preservation effects on yield and quality. p. 67–89. *In* K.J. Moore and M.A. Peterson (ed.) Post-harvest physiology and preservation of forages. CSSA Spec. Publ. 22. ASA, CSSA, SSSA, Madison WI.

Collins, M., and W.K. Coblentz. 2007. Post-harvest physiology. p. 583–616. *In* R.F Barnes et al. (ed.) Forages: The science of grassland agriculture. 6th ed. Blackwell, Ames, IA.

Collins, M., and D.B. Hannaway. 2003. Forage-related animal disorders. p. 415–441. *In* R.F Barnes et al. (ed.) Forages: An introduction to grassland agriculture. 6th ed. Iowa State Press, Ames, IA.

Collins, M., and V.N. Owens. 2003. Preservation of forage as hay and silage. p. 443–471. *In* R.F Barnes et al. (ed.) Forages. An introduction to grassland agriculture. 6th ed. Iowa State Press, Ames, IA.

Cory, D., and W. Martin. 1985. Valuing wildlife for efficient multiple use: Elk versus cattle. *Western J. Agric. Econ.* 10:282–293.

Daliparthy, J., S.J. Herbert, and P.L.M. Veneman. 1994. Dairy manure applications to alfalfa: crop response, soil nitrate, and nitrate in soil water. *Agron. J.* 86:927–933.

Davis, D.K., R.L. McGraw, and P.R. Beuselinck. 1994. Herbage and seed production of annual lespedezas as affected by harvest management. *Agron. J.* 86:704–706.

Davis, D.K., R.L. McGraw, P.R. Beuselinck, and C.A. Roberts. 1995. Total nonstructural carbohydrate accumulation in roots of annual lespedeza. *Agron. J.* 87:89–92.

Debertin, D.L., and A. Pagoulatos. 1985. Optimal management strategies for alfalfa production within a total farm plan. *Southern J. Agric. Econ.* 17:127–137. Dec. 1985.

Digman, M.F., D.J. Undersander, K.J. Shinners, and C. Saxe. 2011. Best practices to hasten field drying of grasses and alfalfa. Univ. Wisconsin Ext. Publ. A3927.

Doll, J.D. 1994. Protein, moisture content and feed value of forage weeds. *Proc. North Central Weed Sci. Soc.* 49:94.

Easton, Z.M., M.T. Walter, and T.S. Steenhuis. 2008. Combined monitoring and modeling indicate the most effective agricultural best management practices. *J. Environ. Qual.* 37:1798–1809.

Esser, N.M., P.C. Hoffman, W.K. Coblentz, M.W. Orth, et al. 2009. The effect of dietary phosphorus on bone development in dairy heifers. *J. Dairy Sci.* 92:1741–1749.

Ethredge, J., E.R. Beaty, and R.M. Lawrence. 1973. Effects of clipping height, clipping frequency and rates of nitrogen on yield and energy content of coastal bermudagrass. *Agron. J.* 65:717–719.

Evers, G.W. 2002. Ryegrass-bermudagrass production and nutrient uptake when combining nitrogen fertilizer and broiler litter. *Agron. J.* 94:905–910.

Fales, S.L., A.S. Laidlaw, and M.G. Lambert. 1996. Cool-season grass ecosystems. p. 267–296. *In* L.E. Moser et al. (ed.) Cool-season forage grasses. Agron. Mono. 34. ASA, CSSA, SSSA, Madison, WI.

Forwood, J.R., and M.M. Magai. 1992. Clipping frequency and intensity effects on big bluestem yield, quality, and persistence. *J. Range Manage.* 45:554–559.

Foster, J.L., A.T. Adesogan, J.N. Carter, L.E. Sollenberger, et al. 2009. Annual legumes for forage systems in the United States Gulf Coast Region. *Agron. J.* 101:415–421.

Fuchs, D.J. 2002. Dairy manure application methods and nutrient loss from alfalfa. *Minnesota Dept. Agric. Greenbook* 1:313–317.

Gates, D.M. 1980. Biophysical ecology. Springer-Verlag, New York.

Geohring, L.D., O.V. McHugh, M.T. Walter, T.S. Steenhuis, et al. 2001. Phosphorus transport into subsurface drains by macropores after manure applications: Implications for best manure management practices. *Soil Sci.* 166:896–909.

George, J.R., C.L. Rhykerd, C.H. Noller, J.E. Dillon, et al. 1973. Effect of N fertilization on dry matter yield, total-N, N recovery, and nitrate-N concentration of three cool-season forage grass species. *Agron. J.* 65:211–216.

Ghebremichael, L.T., P.E. Cerosaletti, T.L. Veith, C.A. Rotz, et al. 2007. Economic and phosphorus-related effects of precision feeding and forage management at a farm scale. *J. Dairy Sci.* 90:3700–3715.

Gist, G.R., and G.O. Mott. 1958. Growth of alfalfa, red clover, and birdsfoot trefoil seedlings under various quantities of light. *Agron. J.* 50:583–586.

Gotlieb, A. 1996. Causes of mycotoxins in silage. p. 213–221. *In* Proc. Silage: Field to feedbunk, Hershey, PA, 11–13 Feb. 1996. NRAES-99. Nat. Resour., Agric., Eng. Serv. Ithaca, NY.

Graber, L.F., and V.G. Sprague. 1935. Cutting treatments of alfalfa in relation to infestations of leafhoppers. *Ecology* 16:48–59.

Hall, M.H., D.B. Beegle, R.S Bowersox, and R.C. Stout. 2003. Optimum nitrogen fertilization of cool-season grasses in the Northeast USA. *Agron. J.* 95:1023–1027.

Hall, M.H., J.M. Dillon, D.J. Undersander, T.M. Wood, et al. 2009. Ecogeographic factors affecting inflorescence emergence of cool-season forage grasses. *Crop Sci.* 49:1109–1115.

Hall, M.H., N.S. Hebrock, P.E. Pierson, J.L. Caddel, et al. 2010. The effects of glyphosate-tolerant technology on reduced alfalfa seeding rates. *Agron. J.* 102: 911–916.

Hall, M.W., J.H. Cherney, and C.A. Rotz. 2007. Saving forage as hay or silage. p. 121–134. *In* E. Rayburn (ed.) Forage utilization for pasture-based livestock production. NRAES-173. Nat. Resour., Agric., Eng. Serv. Ithaca, NY.

Hancock, D.W., R. Hicks, S.P. Morgan, and R.W. Franks. 2011. Georgia forages: Legume species. Univ. Georgia College of Agric. and Environ. Sci. B 1347.

Hannaway, D.B., C. Daly, L. Coop, D. Chapman, and Y. Wei. 2005. GIS-based forage species adaptation mapping. p. 319–342. *In* S.G. Reynolds and J. Frame (ed.) Grasslands: Developments, opportunities, perspectives. FAO and Science Pub., Rome.

Harmon, J.P., A.R. Ives, J.E. Losey, A.C. Olson, and K.S. Rauwald. 2000. *Coleomegilla maculata* (Coleoptera: Coccinellidae) predation on pea aphids promoted by proximity to dandelions. *Oecologia* 125:543–548.

Harris, B., Jr., D. Morse, H.H. Head, and H.H. Van Horn. 1990. Phosphorus nutrition and excretion by dairy animals. Florida Coop. Ext. Serv. Circ. 849.

Hector, A., and M. Loreau. 2005. Relationships between biodiversity and production in grasslands at local and regional scales. p. 295–304. *In* D.A. McGilloway (ed.) Grassland: A global resource. Wageningen Acad. Publ., The Netherlands.

Heichel, G.H., and K.I. Henjum. 2000. Dinitrogen fixation, nitrogen transfer, and productivity of forage legume-grass communities. *Crop Sci.* 31:202–208.

Henning, J.C., C.T. Dougherty, J. O'Leary, and M. Collins. 1990. Urea for preservation of moist hay. *Anim. Feed Sci. Technol.* 31:193–204.

Hoveland, C.S., R.G. Durham, and J.H. Bouton. 1997. Tall fescue response to clipping and competition with no-till seeded alfalfa as affected by fungal endophyte. *Agron. J.* 89:119–125.

Jansen, J., and A. Godkin. 2005. Raising Johne's-free calves. p. 220–225. *In* Advances in dairy technology, Proc. Western Canadian Dairy Seminar, Red Deer, AB.

Jennings, J.A., and C.J. Nelson. 2002. Rotation interval and pesticide effects on establishment of alfalfa after alfalfa. *Agron. J.* 94:786–791.

Joern, B., and J. Volenec. 1996. Manure as a nutrient source for alfalfa. Purdue Univ. Ext. Bull., Dept. Agron., West Lafayette, IN.

Johnson, K.D. 2007. Selecting the "right" legume. Purdue Univ. Coop. Ext. Serv. AY-211.

Jones, P.D., B.K. Strickland, S. Demarais, B.J. Rude, et al. 2010. Soils and forage quality as predictors of white-tailed deer *Odocoileus virginianus* morphometrics. *Wildl. Biol.* 16:430–439.

Kallenbach, R.L., C.J. Nelson, and J.H. Coutts. 2002. Yield, quality and persistence of grazing- and hay-type alfalfa under three harvest frequencies. *Agron. J.* 94:1094–1103.

Kallenbach, R.L., C.J. Nelson, J.H. Coutts and M.D. Massie. 2005. Cutting alfalfa in late autumn increases annual yield, doesn't hurt stands, but is unlikely to increase profit. *Forage Grazingl.* Available at doi:10.1094/FG-2005-0404-01-RS (verified 10 Nov., 2011)

Karlen, D.L., J.L. Lemunyon, and J.W. Singer. 2007. Forages for conservation and improved soil quality. p. 149–166. *In* R.F Barnes et al. (ed.) Forages: The science of grassland agriculture. 6th ed. Blackwell, Ames, IA.

Katayama, N., C. Tanaka, T. Fujita, T. Suzuki, et al. 2001. Effects of silage fermentation and ammonia treatment on activity of *Mycobacterium avium* subsp. *paratuberculosis. Grassl. Sci.* 47:296–299.

Ketterings, Q.M., J.H. Cherney, K.J. Czymmek, E. Frenay, et al. 2008. Manure use for alfalfa-grass production. Dept. Anim. Sci. Mimeo 231/Dept. Crop Soil Sci. Ext. Ser. E08-3. Cornell Univ., Ithaca, NY.

Ketterings, Q.M., E. Frenay, J.H. Cherney, K. Czymmek, et al. 2007. Application of manure to established stands of alfalfa and alfalfa-grass. *Forage Grazingl.* Available at doi:10.1094/FG-2007-0418-01-RV (verified 10 Nov. 2011).

Kim, B.W., and K.A. Albrecht. 2011. Forage quality management of kura clover in binary mixtures with Kentucky bluegrass, orchardgrass, or smooth bromegrass. *Asian-Australasian J. Anim. Sci.* 24:344 350.

Klinner, W.E. 1976. A mowing and crop conditioning system for temperate climates. *Trans. ASAE* 19:237–241.

Knapp, W.R., D.A. Holt, and V.L. Lechtenberg. 1975. Hay preservation and quality improvement by anhydrous ammonia treatment. *Agron. J.* 67:766–769.

Koenig, R., M. Nelson, J. Barnhill, and D. Miner. 2002. Fertilizer management for grass and grass-legume mixtures. Utah State Univ. Coop. Ext. AG-FG-03. Logan, UT.

Kuldau, G.A., and M.A. Mansfield. 2006. Mycotoxins and mycotoxigenic fungi in silages. p. 91–99. *In* Proc. Silage for dairy farms: Growing, harvesting, storing, and seeding. NRAES-181. Harrisburg, PA, 23–25 Jan. 2006. Nat. Resour., Agric., Eng. Serv. Ithaca, NY.

Kust, C.A., and D. Smith. 1961. Influence of harvest management on levels of carbohydrate reserves, longevity of stands and yield of hay and protein from Vernal alfalfa. *Crop Sci.* 1:267–269.

Lamb, J.F.S., D.K. Barnes, M.P. Russelle, C.P. Vance, et al. 1995. Ineffectively and effectively nodulated alfalfas demonstrate biological nitrogen fixation continues with high nitrogen fertilization. *Crop Sci.* 35:153–157.

Lamb, J.F.S., C.C. Sheaffer, L.H. Rhodes, R.M. Sulc, et al. 2006. Five decades of alfalfa cultivar improvement: Impact on forage yield, persistence, and nutritive value. *Crop Sci.* 46:902–909.

Langville, A.R., and G.W. McKee. 1968. Seasonal variation in carbohydrate root reserves and crude protein and tannin in crownvetch forage, *Coronilla varia L. Agron. J.* 60:415–419.

Lawrence, J.R., Q.M. Ketterings, and J.H. Cherney. 2008a. Effect of nitrogen application on yield and quality of silage corn after forage legume-grass. *Agron. J.* 100:73–79.

Lawrence, J.R., Q.M. Ketterings, J.H. Cherney, S.E. Bossard, et al. 2008b. Tillage tools for manure incorporation and nitrogen (N) conservation. *Soil Sci.* 173:649–658.

Leedy, D.L., and L.E. Hicks. 1945. Pheasants in Ohio. p. 57–140. *In* W.L. McAtee (ed.) Ring-necked pheasant and its management in North America. Am. Wildl. Inst., Washington, DC.

Leopold, A., T.M. Sperry, W.S. Feeney, and J.A. Catenhusen. 1943. Population turnover on a Wisconsin pheasant refuge. *J. Wildl. Manage.* 7:383–394.

Liu, X., X. Zhang, and M. Zhang. 2008. Major factors influencing the efficacy of vegetated buffers on sediment trapping: A review and analysis. *J. Environ. Qual.* 37:1667–1674.

Loomis, J., P. Kent, L. Strange, K. Fausch, and A. Covich. 2000. Measuring the total economic value of restoring ecosystem services in an impaired river basin: results from a contingent valuation survey. *Ecol. Econ.* 33:103–117.

Ludwick, A.E., and C.B. Rumberg. 1976. Grass hay production as influenced by N-P top dressing and by residual P. *Agron. J.* 68:933–937.

MacAdam, J.W., and C.J. Nelson. 2003. Physiology of forage plants. p. 73–97. *In* R.F Barnes et al. (ed.) Forages: An introduction to grassland agriculture. 6th ed. Iowa State Press, Ames, IA.

Marten, G.C. 1989. Reed canarygrass. Breeding forage grasses to maximize animal performance. p. 71–104. *In* D.A. Sleper et al. (ed.) Contributions from breeding forage and turf grasses. ASA, CSSA, SSSA, Madison, WI.

Marten, G.C., and R.N. Andersen. 1975. Forage nutritive value and palatability of 12 common annual weeds. *Crop Sci.* 15:821–827.

Matches, A.G. 1969. Influence of cutting height in darkness on measurement of energy reserves of tall fescue. *Agron. J.* 61:896–898.

Matches, A.G., W.F. Wedin, G.C. Marten, D. Smith, et al. 1970. Forage quality on Vernal and DuPuits alfalfa harvested by calendar date and plant maturity schedules in Missouri, Iowa, Wisconsin, and Minnesota. Wisc. Agric. Exp. Stn. Res. Rep. 73.

Mawdsley, J.L., R.D. Bargett, R.J. Merry, B.F. Pain, et al. 1995. Pathogens in livestock waste, their potential for movement through the soil and environmental pollution. *Appl. Soil Ecol.* 2:1–15.

McGechan, M.B. 1990. A cost-benefit study of alternative policies in making grass silage. *J. Agric. Eng. Res.* 46:153–170.

McGraw, R.L., and C.J. Nelson. 2003. Legumes for northern areas. p. 171–190. *In* R.F Barnes et al. (ed.) Forages: An introduction to grassland agriculture. 6th ed. Iowa State Press, Ames, IA.

McGraw, R.L., F.W. Shockley, J.F. Thompson, and C.A. Roberts. 2004. Evaluation of native legume species for forage yield, quality and seed production. *Nativeplants,* Fall 2004, p. 152–159.

McRandal, D.M., and P.B. McNulty. 1978. Impact cutting behaviour of forage crops. I. Mathematical models and laboratory tests. II. Field tests. *J. Agric. Eng. Res.* 23:313–328.

Merry, R.J., R. Jones, and M.K. Theodorou. 2000. The conservation of grass. p. 196–228. *In* A. Hopkins (ed.) Grass: Its production & utilization. 3rd ed., Blackwell Sci., London.

Meyer, D., and J. Helm. 1994. Alfalfa management in North Dakota. North Dakota Agric. Ext. Rep. R-571.

Min, D-H, T.S. Dietz, W.J. Everman, A.E. Chomas, et al. 2012. Glyphosate-resistant alfalfa response to harvest frequency and weed management. *Weed Tech.* 26:399–404.

Mitchell, R.B., L.E. Moser, B. Anderson, and S.S. Waller. 1994. Switchgrass and big bluestem for grazing and hay. Univ. Nebraska NebGuide G94-1198-A.

Monson, W.G. 1966. Effect of sequential defoliation, frequency of harvest and stubble height on alfalfa (*Medicago sativa* L.). *Agron. J.* 58:635.

Moore, K.J., and R.D. Hatfield. 1994. Carbohydrates and forage quality. p. 229–280. *In* G.C. Fahey, Jr. et al. (ed.) Forage quality, evaluation, and utilization. ASA, Madison, WI.

Moore, K.J., and V.L. Lechtenberg. 1987. Chemical composition and digestion in vitro of orchardgrass hay ammoniated by different techniques. *Anim. Feed Sci. Technol.* 17:109–119.

Moore, K.J., V.L. Lechtenberg, and K.S. Hendrix. 1985. Quality of orchardgrass hay ammoniated at different rates, moisture concentrations, and treatment durations. *Agron. J.* 77:67–71.

Morin, C., G. Belanger, G.F. Tremblay, A. Bertrand, et al. 2011. Diurnal variations of nonstructural carbohydrates and nutritive value in alfalfa. *Crop Sci.* 51:1297–1306.

Moser, L.E., and C.J. Nelson. 2003. Structure and morphology of grasses. p. 25–50. *In* R.F Barnes et al. (ed.) Forages: An introduction to grassland agriculture. 6th ed. Iowa State Press, Ames, IA.

Muck, R.E., and L. Kung, Jr. 2007. Silage production. p. 617–633. *In* R.F Barnes et al. (ed.) Forages: The science of grassland agriculture. 6th ed. Blackwell, Ames, IA.

Muir, J.P., W.R. Ocumpaugh, and T.J. Butler. 2005. Trade-offs in forage and seed parameters of annual *Medicago* and *Trifolium* species in north-central Texas as affected by harvest management. *Agron. J.* 97:118–124.

Nelson, C.J. 1996. Physiology and developmental morphology. p. 87–125. *In* L.E. Moser et al. (ed.) Cool-season forage grasses. Agron. Monogr. 34. ASA, CSSA, SSSA, Madison, WI.

Nelson, C.J., and J.C. Burns. 2006. Fifty years of grassland science leading to change: A review. *Crop Sci.* 46:2204–2217.

Nelson, C.J., and L.E. Moser. 1994. Plant factors affecting forage quality. p. 115–154. In G.C. Fahey, Jr., et al. (ed.) Forage quality, evaluation, and utilization. ASA, CSSA, SSSA, Madison, WI.

Nicholson, F.A., B.J. Chambers, J.R. Williams, and R.J. Unwin. 1999. Heavy metal contents of livestock feeds and animal manures in England and Wales. *Bioresour. Technol.* 70:23–31.

Ochterski, J. 2006. Hayfield management and grassland bird conservation. Cornell Coop. Ext., Schuyler County, NY.

Omiccioli, E., G. Amagliani, and G. Brandi. 2009. A new platform for real-time PCR detection of Salmonella spp., *Listeria monocytogenes* and *Escherichia coli* O157 in milk. *J. Food Microbiol.* 26:615–622.

Owensby, C.E., J.R. Rains, and J.D. McKendrick. 1974. Effect of one year of intensive clipping on big bluestem. *J. Range. Manage.* 27:341–343.

Parsons, D., J.H. Cherney, and P.R. Peterson. 2009. Pre-harvest fiber concentration of alfalfa as influenced by stubble height. *Agron. J.* 101:769–774.

Parsons, D., K. McRoberts, J.H. Cherney, D.J.R. Cherney, et al. 2011. Preharvest neutral detergent fiber concentration of temperate perennial grasses as influenced by stubble height. *Crop Sci.* 52:914–922.

Pederson, G.A., G.A. Brink, and T.E. Fairbrother. 2002. Nutrient uptake in plant parts of sixteen forages fertilized with poultry litter: Nitrogen, phosphorus, potassium, copper and zinc. *Agron. J.* 94:895–904.

Peters, E.J., and D.L. Linscott. 1988. Weeds and weed control. p. 705–735. *In* A.A. Hanson et al. (ed.) Alfalfa and alfalfa improvement. Agron. Mono. 29. ASA CSSA, SSSA. Madison, WI.

Peterson, P., and E. Thomas. 2008. Grass sensitivity to cutting height. *Univ. Minn. Forage Qual.* 2(3):1.

Ponican, J., and V. Lichar. 2004. Technical parameters of machines and their influence on the forage crop harvest. *Acta Technol. Agric.* 7:67–70.

Posler, G.L., A.W. Lenssen, and G.L. Fine. 1993. Forage yield, quality, compatibility, and persistence of warm-season grass-legume mixtures. *Agron. J.* 85:544–560.

Prairie Agricultural Machinery Institute. 1993. Hay and forage moisture meters: Delmhorst HTM-1, Delmhorst RDM-H, DANI Haytester, and Omni-Mark Preagro-25. PAMI Report 700. Portage la Prairie, MB.

Probst, T.A., and S.R. Smith. 2011. Harvest frequency effects on yield, persistence, and regrowth rate among new alfalfa cultivars. Available at http://www.plantmanagementnetwork.org/sub/fg/research/2011/alfalfa (verified 10 Nov. 2011).

Putnam, D.H., M. Russelle, S.B. Orloff, J. Kuhn, et al. 2001. Alfalfa, wildlife and the environment: The importance and benefits of alfalfa in the 21st century. California Alfalfa Forage Assoc., Novato, CA.

Radcliffe, E.B., and K.L. Flanders. 1998. Biological control of alfalfa weevil in North America. *Integr. Pest Manage. Rev.* 3:225–242.

Rains, J.R., C.E. Owensby, and K.E. Kemp. 1975. Effects of nitrogen fertilization, burning, and grazing on reserve constituents of big bluestem. *J. Range Manage.* 28:358–362.

Rao, S.C., and B.K. Northup. 2009. Capabilities of four novel warm-season legumes in the Southern Great Plains: Biomass and forage quality. *Crop Sci.* 49:1096–1102.

Rayburn, E. 2002. Forage species adapted to the northeast. West Virginia Univ. Ext. Serv. Available at www.wvu.edu/~agexten/pubnwsltr/TRIM/5823.htm (verified 10 Nov. 2011).

Rayburn, E.B. 1993. Plant growth and development as the basis of forage management. West Virginia Univ. Ext. Serv. Available at www.caf.wvu.edu/~foragegrowth.htm (verified 10 Nov. 2011).

Redfearn, D.D., and C.J. Nelson. 2003. Grasses for southern areas. p. 149–213. *In* R.F Barnes et al. (ed.) Forages: An introduction to grassland agriculture. 6th ed. Iowa State Press, Ames, IA.

Risser, P.G., and W.J. Parton. 1982. Ecosystem analysis of the tallgrass prairie: Nitrogen cycle. *Ecology* 63:1342–1351.

Roth, A.M., D.W. Sample, C.A. Ribic, L. Paine, D.J. Undersander, and G.A. Bartelt. 2005. Grassland bird response to harvesting switchgrass as a biomass energy crop. *Biomass Bioenergy* 28:490–498.

Rotz, C.A. 1995. Field curing of forages. p. 39–66. *In* K.J. Moore and M.A. Peterson (ed.) Post-harvest physiology and preservation of forages. CSSA Spec. Publ. 22. ASA, CSSA, Madison, WI.

Rotz, C.A., and S.M. Abrams. 1988. Losses and quality changes during alfalfa hay harvest and storage. *Trans. ASAE* 31:350–355.

Rotz, C.A., D.R. Buckmaster, D.R. Mertens, and J.R. Black. 1989. DAFOSYM: A dairy forage system model for evaluating alternatives in forage conservation. *J. Dairy Sci.* 72:3050–3063.

Rotz, C.A., and Y. Chen. 1985. Alfalfa drying model for the field environment. *Trans. ASAE* 28:1686–1691.

Rotz, C.A., P.J.A. Kleinman, C.J. Dell, T.L. Veith, et al. 2011. Environmental and economic comparisons of manure application methods in farming systems. *J. Environ. Qual.* 40:438–448.

Rotz, C.A., F. Montes, and D.S. Chianese. 2010. The carbon footprint of dairy production systems through partial life cycle assessment. *J. Dairy Sci.* 1266–1282.

Rotz, C.A., and R.E. Muck. 1994. Changes in forage quality during harvest and storage. p. 828–868. *In* G.C. Fahey, Jr., et al. (ed.) Forage quality, evaluation, and utilization. ASA, Madison, WI.

Rotz, C.A., and P. Savoie. 1991. Economics of swath manipulation during field curing of alfalfa. *Appl. Eng. Agric.* 7:316–323.

Rotz, C.A., and D.J. Sprott. 1984. Drying rates, losses and fuel requirements for mowing and conditioning alfalfa. *Trans. ASAE* 27:715–720.

Russelle, M.P., M.H. Entz, and A.J. Franzluebbers. 2007. Reconsidering integrated crop-livestock systems in North America. *Agron. J.* 99:325–334.

Saumure, R.A., T.B. Herman, and R.D. Titman. 2007. Effects of haying and agricultural practices on a declining species: The North American wood turtle, *Glyptemys insculpta*. *Biol. Conserv.* 135:565–575.

Savoie, P. 1987. Hay tedding loses. *Can. Agric. Eng.* 30:151–154.

Schnepf, M., and C. Cox. (ed.) 2006. Environmental benefits of conservation on cropland: The status of our knowledge. Soil Water Conserv. Soc. Ankeny, IA.

Sedorovich, D.M., C.A. Rotz, P.A. Vadas, and R.D. Harmel. 2007. Predicting management effects on phosphorus loss from farming systems. *Trans. ASAE* 50:1443–1453.

Sharpley, A.N., S. Chapra, R. Wedepohl, J.T. Sims, et al. 1994. Managing agricultural phosphorus for protection of surface waters: Issues and options. *J. Environ. Qual.* 23:437–451.

Sheaffer, C.C., G.D. Lacefield, and V.L. Marble. 1988. Cutting schedules and stands. p. 411–437. *In* A.A. Hanson, D.K. Barnes, and R.R. Hill (ed.) Alfalfa and alfalfa improvement. Agron. Mono. 29. ASA, CSSA, SSSA, Madison, WI.

Sheaffer, C.C., and D.L. Wyse. 1982. Common dandelion (*Taraxicum officianale*) control in alfalfa (*Medicago sativa*). *Weed Sci.* 30:216–220.

Shuler, P.E., and D.B. Hannaway. 1993. The effect of preplant nitrogen and soil temperature on yield and nitrogen accumulation of alfalfa. *J. Plant Nutr.* 16:373–392.

Simpson, K. 1991. Fertilizers and manures. John Wiley, New York.

Skinner, R.H., and K.J. Moore. 2007. Growth and development of forage plants. p. 53–66. *In* R.F Barnes et al. (ed.) Forages: The science of grassland agriculture. 6th ed. Blackwell Publ., Ames, IA.

Sleper, D.A., and C.P. West. 1996. Tall fescue. p. 471–502. In L.E. Moser et al. (ed.) Cool-season forage grasses. Agron. Monogr. 34. ASA, CSSA, and SSSA, Madison, WI.

Sleugh, B., K.J. Moore, J.R. George, and E.C. Brummer. 2000. Binary legume-grass mixtures improve forage yield, quality, and seasonal distribution. *Agron. J.* 92:24–29.

Smith, D. 1962. Carbohydrate root reserves in alfalfa, red clover, and birdsfoot trefoil under several management schedules. *Crop Sci.* 2:75–78.

Smith, D., and C.J. Nelson. 1967. Growth of birdsfoot trefoil and alfalfa. I. Response to height and frequency of cutting. *Crop Sci.* 7:130–133.

Smith, M. 2008. Iowa crop performance tests-alfalfa. Iowa State Univ. Ext. Guide 84.

Sollenberger, L.E., and M. Collins. 2003. Legumes for southern areas. p. 191–213. *In* R.F Barnes et al. (ed.) Forages: An introduction to grassland agriculture. 6th ed. Iowa State Press, Ames, IA.

Stabel, J.R. 1998. Johne's disease: A hidden threat. *J. Dairy Sci.* 81:283–288.

Strickland, B.K., and S. Demarais. 2008. Influence of landscape composition and structure on antler size of white-tailed deer. *J. Wildl. Manage.* 72:1101–1108.

Sulc, R.M., and W.O. Lamp. 2007. Insect pest management. p. 411–424. *In* R.F Barnes et al. (ed.) Forages: The science of grassland agriculture. Blackwell Publ., Ames, IA.

Sulc, R.M., E. van Santen, K.D. Johnson, C.C. Sheaffer, et al. 2001. Glandular-haired cultivars reduce potato leafhopper damage in alfalfa. *Agron. J.* 93:1287–1296.

Trautman, C.G. 1982. History, ecology and management of the ring-necked pheasant in South Dakota. South Dakota Game, Fish and Parks Dept. Pierre, SD.

Van Horn, H.H., R.A. Nordstedt, A.V. Bottcher, E.A. Hanlon, et al. 1991. Dairy manure management: Strategies for recycling nutrients to recover fertilizer value and avoid environmental pollution. Florida Coop. Ext. Serv. Circ. 1016.

Vetsch, J.A., and M.P. Russelle. 1999. Reed canarygrass yield, crude protein, and nitrate N response to fertilizer N. *J. Prod. Agric.* 12:465–471.

Volenec, J.J., and C.J. Nelson. 2003. Environmental aspects of forage management. p. 99–124. *In* R.F Barnes et al. (ed.) Forages: An introduction to grassland agriculture. 6th ed. Iowa State Press, Ames, IA.

Volenec, J.J., and C.J. Nelson. 2007. Physiology of forage plants. p. 37–52. *In* R.F Barnes et al. (ed.) Forages: The science of grassland agriculture. 6th ed., Blackwell Publ., Ames, IA.

Volenec, J.J., A. Ourry, and B.C. Joern. 1996. A role for nitrogen reserves in forage regrowth and stress tolerance. *Physiol. Plant.* 97:185–193.

Ward, C.Y., and R.E. Blaser. 1961. Carbohydrate food reserves and leaf area in regrowth of orchardgrass. *Crop Sci.* 1:366–370.

Warner, R.E. 1981. Illinois pheasants: Population, ecology, distribution, and abundance, 1900–1978. Biol. Illinois Nat. Hist. Surv. Notes 115. Springfield, IL.

Warner, R.E., and S.J. Brady. 1996. Managing farmlands for wildlife. p. 648–662. *In* T.A. Bookout (ed.) Research and management techniques for wildlife and habitats. Wildlife Society, Bethesda, MD.

Warner, R.E., and S.L. Etter. 1989. Hay cutting and the survival of pheasants: A long-term perspective. *J. Wildl. Manage.* 53:455–461.

West, C.P., and C.J. Nelson. 2003. Naturalized grassland ecosystems and their management. p. 315–337. *In* R.F Barnes et al. (ed.) Forages: An introduction to grassland agriculture. 6th ed. Iowa State Press, Ames, IA.

Wilson, J.D., M.J. Whittingham, and R.B. Bradbury. 2005. The management of crop structure: a general approach to reversing the impacts of agricultural intensification of birds? *Ibis* 147:453–463.

Wiersma, D., M. Bertram, R. Wiederholt, and N. Schneider. 2007. The long and short of alfalfa cutting height. Available at www.uwex.edu/ces/crops/uwforage/AlfalfaCutHeight.htm (verified 11 Oct. 2011).

Woolford, M.K., and R.M. Tetlow. 1984. The effect of anhydrous ammonia and moisture content on the preservation and chemical composition of perennial ryegrass hay. *Anim. Feed Sci. Tech.* 11:159–166.