FORAGES AND PASTURE MANAGEMENT

Sequential Grazing of Cool- and Warm-Season Pastures

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ABSTRACT

Pasture productivity in Iowa is often limited by low productivity of cool-season grasses during summer. Our overall objectives were to (i) evaluate the impact of legumes on the productivity and nutritive value of cool-season pastures, (ii) evaluate warm-season grasses for summer grazing, and (iii) determine the effects of pasture sequence on the productivity of season-long grazing systems. Cool-season pastures consisted of smooth bromegrass (*Bromus inermis* Leyss.) alone or in mixture with birdsfoot trefoil (*Lotus corniculatus* L.), alfalfa (*Medicago sativa* L.), or kura clover (*Trifolium ambiguum* M. Bieb.). Warm-season pastures were monocultures of big bluestem (*Andropogon gerardii* Vitman) or switchgrass (*Panicum virgatum* L.). Kura clover was the only legume that persisted well over time, and because of this, pastures interseeded with kura clover maintained a higher nutritive value than either those interseeded with alfalfa or birdsfoot trefoil. This resulted in higher total liveweight gains for cattle grazing sequences that included pastures interseeded with kura clover. In general, rotating cattle to warm-season grass pastures during summer was less advantageous than having them remain on cool-season pastures at a lower stocking rate because warm-season pasture nutritive value was lower and declined more rapidly. However, despite lower nutritive value and consequently animal performance, sequences with warm-season grass pastures did perform well under some conditions and may be a desirable alternative under some circumstances. Having a warm-season grass pasture in the grazing sequence provides an opportunity to relieve cool-season pastures when growth conditions become limiting and introduces flexibility into the management system.

UNEVEN SEASONAL distribution of forage production is a primary complication in the utilization of pastures. In Iowa and most of the Midwest, cool-season grass pastures are the base forage for beef cattle production. These pastures produce most of their growth in the spring and early summer. Consequently, their carrying capacity is greatly reduced as the season progresses. Under typical management practices, much of the early growth is undergrazed to stockpile forage for later use. A major problem with this management system is that as ungrazed forage is allowed to mature, its nutritive value is diminished to very low levels. The energy value of cool-season grasses can change as much as 30% as they develop from a vegetative to a mature stage of maturity (Nelson and Moser, 1994).

A number of different strategies have been previously evaluated for managing the seasonal distribution of forage production. These have included the use of mixed-species pastures, which generally involve the use of legumes in mixtures with grasses (Beuselinck et al., 1992; Posler et al., 1993); the use of plant growth regulators to control the reproductive growth of grasses and grass competition with legumes in mixed stands (Fritz et al., 1987; Roberts and Moore, 1990); various vegetation manipulation treatments such as burning, clipping, and grazing management (Mitchell et al., 1994); and the use of multiple species in complementary grazing systems.

Complementary grazing systems involve rotating cattle among pastures consisting of forage species with differing patterns of seasonal growth and development (Jung et al., 1985). These systems typically utilize cool-season grasses for spring and fall grazing and warm-season grasses for summer grazing. Species are generally selected for complementary grazing systems based on seasonal forage production (Anderson, 1988). Warm-season grasses produce most of their growth during the summer months and therefore are complementary to cool-season species within the context of a grazing system.

The use of legumes grown in mixtures with grasses for pasture offers several advantages over grasses grown alone. Legumes are able to obtain N from the atmosphere through symbiosis with N-fixing bacteria that occupy nodules on their roots (MacAdam and Nelson, 2003). This ability to fix N reduces the fertilizer requirements necessary to maintain pasture production at high levels and minimizes the environmental risks associated with N fertilization (Natl. Res. Counc., 1993). Legumes typically have higher protein concentrations than grasses and therefore improve the nutritive value of the pasture, particularly for high-producing classes of livestock (Van Soest, 1994). Although legumes are C_3 plants, the photosynthetic responses of many forage legumes to temperature are intermediate to those of C_3 and C_4 grasses (Nelson and Moser, 1994). Consequently, the seasonal biomass accumulation of many forage legumes is complementary to that of grasses.

The overall objective of this project was to evaluate the productivity of complementary grazing systems for beef cattle production on marginal land in southern Iowa. Specific objectives were to (i) evaluate the impact of legumes on the productivity of cool-season pastures grazed in the spring and fall, (ii) evaluate warm-season grasses for summer grazing, and (iii) determine the effects of pasture sequence on the productivity of season-long grazing systems.

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Abbreviations: NIRS, near-infrared reflectance spectroscopy; RCBD, randomized complete block design.

MATERIALS AND METHODS

Eight complementary and four continuous grazing systems were evaluated to determine the impacts of legumes and warm-season grasses on season-long productivity of grazing systems. The systems consisted of 12 grazing sequences of cool- and warm-season pastures. The cool-season pastures all contained smooth bromegrass either alone or interseeded with birdsfoot trefoil, alfalfa, or kura clover. These pastures were grazed in sequence with warm-season pastures of big bluestem or switchgrass.

Pastures were established at the McNay Research Farm (40°55′ N, 93°20′ W) near Chariton, IA, on a Grundy-Haig soil (fine, smectitic, mesic Aquertic or Vertic Argiudoll). Smooth bromegrass (cv. Bounty) was seeded into twelve 1.2-ha pastures in early spring 1996. At the same time, birdsfoot trefoil (cv. Norcen), alfalfa (cv. Alfagraze), and kura clover (cv. Rhizo) were each seeded into three of the pastures. All seeding was done with a no-till drill into grass sod killed with glyphosate [*N*-(phosphonomethyl) glycine]. Seeding rates were 13.4 kg ha^{-1} for smooth bromegrass, 5.6 kg ha^{-1} for birdsfoot trefoil, and 9.0 kg ha^{-1} for alfalfa and kura clover. Pastures were blocked by soil characteristics such that each legume treatment and a control (N-fertilized) pasture occurred in each of three blocks. Big bluestem (cv. Rountree) and switchgrass (cv. Cave-in-Rock) were established into an adjacent set of six 1.8-ha pastures during the summer of 1996 using corn (*Zea mays* L.) as a companion crop. Big bluestem was seeded at 9.0 kg ha^{-1}, and switchgrass was seeded at 6.2 kg ha^{-1}, both with corn at a population of 37 000 plants/ha (Hintz et al., 1998). Nitrogen fertilizer was applied at 78 kg ha^{-1} to the cool-season control pastures and 112 kg ha^{-1} to warm-season grass pastures in early May of each year.

The grazing systems were designed on the basis of a fixed seasonal carrying capacity, and pastures were stocked accordingly with growing cattle (*Bos taurus*) throughout the 1997, 1998, 1999, 2000, and 2001 grazing seasons. Cattle were assigned to treatments using the multiple tester assignment technique (Matches et al., 1974). Six cattle were randomly allocated to each cool-season pasture with the restriction that each group was approximately balanced for gender (approximately 1:1) and initial weight (mean = 244 kg, s = 27.7). After the initial grazing period, two cattle from each pasture group were rotated to switchgrass pasture, another two were rotated to big bluestem pasture, and two remained on cool-season pasture throughout the summer grazing period. At the end of the summer grazing period, all cattle returned to their original pasture for the remainder of the grazing season. Grazing of cool-season pastures began during the second week of May each year, and cattle were rotated to summer pastures based on available forage of cool-season pastures and grazing readiness of warm-season grasses (Table 1). Cattle were rotated back to cool-season pasture when availability and nutritive value of warm-season forage became limiting. Animals were weighed at the beginning and end of each grazing period and at approximately 4-wk intervals intermediately. Grazing was terminated each year when available forage became limiting. Temperature and precipitation data were collected daily at a weather station located 3 km northwest of the experimental area.

Table 1. Dates and number of days cool- and warm-season pastures were grazed during five grazing seasons. Cattle began grazing cool-season pastures in spring, were rotated to warm-season pastures in summer, and returned to cool-season pastures for the remainder of the grazing season.

Sequence	1997	1998	1999	2000	2001
Start	13 May	13 May	13 May	11 May	9 May
→Warm season	10 July	24 June	8 July	5 June	5 July
→Cool season	3 Sept.	18 Aug.	19 Aug.	20 July	1 Aug.
End	1 Oct.	18 Sept.	23 Sept.	26 Sept.	29 Aug.
Total days	141	128	133	138	112
Cool season	86	72	91	93	85
Warm season	55	56	42	45	27

Pastures were sampled biweekly during the grazing period each year. Available forage was determined by clipping the forage within six randomly assigned 0.19-m^2 subplots to a height of 2.5 cm. An additional 20 biomass measurements were made in each pasture using a rising-plate meter, which was calibrated against the clipped samples (Harmoney et al., 1997). Samples collected from each pasture were composited and dried at 60°C in a forced-draft oven and were ground to pass a 6-mm screen in a shear mill. The samples were subsequently reground in a cyclone mill fitted with a 1-mm screen to improve particle size uniformity.

Concentrations of crude protein, total fiber, and digestible dry matter were determined by near-infrared reflectance spectroscopy (NIRS) using the protocol described by Windham et al. (Windham et al., 1989). Reflectance (log 1/R) measurements were taken for all samples between 400 and 2500 nm at 2-nm intervals using a scanning monochromator (Model 6500, NIRSystems, Silverspring, MD). A subset of samples was selected for calibration on the basis of spectral characteristics. Separate calibrations were developed for cool- and warm-season pastures using modified partial least squares. Fiber concentration of calibration samples was determined by extraction with neutral detergent using the ANKOM method (ANKOM Technol. Corp., Fairport, NY) as described by Vogel et al. (Vogel et al., 1999). Total N was determined by dry combustion (CHN-2000, LECO Corp., St. Joseph, MI) using a modification of the Dumas Method and multiplied by a factor of 6.25 to calculate crude protein (AOAC, 2000). Dry matter digestibility was determined in vitro using the NC-64 direct acidification procedure (Marten and Barnes, 1980). Botanical composition of the grass–legume pastures was determined using NIRS calibrated with pure grass and legume samples (Moore et al., 1990).

Seasonal, cool-season, and warm-season animal responses were analyzed by analysis of variance using a randomized complete block design (RCBD), with years treated as a repeated measurement (Littell et al., 1997). Years were considered fixed because trends in botanical composition were anticipated and grazing management varied within years depending on pasture condition. The combined analysis indicated that a grazing sequence × year interaction occurred ($P < 0.10$) for animal performance, so each year was evaluated separately. Contrasts were used to compare grass and grass–legume cool-season pastures, warm-season grass pastures, and warm-season vs. cool-season summer pastures (Steel et al., 1997). Stability of the 12 grazing sequences over years was evaluated using the method of Francis and Kannenberg (1978). Pasture nutritive value, composition, and availability were analyzed by year for the reasons noted above. The design was a RCBD, with sampling dates treated as a repeated measurement. There was no significant interaction between grazing sequence and sampling date for quality, composition, and availability parameters, so main-effect means were evaluated. All statistical analyses were performed using the SAS software (SAS Inst., Cary, NC), and tests of significance were made at the 0.10 probability level unless otherwise noted.

RESULTS

Precipitation and Temperature

Weather conditions during the growing season varied considerably during the 5 yr that the pastures were

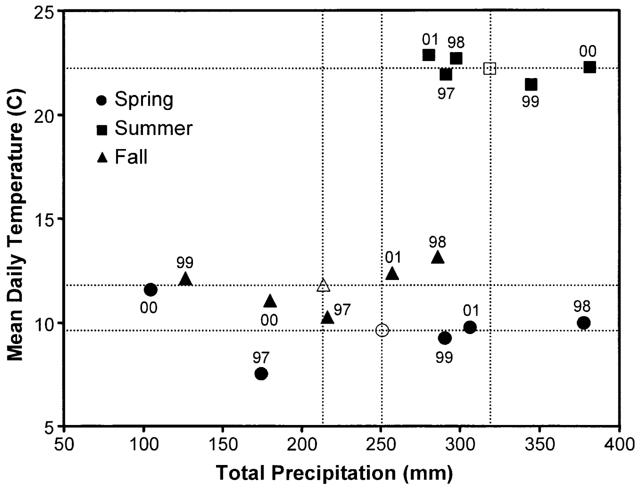

Fig. 1. Total precipitation and average daily temperature during the spring (Mar.–May), summer (June–Aug.), and fall (Sept.–Nov.) during 5 yr of grazing at the McNay Agricultural Research Farm near Chariton, IA. Open symbols represent the 30-yr mean for each season.

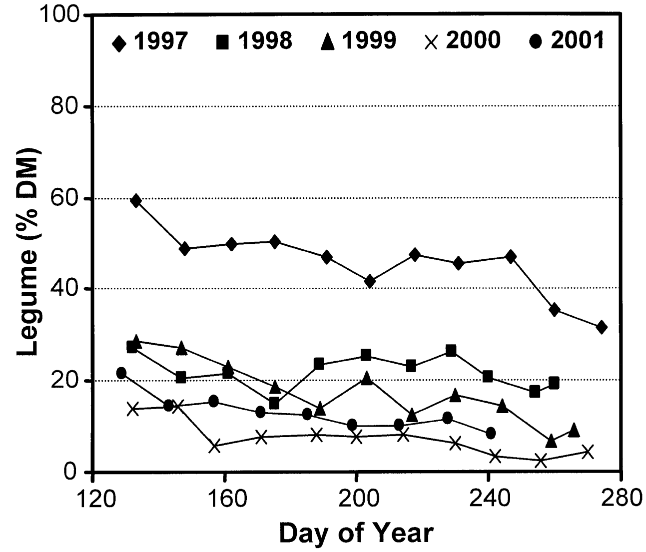

Fig. 2. Average legume percentage in cool-season pastures during 5 yr of grazing. Appropriate standard errors of the mean for comparisons within years are 2.8, 2.2, 2.0, 1.5, and 1.5, consecutively. DM, dry matter.

grazed (Fig. 1). The first year, 1997, was relatively cool throughout the spring and summer, and precipitation was significantly below normal, especially in the spring. The spring of the following year was very wet with near-average temperatures and was followed by a summer of near-average precipitation and temperatures. In 1999, spring precipitation and mean daily temperature were near average. Precipitation during the summer of 1999 was near average and the mean temperature a few degrees below average. The spring of 2000 was very dry and relatively warm. That summer, however, had above-average precipitation with near-average temperatures. In 2001, spring and summer temperatures were near average, and precipitation was above average in the spring and below average in summer. The diverse weather experienced during the study afforded an excellent opportunity to evaluate the productivity and stability of the 12 grazing systems over multiple growth environments.

Pasture Composition and Availability

At the beginning of the first year of grazing, species composition of all cool-season pastures was very diverse and did not represent the desired binary grass–legume mixtures. By disturbing the soil and suppressing grass competition, a very diverse legume seed bank was activated. All of the cool-season pastures contained large numbers of additional legume species. White clover (*Trifolium repens* L.) was the most abundant species recruited from the seed bank and was the dominant legume in control pastures. All pastures, including the control, contained a high proportion of legumes throughout the season (Fig. 2). Growing conditions in 1997 were cool and wet and therefore very conducive to growth of cool-season species (Fig. 1).

The proportion of legumes in cool-season pastures declined significantly during the 1997 grazing season; from an average of almost 60% to 34% by the end of the grazing season (Fig. 2). As the season progressed, the sown legumes became more dominant in the interseeded cool-season pastures. Botanical composition was more stable during 1998, but there were significant declines in legume proportion at the end of the fall and spring grazing seasons. In 1999, the proportion of legumes followed a similar pattern as the previous year during the early grazing season. However, the legumes did not recover as well in the summer and fall, so by the end of the third grazing season, the average legume proportion in cool-season pastures was less than 10%. The spring of 2000 was very dry, and consequently the legumes did not recover well from the previous grazing season. The average legume proportion was approximately 14% at the beginning of the grazing season and declined to an experiment low of only 4% by the end. The legumes recovered somewhat the following year due to above-average precipitation received that spring. Legume proportions for all cool-season pastures except those interseeded with kura clover averaged less than 10% during the final year of grazing. The proportion of kura clover doubled from the previous year to 30% in response to a wet spring (Table 2). Averaged over all cool-season pastures, the proportion of legumes was about 21% at the initiation of grazing, declined to 14% after 2 wk of grazing, and then slowly declined to about 8% by the end of the 2001 grazing season (Fig. 2).

Forage availability, which represents the balance between dry matter produced and that consumed by cattle, is presented for cool- and warm-season pastures in Fig. 3 and 4, respectively. Variability in forage availability largely reflects growing conditions during the grazing period and in this experiment was primarily affected by available soil moisture. The general trend observed was for forage availability to continue to increase early within a grazing period, reach a peak somewhere near the middle, and decline thereafter until the stocking rate was reduced or cattle were removed altogether. This trend was especially apparent in warm-season grass pastures

Table 2. Mean botanical composition, available forage, crude protein, in vitro dry matter (DM) digestibility, and neutral detergent fiber of smooth bromegrass pastures interseeded with various legumes over five grazing seasons.

Pasture	1997	1998	1999	2000	2001
Legume			% DM		
Control	42.0	9.6	12.2	2.7	5.8
Birdsfoot trefoil	58.9	25.9	13.9	2.5	6.3
Kura clover	45.3	29.0	26.2	15.0	30.4
Alfalfa	37.2	22.3	17.2	9.7	9.2
SE†	6.40	3.61	2.80	3.24	6.10
Available forage			kg ha^{-1}		
Control	1842	2352	3034	2271	2461
Birdsfoot trefoil	2221	2690	3067	1884	2027
Kura clover	2083	2684	2762	1970	2275
Alfalfa	1948	2793	2808	1869	2004
SE	256.3	172.7	204.8	108.3	152.1
Crude protein			g kg^{-1} DM		
Control	154	133	135	124	129
Birdsfoot trefoil	174	146	128	111	106
Kura clover	155	146	145	128	143
Alfalfa	147	137	131	118	116
SE	4.3	4.4	5.4	3.0	6.6
Digestibility			g kg^{-1} DM		
Control	582	487	492	504	500
Birdsfoot trefoil	591	499	496	495	504
Kura clover	574	507	531	534	553
Alfalfa	571	490	508	511	506
SE	12.8	11.5	10.3	11.0	15.5
Fiber			g kg^{-1} DM		
Control	506	602	598	606	600
Birdsfoot trefoil	470	571	601	620	614
Kura clover	506	559	561	576	544
Alfalfa	527	580	589	603	589
SE	16.8	10.9	10.6	9.0	14.9

† SE = standard error of the mean.

(Fig. 4) but was observed to a lesser extent in the cool-season pastures (Fig. 3). Available forage was especially low in 2000 because of the low amount of precipitation received that spring.

There were no differences in average available forage among cool-season pastures in any year of the experiment except 2000 (Table 2). In that year, available forage in the control cool-season pastures was significantly

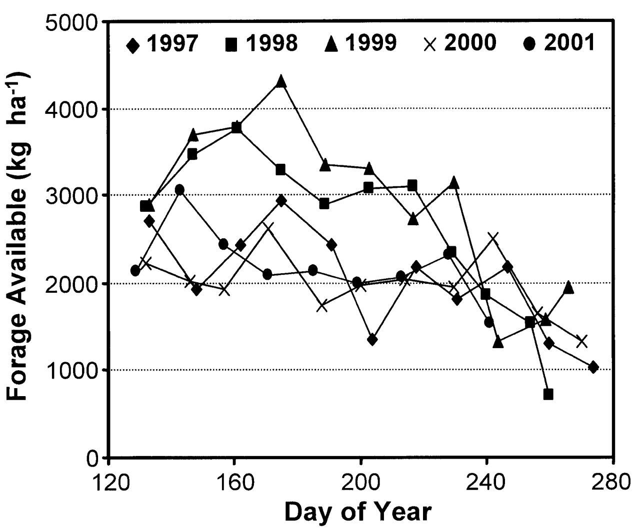

Fig. 3. Average forage available of cool-season pastures during 5 yr of grazing. Appropriate standard errors of the mean for comparisons within years are 118, 146, 221, 134, and 172, consecutively.

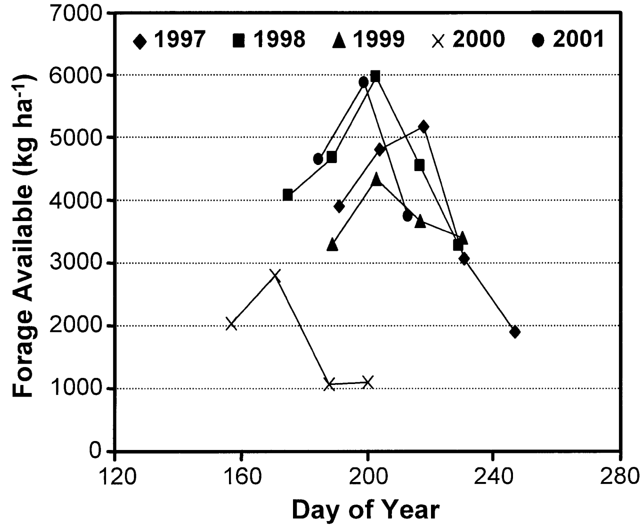

Fig. 4. Average forage available of warm-season grass pastures during 5 yr of grazing. Appropriate standard errors of the mean for comparisons within years are 397, 408, 279, 239, and 355, consecutively.

greater than those into which legumes had been interseeded. Forage growth was limited in 2000 by a dry spring, and as noted above, legume composition of interseeded pastures was relatively low that year.

Switchgrass forage availability was greater on average than that of big bluestem during the first 2 yr of the experiment (Table 3). It is likely that this occurred because the phenological development of big bluestem is slower than that of switchgrass. In 1999, initial spring growth of switchgrass was harvested as hay before the summer grazing period to better synchronize its development with big bluestem. Consequently, in that year, average available forage was higher for big bluestem than switchgrass. There were no differences in available forage between the two warm-season grasses during the last 2 yr of the experiment.

Nutritive Value

Nutritive value of all cool-season pastures was relatively high in 1997 due to the large proportion of le-

Table 3. Mean available forage, crude protein, in vitro dry matter (DM) digestibility, and neutral detergent fiber of warm-season pastures throughout five grazing seasons.

Pasture	1997	1998	1999	2000	2001
Available forage			kg ha^{-1}		
Big bluestem	3636	3009	5336	1762	4744
Switchgrass	3896	5998	2020	1742	4753
SE†	49.6	274.0	136.6	49.8	435.6
Crude protein			g kg^{-1} DM		
Big bluestem	66.4	67.8	58.6	90.8	63.9
Switchgrass	67.2	54.9	76.4	93.9	67.7
SE	1.55	2.72	1.25	1.67	5.98
Digestibility			g kg^{-1} DM		
Big bluestem	515	505	474	502	493
Switchgrass	482	452	508	498	471
SE	4.9	5.4	5.5	12.5	11.5
Fiber			g kg^{-1} DM		
Big bluestem	663	686	668	627	661
Switchgrass	659	708	660	615	657
SE	8.2	5.9	2.9	12.2	6.8

† SE = standard error of the mean. Appropriate for comparisons within column.

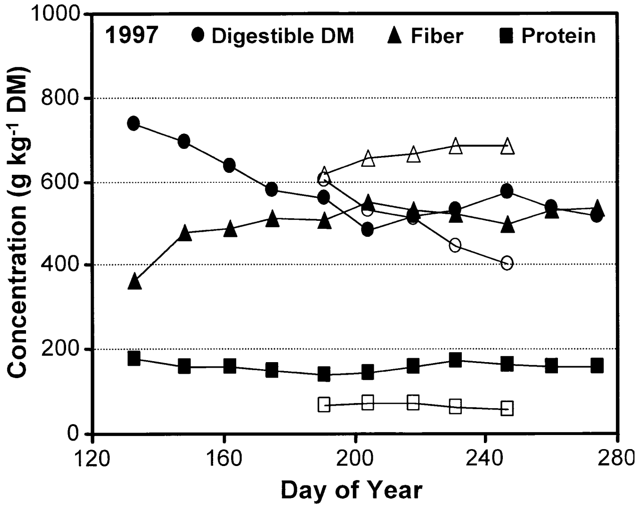

Fig. 5. Nutritive value of cool-season (closed symbols) and warm-season (open symbols) pastures during the 1997 grazing season. Standard errors of the mean are 4.6, 7.5, and 9.2 for cool-season pastures and 5.4, 8.9, and 10.1 for warm-season pastures for crude protein, in vitro dry matter (DM) digestibility, and neutral detergent fiber, respectively.

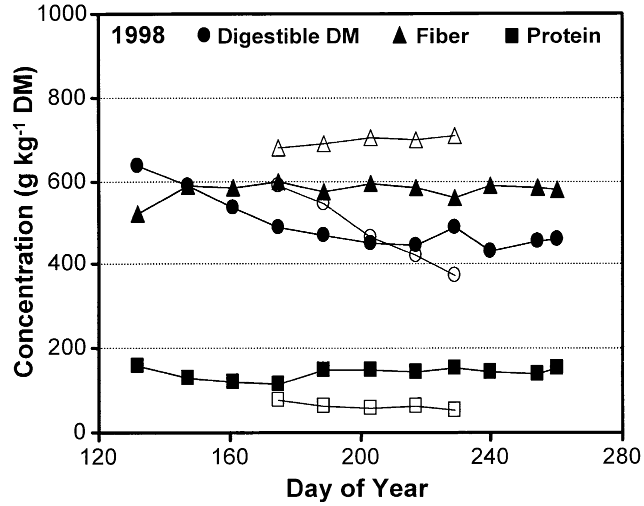

Fig. 6. Nutritive value of cool-season (closed symbols) and warm-season (open symbols) pastures during the 1998 grazing season. Standard errors of the mean are 3.4, 8.9, and 8.7 for cool-season pastures and 2.6, 7.5, and 6.2 for warm-season pastures for crude protein, in vitro dry matter (DM) digestibility, and neutral detergent fiber, respectively.

gumes (Table 2). Crude protein concentration of the birdsfoot trefoil mixture was significantly greater than the others, but there were no other differences among cool-season pastures for protein. Fiber concentration and dry matter digestibility did not differ among cool-season pastures. There were no differences between switchgrass and big bluestem pasture in concentrations of protein and fiber. However, digestibility of big bluestem pasture was significantly higher than that of switchgrass pasture (Table 3). Protein concentration of cool-season pastures declined early in the grazing season, increased during the summer, and then stabilized for the remainder of the season (Fig. 5). Digestibility decreased and fiber concentration increased early in the grazing season and were relatively stable for the remainder of the grazing season. For warm-season grass pastures, digestibility decreased and fiber concentration increased linearly during the summer grazing season. Protein concentration of warm-season grass pastures did not vary significantly during the grazing season.

Nutritive value did not vary among cool-season pastures during the 1998 grazing season (Table 2). However, forage from big bluestem pastures was higher in crude protein and digestibility than that from switchgrass pastures (Table 3). There was no difference in fiber concentration between the two warm-season species. Protein concentration of cool-season pastures declined early in the grazing season, increased during the summer, and then stabilized for the remainder of the season (Fig. 6). Digestibility decreased and fiber concentration increased early in the grazing season and leveled off during summer. Protein concentration and digestibility of warm-season grass pastures declined during the summer grazing season while fiber concentration increased.

Nutritive value of pastures containing kura clover was superior to that of all other cool-season pastures in 1999 (Table 2). Pastures interseeded with alfalfa and birdsfoot trefoil did not differ from the control in digestibility or concentrations of protein and fiber. Although protein concentration did not vary among cool-season pastures, average digestibility of kura clover pastures was higher, and fiber concentration was lower than the control pastures. Switchgrass pastures were higher in digestibility and protein than big bluestem pastures (Table 3). However, there was no difference in fiber concentration between the two species. Seasonal trends in nutritive value of cool and warm-season pastures during the grazing season were similar to the previous grazing season (Fig. 7).

Nutritive value during the 2000 grazing season was similar among cool-season pastures containing alfalfa, birdsfoot trefoil, and no legume. Forage from pastures containing kura clover was more digestible and had less

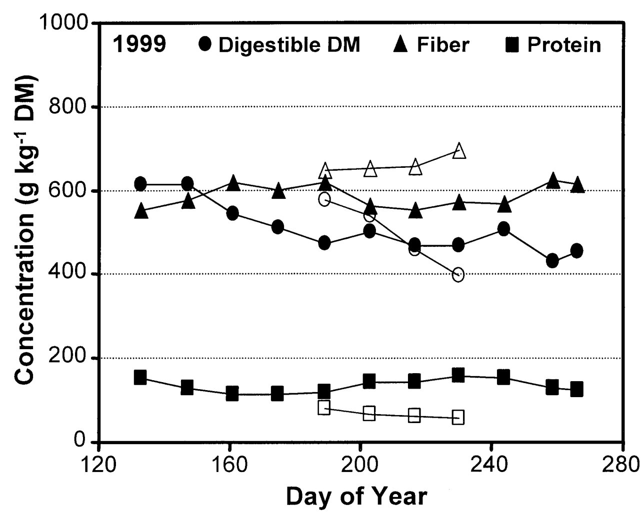

Fig. 7. Nutritive value of cool-season (closed symbols) and warm-season (open symbols) pastures during the 1999 grazing season. Standard errors of the mean are 3.4, 7.3, and 7.5 for cool-season pastures and 3.1, 5.5, and 6.6 for warm-season pastures for crude protein, in vitro dry matter (DM) digestibility, and neutral detergent fiber, respectively.

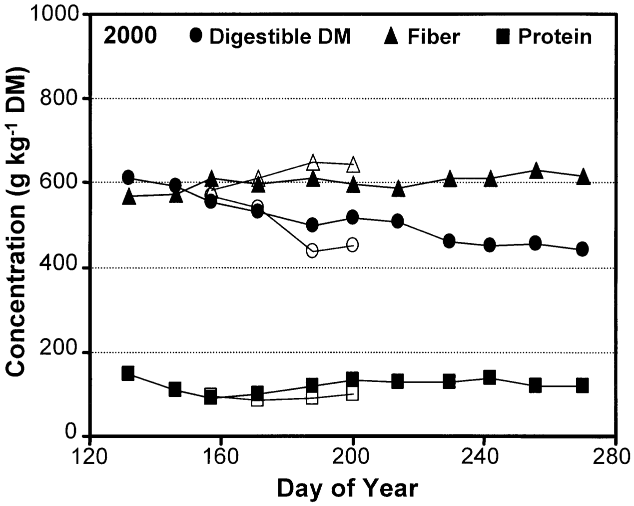

Fig. 8. Nutritive value of cool-season (closed symbols) and warm-season (open symbols) pastures during the 2000 grazing season. Standard errors of the mean are 2.6, 6.0, and 5.1 for cool-season pastures and 2.3, 14.0, and 5.6 for warm-season pastures for crude protein, in vitro dry matter (DM) digestibility, and neutral detergent fiber, respectively.

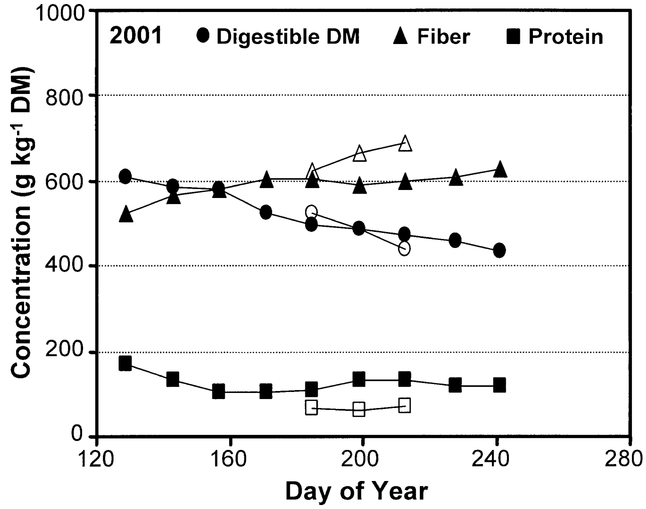

Fig. 9. Nutritive value of cool-season (closed symbols) and warm-season (open symbols) pastures during the 2001 grazing season. Standard errors of the mean are 2.9, 7.2, and 6.2 for cool-season pastures and 2.8, 7.5, and 6.4 for warm-season pastures for crude protein, in vitro dry matter (DM) digestibility, and neutral detergent fiber, respectively.

fiber than that from control pastures (Table 2). Warm-season grass pastures did not differ in digestibility or fiber concentration (Table 3). However, switchgrass protein concentration was slightly higher than that of big bluestem. Seasonal trends in nutritive value of cool-season pastures during the grazing season were similar to previous grazing seasons (Fig. 8). Warm-season grass pastures were grazed earlier in 2000 than previous seasons because of the spring drought, so their initial nutritive value was somewhat better. Digestibility decreased and fiber increased during the grazing period. In contrast to previous seasons, protein concentration actually increased slightly.

Nutritive value of pastures interseeded with kura clover was very high due to the relatively high proportion of legume in 2001 (Table 2). These pastures had the highest digestibility and protein concentration and lowest concentration of fiber. Forage from pastures interseeded with alfalfa or birdsfoot trefoil did not differ in quality from that of the control pastures. Nutritive value of warm-season grass pastures was similar between species (Table 4). Trends in cool-season pasture quality were similar to previous grazing seasons (Fig. 9). Even though the summer grazing period was shorter in 2001, overall trends in quality were similar to the previous grazing season.

Animal Performance

As a consequence of the unusually high legume proportion in all pastures in 1997, there were no differences in season-long animal performance due to the cool-season pasture grazed initially in the spring (Table 4). There were also no differences in performance between cattle grazing switchgrass and big bluestem pastures. However, those animals that grazed warm-season grass pastures during the summer gained less weight than those that grazed cool-season pasture for the entire sea-

Table 4. Cool-season, warm-season, and total liveweight gains of cattle grazing various sequences of cool- and warm-season pastures. Spring and fall pastures were smooth bromegrass and smooth bromegrass interseeded with bridsfoot trefoil, kura clover, or alfalfa. Cattle grazed big bluestem and switchgrass pastures during summer or remained on their initial cool-season pasture (control).

Initial pasture	Summer pasture	1997			1998			1999			2000			2001		
		Cool	Warm	Total	Cool	Warm	Total	Cool	Warm	Total	Cool	Warm	Total	Cool	Warm	Total
		kg/animal														
Control	bluestem	63.1	46.3	109.4	53.5	41.4	94.8	57.2	31.0	88.2	48.1	44.0	92.1	48.3	10.3	58.6
Control	switchgrass	75.7	36.1	111.8	53.7	26.7	80.4	63.7	37.1	100.9	63.6	26.0	89.6	43.3	9.7	53.0
Control	control	92.6	35.6	128.2	46.4	45.1	91.5	65.3	37.7	103.1	68.5	32.8	101.3	59.9	12.9	72.8
Trefoil	bluestem	73.0	37.4	110.3	55.1	52.0	107.2	59.7	27.0	86.7	49.7	33.7	83.3	43.3	23.0	66.2
Trefoil	switchgrass	66.8	35.2	102.1	49.8	36.2	86.1	60.6	28.0	88.6	49.6	27.9	77.5	45.3	19.0	64.3
Trefoil	control	87.3	47.9	135.1	63.4	44.5	108.0	62.8	31.6	94.4	56.6	37.0	93.6	48.0	12.8	60.8
Clover	bluestem	81.3	43.5	124.8	58.8	58.3	117.1	73.6	24.0	97.6	77.5	34.3	111.8	61.8	14.5	76.3
Clover	switchgrass	66.5	37.7	104.1	50.2	37.0	87.2	84.5	31.9	116.5	75.7	18.9	94.6	72.3	9.5	81.7
Clover	control	76.8	50.7	127.4	58.7	51.4	110.1	74.6	41.5	116.1	84.5	44.1	128.6	76.0	16.2	92.2
Alfalfa	bluestem	70.9	35.9	106.9	44.3	42.9	87.2	74.1	20.9	95.0	63.9	32.7	96.6	45.8	6.3	52.1
Alfalfa	switchgrass	70.8	38.7	109.5	46.9	33.5	80.4	71.0	30.1	101.1	64.4	29.2	93.6	47.5	10.7	58.2
Alfalfa	control	83.1	49.0	132.1	64.9	43.0	107.8	76.1	26.4	102.5	60.5	40.3	100.8	53.5	10.1	63.6
Mean		75.7	41.2	116.8	53.8	42.7	96.5	68.6	30.6	99.2	63.6	33.4	97.0	53.8	12.9	66.7
SE†		6.08	4.94	6.85	4.90	6.30	7.30	5.62	4.31	6.58	6.17	4.85	5.58	6.71	3.81	5.62

† SE = standard error of the mean. Appropriate for comparisons within column.

son. With the exception of animals grazing big bluestem pasture following smooth bromegrass pasture, liveweight gains for animals grazing warm-season grass pastures during summer were lower than for those that remained on cool-season pasture.

In 1998, sequences containing kura clover and birdsfoot trefoil produced more total gain than either the control or pastures interseeded with alfalfa (Table 4). However, animals grazing pastures containing alfalfa performed as well those grazing pastures containing kura clover and birdsfoot trefoil in systems in which cool-season pastures were grazed all season. Grazing sequences with big bluestem and cool-season summer pastures produced significantly higher annual gains than those with switchgrass. Rate of liveweight gain was generally much lower during the summer grazing period than the spring/fall grazing periods (Table 4).

Total season liveweight gains in 1999 were highest for cattle grazing pasture sequences containing kura clover. In particular, sequences with kura clover pastures grazed season long and those in sequence with switchgrass produced superior rates of liveweight gain (Table 4). Switchgrass pastures were harvested for hay earlier in the spring that year in an attempt to better synchronize their morphological development with that of big bluestem. This treatment was successful because overall, grazing sequences with switchgrass produced higher liveweight gains than those with big bluestem. In fact, in contrast to previous years, there were no differences in gains between cattle grazing switchgrass pasture in the summer and those that remained on cool-season pasture.

Due to poor forage growth in the spring, animals were rotated to warm-season grass pastures several weeks earlier in 2000 than previous years. Grazing sequences containing kura clover resulted in the highest total cattle gains (Table 4). Pastures in which birdsfoot trefoil had been interseeded actually produced significantly less liveweight gain than the alfalfa and control pastures, which did not differ from one another. Cattle that remained on cool-season pastures during the summer gained faster than those rotated to warm-season grass pastures. Cattle that grazed warm-season grass pastures in the summer performed better overall on big bluestem pastures. This was especially true for the kura clover sequences where total gain was 17.2 kg higher for big bluestem than switchgrass sequences.

Total season gains were lower in 2001 than in previous years due to the summer drought (Table 4). Nevertheless, cattle grazing pasture sequences with kura clover produced higher total gains than those with no legume or birdsfoot trefoil and alfalfa. Total gain averaged 21.8 kg higher for grazing sequences with kura clover compared with those with no legume. Gains from the summer grazing period were very low due to the shortened grazing period and below-average rates of gain for most of the grazing sequences (Table 2).

System Stability

The stability of the 12 grazing sequences was evaluated by comparing variation in total liveweight gain over years and mean animal performance (Fig. 10). Sequences with lower variation over years were more stable than those with higher variation. The ideal sequence would be one with low year-to-year variation and above-average performance in terms of total gain (Quadrant I in Fig. 10). By these criteria, sequences containing kura clover were the most productive and stable over years. The sequence where cattle remained on pastures interseeded with kura clover the entire grazing season was more productive than those where cattle were rotated to warm-season grass pastures in the summer. However, these sequences had above-average performance and better stability than sequences containing alfalfa, birdsfoot trefoil, or no legume. The other three sequences, where cattle remained on their initial pasture at a lower stocking rate during the summer, had above-average performance but were relatively unstable (Quadrant II in Fig. 10). These systems performed very well in some years but not others. The remaining sequences had below-average performance, and most had below-average stability (Quadrants III and IV in Fig. 10). These sequences, therefore, would be much less desirable than the others.

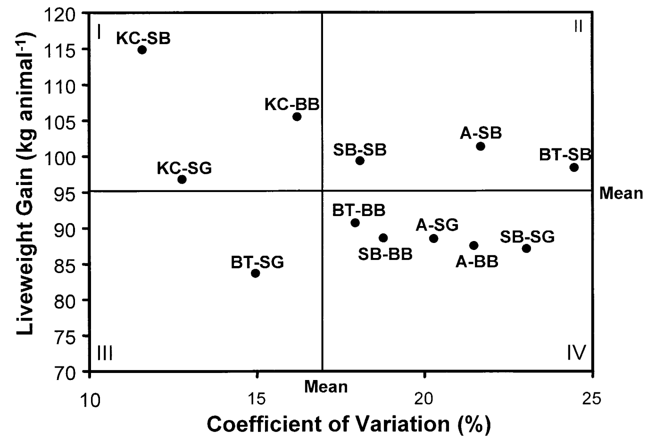

Fig. 10. Plot of average liveweight gain over years for each grazing sequence against its coefficient of variation over years. BT = birdsfoot trefoil, KC = kura clover, A = alfalfa, BB = big bluestem, SG = switchgrass, and SB = smooth bromegrass; SB indicates cattle remained on cool-season pasture during summer grazing period.

One of the more striking results of this experiment was the large impact that year has on performance of the various systems. Much of this variation is due to differences in temperature and precipitation between years, but some can be attributed to differences in legume persistence. The productivity of the species included varied with respect to prevailing climatic conditions, with different combinations of species producing the highest gains in each of the first four grazing seasons. This suggests that the stability of grazing systems over time might be improved by including a higher diversity of species. However, it became increasingly evident that kura clover should be included as a legume species regardless of the grazing sequence followed. Sequences with kura clover produced the highest gains in all but the initial grazing season.

DISCUSSION

The results of this study clearly indicate that kura clover should be a preferred pasture legume for southern Iowa and other areas with similar soils and climate. Unlike alfalfa and birdsfoot trefoil, kura clover persisted well under 5 yr of grazing and appeared to be more resilient following adverse growing conditions. Brummer and Moore (2000) similarly reported that kura clover persisted better than alfalfa and birdsfoot trefoil under grazing in another Iowa study located on a more productive soil. Because of its superior persistence, pastures interseeded with kura clover maintained a higher level of quality than either those interseeded with alfalfa or birdsfoot trefoil. This resulted in higher total liveweight gains for cattle-grazing sequences that included pastures interseeded with kura clover. In addition, pasture sequences containing kura clover were more stable over years, indicating that these pastures were less susceptible to variation in growth environment than those interseeded with alfalfa or birdsfoot trefoil or fertilized with N. Mouriño et al. (2003) similarly observed higher growth rates for cattle grazing mixed pastures interseeded with kura clover than mixed pastures overseeded with red clover (*Trifolium pratense* L.). In another study (Sleugh et al., 2000), quality of kura clover forage was reported to be better than that of alfalfa and birdsfoot trefoil, and this may have also contributed to the superior animal performance on kura clover pastures. Cool-season pastures were continuously stocked at a variable stocking rate. This likely affected the survival of alfalfa and birdsfoot trefoil, which are more persistent under rotational stocking (Leep et al., 2002; Hermann et al., 2002).

In general, rotating cattle to warm-season grass pastures during summer was less advantageous than having them remain on cool-season pastures at a lower stocking rate. The quality of warm-season grass pastures was lower and declined more rapidly than that of cool-season pastures during the summer grazing period. Switchgrass and big bluestem are relatively indeterminate and continue to produce reproductive tillers throughout the summer (Mitchell et al., 1998; Redfearn et al., 1999). Consequently, nutritive value of both species declines rapidly unless swards are kept vegetative either through grazing or some other management practice (Anderson, 2000; George and Obermann, 1989). In 1999, switchgrass was hayed early to delay reproductive development. This strategy was successful in improving summer gains from switchgrass pastures but may be unsustainable due to weakening of the stands when practiced over consecutive years (Hintz, 1995). Despite lower overall quality and performance, sequences with warm-season grass pastures did perform well under some conditions and may be a desirable alternative under some circumstances. Stocking rates varied between sequences using warm-season grass and cool-season summer pastures, with the latter requiring more land to carry the same number of cattle. Decreasing stocking rates on cool-season pastures during summer in response to reduced productivity is a common practice (Barnhart et al., 1998). This requires more land, but the value of excess spring forage is usually conserved as hay or is utilized by other classes of livestock. In situations where the producer wishes to avoid harvesting hay, use of warm-season grass pastures during the summer may be a good way to maintain an appropriate stocking density on cool-season pastures in both spring and summer. Having a warm-season grass pasture in the grazing sequence provides an opportunity to relieve cool-season pastures when growth conditions become limiting and introduces flexibility into the management system.

REFERENCES

Anderson, B.E. 1988. Sequential grazing of cool–warm–cool season perennial grasses: The concept and practice. p. 274–281 *In* Proc. 1988 Am. Forage and Grassl. Conf., Baton Rouge, LA. 11–14 Apr. 1988. Am. Forage and Grassl. Counc., Belleville, PA.

Anderson, B.E. 2000. Use of warm-season grasses by grazing animals. p. 147–157. *In* K.J. Moore and B.E. Anderson (ed.) Native warm-season grasses: Research trends and issues. CSSA Spec. Publ. 30. CSSA and ASA, Madison, WI.

AOAC. 2000. Official methods of analysis of the AOAC international. AOAC Int., Gaithersburg, MD.

Barnhart, S.K., D.G. Morrical, J.R. Russell, K.J. Moore, P.A. Miller, and C.E. Brummer. 1998. Pasture management guide for livestock producers. Pm-1713. Iowa State Univ. Ext., Ames.

Beuselinck, P.R., D.A. Sleper, S.S. Bughrara, and C.A. Roberts. 1992. Effect of mono and mixed culture of tall fescue and birdsfoot trefoil on yield and quality. Agron. J. 84:133–137.

Brummer, E.C., and K.J. Moore. 2000. Persistence of perennial cool-season grass and legume cultivars under continuous grazing by beef cattle. Agron. J. 92:466–471.

Francis, T.R., and L.W. Kannenberg. 1978. Yield stability studies in short-season maize: I. A descriptive method for grouping genotypes. Can. J. Plant Sci. 58:1029–1034.

Fritz, J.O., K.J. Moore, and C.A. Roberts. 1987. Chemical regulation of quality and botanical composition of alfalfa–grass mixtures. p. 166–170. *In* Proc. 1987 Am. Forage and Grassl. Conf., Springfield, IL. 2–5 Mar. 1987. Am. Forage and Grassl. Counc., Lexington, KY.

George, J.R., and D. Obermann. 1989. Spring defoliation to improve summer supply and quality of switchgrass. Agron. J. 82:47–52.

Harmoney, K.R., K.J. Moore, J.R. George, E.C. Brummer, and J.R. Russell. 1997. Determination of pasture biomass using four indirect methods. Agron. J. 89:665–672.

Hermann, M.L., J.R. Russell, and S.K. Barnhart. 2002. Evaluation of hay-type and grazing-tolerant alfalfa cultivars in season-long or complementary rotational stocking systems for beef cows. J. Anim. Sci. 80:768–779.

Hintz, R.L. 1995. Animal and plant responses for steers grazing switchgrass and big bluestem pastures. M.S. thesis. Iowa State Univ., Ames.

Hintz, R.L., K.R. Harmoney, K.J. Moore, J.R. George, and E.C. Brummer. 1998. Establishment of switchgrass and big bluestem in corn with atrazine. Agron. J. 90:591–596.

Jung, G.A., R.L. Reid, L.C. Vona, and L.P. Stephens. 1985. Grazing systems, herbage quality, and animal behavior on warm-season and cool-season grass pastures on hill country in the Northeastern United States. p. 45–63. *In* F.P. Horn (ed.) Grazing-lands research at the plant–animal interface. Winrock Int., Morrilton, AR.

Leep, R., P. Jeranyama, D.H. Min, T. Dietz, S. Bughrara, and J. Isleib. 2002. Grazing effects on herbage mass and composition in grass–birdsfoot trefoil mixtures. Agron. J. 94:1257–1262.

Littell, R.C., P.R. Henry, and C.B. Ammerman. 1997. Statistical analysis of repeated measures data using SAS procedures. J. Anim. Sci. 76:1216–1231.

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

Marten, G.C., and R.F Barnes. 1980. Prediction of energy digestibility of forages with *in vitro* rumen fermentation and fungal enzyme systems. p. 61–71. *In* W.J. Pigden et al. (ed.) Standardization of analytical methodology of feeds. Proc. Workshop, Ottawa, ON, Canada. 12–14 Mar. 1979. Int. Dev. Res. Cent., Ottawa, ON, Canada.

Matches, A.G., F.A. Martz, and G.B. Thompson. 1974. Multiple assignment tester animals for pasture–animal systems. Agron. J. 66:719–722.

Mitchell, R.B., R.A. Masters, S.S. Waller, K.J. Moore, and L.E. Moser. 1994. Big bluestem production and forage quality responses to burning date and fertilizer in tallgrass prairies. J. Prod. Agric. 7:355–359.

Mitchell, R.B., L.E. Moser, K.J. Moore, and D.D. Redfearn. 1998. Tiller demographics and leaf area index of four perennial pasture grasses. Agron. J. 90:47–53.

Moore, K.J., C.A. Roberts, and J.O. Fritz. 1990. Indirect estimation of the botanical composition of alfalfa–smooth bromegrass mixtures at three stages of maturity. Agron. J. 82:287–290.

Mouriño, F., K.A. Albrecht, D.M. Schaefer, and P. Berzaghi. 2003. Steer performance on kura clover–grass and red clover–grass mixed pastures. Agron. J. 95:652–659.

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

National Research Council. 1993. Soil and water quality: An agenda for agriculture. Natl. Res. Counc., Natl. Academy Press, Washington, DC.

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. 85:554–560.

Redfearn, D.D., K.J. Moore, K.P. Vogel, S.S. Waller, and R.B. Mitchell. 1999. Fiber digestion dynamics of sward components within switchgrass populations. Crop Sci. 39:784–789.

Roberts, C.A., and K.J. Moore. 1990. Chemical regulation of tall fescue growth and quality. Agron. J. 82:523–526.

Sleugh, B.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.

Steel, R.G.D., J.H. Torrie, and D.A. Dickey. 1997. Principles and procedures of statistics: A biometrical approach. The McGraw-Hill Co., New York.

Van Soest, P.J. 1994. Nutritional ecology of the ruminant. 2nd ed. Cornell Univ. Press, Ithaca, NY.

Vogel, K.P., J.F. Pedersen, S.D. Masterson, and J.J. Toy. 1999. Evaluation of a filter bag system for NDF, ADF, and IVDMD forage analysis. Crop Sci. 39:276–279.

Windham, W.R., D.R. Mertens, and F.E. Barton II. 1989. Protocol for NIRS calibration: Sample selection and equation development and validation. p. 96–103. *In* G.C. Marten et al. (ed.) Near infrared reflectance spectroscopy (NIRS): Analysis of forage quality. USDA Agric. Handb. 643. U.S. Gov. Print. Office, Washington, DC.