JOURNAL OF ANIMAL SCIENCE
The Premier Journal and Leading Source of New Knowledge and Perspective in Animal Science

Dry matter intake and digestion of alfalfa harvested at sunset and sunrise

J. C. Burns, H. F. Mayland and D. S. Fisher

J Anim Sci 2005. 83:262-270.

Dry matter intake and digestion of alfalfa harvested at sunset and sunrise[1]

J. C. Burns*[2], H. F. Mayland†, and D. S. Fisher‡

*ARS-USDA, and Crop Science and Animal Science Departments, North Carolina State University, Raleigh 27695; †ARS-USDA, Northwest Irrigation and Soils Research Laboratory, Kimberly, ID 83341; and ‡ARS-USDA, JPCS Natural Resource Conservation Center, Watkinsville, GA 30677-2375

ABSTRACT: The preference exhibited by animals in selecting one feed over another is important only if the preferred diet is consumed daily in larger quantities, digested to a greater extent, or both. Six alfalfa (*Medicago sativa* L.) hays were harvested in pairs at sunset (PM) and sunrise (AM) on consecutive days at three harvest dates. A previous study of these hays demonstrated differences in ruminant preference favoring PM harvests. This study evaluated the effects of time of cutting and harvest date on voluntary DMI and nutrient digestibility. The hays were field-cured, baled, and chopped before evaluation for intake and digestibility. Studies were conducted for sheep (*Ovis aries*), goats (*Capra hircus*), and cattle (*Bos taurus*). Goats, but not steers or sheep, demonstrated differences in nutrient digestibility between PM- and AM-cut hays. Goats consumed more PM than AM hay (2.97 vs. 2.83 kg/100 kg of BW; $P = 0.07$) and digested it to a greater extent (0.710 vs. 0.696; $P = 0.03$), resulting in greater digestible DMI (2.11 vs. 1.97 kg/100 kg of BW; $P = 0.03$). Sheep consumed (mean = 2.52 kg/100 kg of BW; $P = 0.59$) and digested (mean = 0.681; $P = 0.25$) PM- and AM-cut hays similarly. Steers consumed larger quantities of PM- than AM-cut hay (2.90 vs. 2.62 kg/100 kg of BW; $P = 0.11$), but digestion did not differ with cutting time (mean = 0.660; $P = 0.75$). Difference values (composition of fed hay minus composition of orts) indicated that sheep and goats selected from the feed offered similarly, whereas steers selected differently. Difference values for CP averaged 94 and 101 g/kg for goats and sheep and 32 g/kg for steers ($P < 0.01$), and difference values for NDF averaged 185 and 196 g/kg for goats and sheep and 73 g/kg for steers ($P \leq 0.01$). Steer DMI and digestible DMI were associated with preference ($r = +0.83$, $P \leq 0.05$; and $r = +0.89$, $P \leq 0.05$) and with coordinates for preference criteria (dimension 1; $r = +0.90$, $P \leq 0.05$; and $r = +0.89$, $P \leq 0.05$) from a previous preference trial. Intake and digestion responses for goats and sheep showed no relationship with the previous preference trial measurements. For cattle and goats, the management strategy of mowing in the afternoon seems to take advantage of small, but influential diurnal changes in the soluble carbohydrate fraction and offers the potential to improve forage quality.

Key Words: Digestion, Goats, Intake, Sheep, Steers

 J. Anim. Sci. 2005. 83:262–270

Introduction

Recent studies showed that cattle, sheep, and goats preferred both tall fescue and alfalfa hay harvested on a clear day at sunset compared with the same forage harvested at the following sunrise (Fisher et al., 1999, 2002). This harvest strategy takes advantage of the plant's potential to accumulate carbohydrates during the daytime (Bowden et al., 1968; Gordon, 1996), resulting in forage with improved nutritive value (Lechtenberg et al., 1971). Of the constituents analyzed in these forages, multidimensional scaling (**MDS**) statistical procedures (Buntinx et al., 1997) used in these trials have consistently implicated total nonstructural carbohydrates or one or more of its constituents as important contributors to preference in at least one preference criterion (dimension). The extent to which animal short-term preference relates to potential animal performance is not known. The objective of this study was to determine whether the short-term preference reported for alfalfa hays harvested at sunset compared with sunrise (Fisher et al., 2002) was reflected in daily DMI and DM digestion of the same alfalfa hay lots when fed in conventional intake and digestion trials.

[1]Cooperative investigation of the USDA-ARS and the North Carolina ARS, Raleigh. The use of trade names does not imply endorsement by USDA or by the North Carolina ARS of the products named or criticism of similar ones not mentioned.

[2]Correspondence: Box 7620 (phone: 919-515-7599; fax: 919-515-7959; e-mail: joe_burns@ncsu.edu).

Received June 5, 2003.
Accepted October 7, 2004.

Materials and Methods

Source of Hays

Hays were harvested at the mid-bud stage from a well-established field of Germain WL 322HQ alfalfa near Kimberly, ID. The initial spring growth was harvested from the field and not used in the trial. Subsequent paired harvests of the regrowth were taken at sunset (**PM**) after a sunny day followed by another cut the next morning (**AM**) at sunrise. Three paired harvests were made in this way, resulting in six experimental hays (Hay 1, July 8 PM [2116]; Hay 2, July 9 AM [0607]; Hay 3, August 13 PM [2041]; Hay 4, August 14 AM [0642]; Hay 5, September 22 PM [1954]; and Hay 6, September 23 AM [0725]). The hays were field-cured in the absence of rain and each pair of hays was baled on the same day and stored under tarps until all six treatments were obtained. The hays were transported to Raleigh, NC, for subsequent animal evaluation. Once at Raleigh, all hays were stored on pallets in a metal building designed for the storage of experimental hays. The DM of the stored hays averaged 909 g/kg (range = 902 to 913).

Alfalfa hay harvested at the late vegetative stage was produced in Raleigh and used for all standardization periods. Just before feeding, all hays were passed through a hydraulic Van Dale 5600 bale processor (J. Starr Industries, Port Atkinson, WI) with stationary knives spaced 10 cm apart. This decreased the hay length (ranging from 8 to 13 cm) for feeding with minimal leaf loss.

Intake and Digestion

Procedure and Design. Dry matter intake and digestion trials were conducted with conventional protocols using steers, sheep, and goats (Burns et al., 1994). The animal care and handling procedures were approved by the North Carolina State University Institutional Animal Care and Research Committee (Approval No. 03-047A). In the steer intake trial, six Angus steers (initial mean BW = 334 kg) were confined in the intake facility fitted with electronic gates (Calan gate system, American Calan, Inc., Northwood, NH; Burns et al., 1997). Each steer was fitted with a key to permit access to only one manger, but animals could lounge together and had free access to trace mineral salt block (consisting of salt and oxides of Zn, Mn, Fe, Cu, and carbonates of Fe, Co, calcium periodate, and mineral oil, and contained not less or more than 970 and 985 g/kg of NaCl and 0.03 and 0.45 g/kg of Ca, and not less than 3.5 g/kg of Zn, 2.8 g/kg of Mn, 1.7 g/kg of Fe, 0.07 g/kg of I, and 0.07 g/kg of Co) and water. After acclimation to the gates, each animal was randomly assigned to one of six hay treatments in a 6×6 Latin square design. Each intake period consisted of 21 d. A separate digestion trial was conducted with steers using a randomized complete block design with four animals (replicates) per treatment. The 24 Angus steers used in the trial ranged from 284 to 356 kg. The steers were blocked by weight with one of the four replicates conducted at a time. The standard alfalfa hay was fed for 7 d to permit initial adjustment by the animals to the digestion crates (conventional raised steel crates fitted with a rubber mat, a swivel stanchion allowing for free head access to water and a mineralized salt block [described above], and a front, tip-down manger providing easy access to the animal and for feeding). This was followed by a 12-d experimental period consisting of a 7-d adjustment to the forage treatment followed by a 5-d total fecal collection period.

The intake and digestion trials with sheep and goats were conducted similarly using conventional wooden crates. Six Katahdin wether sheep (initial mean BW = 36 kg) and six Boer × Spanish wether goats (initial mean BW = 31 kg) were used in 6×6 Latin square designs. The animals were placed into digestion crates located in an enclosed, well-ventilated building. Animals were fitted with conventional collection harnesses with canvas fecal collection bags unzipped and positioned to avoid collection of feces during the acclimation and intake phases. All animals were initially fed the common standard alfalfa hay for a 14-d adjustment period. Animals were then randomly assigned to one of the experimental hays to begin the first period of the Latin square. Each period lasted 18 d and consisted of a 4-d adjustment to the experimental forage, followed by a 14-d intake period with daily total fecal collection occurring on the last 5 d. Total fecal collection was achieved by simply repositioning the harness, inserting a plastic bag liner, and zipping up the canvas collection bags. At the end of the third period, animals were removed from the crates for a 7-d break and were fed the standard alfalfa hay until initiating Period 4.

Feeding and Sampling. All animals were fed at 115% ad libitum intake in all trials. A recorded weight of hay was fed twice daily based on the previous day's intake. To guard against differences within each batch of hay constituting a treatment, a daily sample of the fed hay was obtained during each experimental period and composites were made for a 7-d period. Orts from each animal were weighed twice daily and composited every 7 d. In the digestion phase of each trial, the feed and ort samples were composited for the 5-d collection period and analyzed separately from the samples taken during the intake phase. The last two 7-d samples from the intake phase were further composited for each experimental period. All forage samples were thoroughly mixed, subsampled, oven-dried (55°C), ground in a Wiley mill to pass a 1-mm screen, and stored in an airtight container at room temperature until analyzed.

In the digestion trials, feces were collected and weighed for each consecutive 24-h period. Feces were thoroughly mixed daily, and approximately 5% of the fresh weight placed in a freezer (–14°C). At the end of the 5-d collection, the composite frozen samples were oven-dried (55°C), weighed for DM determination, ground in a Wiley mill to pass a 1-mm screen, thoroughly

Table 1. The range for each forage variable predicted by near-infrared reflectance spectrophotometry, its standard error of calibration (SEC), and its standard error of cross-validation (SECV) in both the intake and digestion experiments

Variable[a]	No.	Range	SEC	SECV
			g/kg	
IVTDMD	162	542 to 845	17	18
CP	162	80 to 259	4	5
NDF	162	327 to 682	7	8
CELL	162	186 to 423	5	6
Lignin	162	54 to 118	2	2
MS	80	3 to 20	1	1
DS	80	0.3 to 40	2	2
SP	80	4 to 14	2	2
Starch	80	0.6 to 12	2	2
TNC	80	17 to 73	4	4

[a]IVTDMD = in vitro true DM disappearance; CELL = cellulose; MS = monosaccharides; DS = disaccharides; SP = short-chained polysaccharides; and TNC = total nonstructural carbohydrate.

mixed, subsampled, and stored at room temperature until analyzed. All intake and digestion data are presented on a DM basis.

Laboratory Analyses

Composition and in vitro true DM disappearance (**IVTDMD**) of fed hays and orts and composition of feed samples were determined using a near infrared reflectance spectrophotometer (**NIRS**). All samples were first scanned through a model 5000 NIRS (Foss North America, Inc., Eden Prairie, MN). Samples with different spectra (using H-distance ≤ 0.6) were designated for laboratory analyses. When analyses were to be conducted on both feed and ort samples, 162 were selected; and when just on the feed samples, as in the case for soluble carbohydrates, only 80 samples were selected (Table 1).

The IVTDMD was determined using ruminal inoculum collected from a cannulated mature Hereford steer fed a mixed alfalfa and orchardgrass hay. After batch incubation for 48 h with ruminal inoculum combined with artificial saliva (Burns et al., 1970) in fermentation vessels (Ankom Technology Corp., Fairport, NY), samples were extracted with neutral detergent solution for estimation of IVTDMD. Fiber fractions (NDF, ADF, cellulose, and sulfuric acid lignin) were estimated on the feed, ort and fecal samples according to Van Soest and Robertson (1980) in a batch processor (Ankom Technology Corp.). Crude protein was calculated on the same samples as 6.25 times the N concentration as determined with an autoanalyzer (AOAC, 1990; Procedure 976.06).

Total nonstructural carbohydrates (**TNC**) were analyzed by an adaptation (Fisher and Burns, 1987) of the method described by Smith (1969). The TNC were fractionated into monosaccharides (**MS**), disaccharides, short-chain polysaccharides, and starch. Starch was determined by digesting to glucose with amyloglucosidase and reading the monomer concentration on a YSI model 27 industrial analyzer (Yellow Springs Instrument Co., Yellow Springs, OH).

Following laboratory analyses, the spectra from the NIRS for each sample and corresponding laboratory values were used to develop appropriate calibration equations. These equations were then applied to the remainder of the samples to estimate concentrations of each variable (Table 1). All data were reported on a DM basis.

Statistical Analyses

All data from the steer, sheep, and goat intake trials and the sheep and goat digestion trials were analyzed as a 6 × 6 Latin square design. In all cases, the model included terms for animal, period, and treatment. The three-way interaction was used to test all sources of variation for significance according to the *F*-test (Steel and Torrie, 1980). The data from the steer digestion trial were analyzed as a randomized complete block design. The model included terms for animal and treatment. The two-way interaction was used to test all sources of variation for significance. Means for all variables analyzed were compared using orthogonal contrasts. The 5 df for treatments were separated into a single-df contrast testing time of cut (**TC**) effect (i.e., PM vs. AM). Another 2 df were used to estimate harvest date (**HD**) effects. The 2 df were further partitioned into 1 df to estimate the linear (**L**) effect and the other for lack of fit (**LOF**). If the L effect was significant and the LOF not, then the data from each harvest date differed. If both the L effect and LOF were significant, then the data for the middle harvest date deviated significantly from the numeric average of the first and third harvest and might even be greater or lesser than observations of the first or third harvest dates. If the L effect was not significant and the LOF was, then the data from the second harvest date differed from that of the first and third harvest date, whereas the data from the first and third harvest dates were similar. The

Table 2. Average DM intake, apparent digestion coefficients, and digestible intakes for DM, CP, NDF, and constituent fiber fractions from alfalfa hays fed to goats (DM basis)

	Time of cut (TC)[a]		Harvest date (HD)[b]				Effect[c]		
								HD	
Item	PM	AM	July	August	September	SE	TC	L	LOF
							– Signficance ($P > F$) –		
Intake, kg/100 kg BW									
DM	2.97	2.83	2.70	2.94	3.07	0.090	0.07	<0.01	0.53
Digestion coefficients									
DM	0.710	0.696	0.684	0.696	0.730	0.007	0.03	<0.01	0.08
CP	0.809	0.808	0.804	0.805	0.817	0.006	0.79	0.07	0.31
NDF	0.635	0.617	0.609	0.629	0.640	0.013	0.11	0.08	0.72
ADF	0.624	0.598	0.598	0.604	0.632	0.013	0.03	0.04	0.02
HEMI[d]	0.661	0.664	0.637	0.688	0.663	0.016	0.84	0.02	0.01
CELL[d]	0.705	0.691	0.674	0.697	0.724	0.012	0.17	0.01	0.90
Digestible intake, kg/100 kg BW									
DM	2.11	1.97	1.85	2.04	2.24	0.069	0.03	<0.01	0.99
CP	0.55	0.53	0.49	0.55	0.58	0.019	0.14	<0.01	0.35
NDF	0.70	0.67	0.64	0.73	0.69	0.030	0.18	0.02	0.01
ADF	0.51	0.47	0.45	0.51	0.50	0.022	0.05	0.04	0.12
HEMI	0.20	0.20	0.19	0.23	0.19	0.009	0.73	0.01	0.01
CELL	0.44	0.42	0.39	0.45	0.44	0.019	0.22	0.01	0.05

[a]Each value is the mean of 18 observations (six animals and three harvest dates). AM = harvested at sunrise, PM = harvested at sunset.
[b]Each value is the mean of 12 observations (six animals and two time of cuts).
[c]L = linear contrast; LOF = lack of fit.
[d]HEMI = hemicellulose; CELL = cellulose.

remaining 2 df were used to estimate the TC × HD interaction. All forage and fecal composition data were considered significant at $P \leq 0.05$. Simple linear correlation was used to examine the relationship between measured preference from previous trials (Fisher et al., 2002) and DMI and DM digestion from intake and digestion trials, as well as other selected relationships of interest. A decision was made *a priori* to consider animal intakes, digestion, and digestible intakes significant with statistical tests at $P \leq 0.15$.

Results and Discussion

Four separate experiments were conducted, including a separate DMI and digestion trial for steers and combined intake and digestion trials for sheep and goats. In all cases, when the TC × HD interaction was not significant, only the main effects are reported.

Intake and Digestion

Animal Response. Goats consumed ($P = 0.07$) more DM of hay cut in the PM compared with hay cut in the AM (Table 2). Further, DMI increased linearly ($P < 0.01$) from July (2.70 kg/100 kg of BW) to September (3.07 kg/100 kg of BW). The digestion coefficients for DM ($P = 0.03$), NDF ($P = 0.11$), and ADF ($P = 0.03$) were greater when goats consumed PM hay than AM hay (Table 2). Digestion coefficients for DM, CP, NDF, ADF, hemicellulose, and cellulose increased from July to the September harvest ($P \leq 0.08$). The significant ($P = 0.08$) LOF for DM digestion (Table 2) was the result of a slightly lower value for the August harvest than a simple linear effect would have produced. The significant ($P = 0.02$) LOF for ADF (Table 2) resulted because the means for the July and August harvest dates were similar, whereas the September coefficient was higher. The LOF was also significant ($P = 0.01$) for the hemicellulose digestion coefficients because the mean for the August harvest was higher than either the July or September harvests.

Digestible intakes by goats were greater for DM ($P = 0.03$), CP ($P = 0.14$), and ADF ($P = 0.05$) from PM- vs. AM-cut hays. Digestible intakes of DM and CP increased linearly ($P = 0.01$) from July to the September harvest. The significant ($P = 0.01$) LOF for digestible intakes of NDF and hemicellulose (Table 2) indicated a peak in the means for the August harvest. The significant LOF for digestible intake in ADF ($P = 0.12$) and cellulose ($P = 0.01$) indicated that the August and September harvest dates were similar.

Sheep responses were generally not altered by time of cut (Table 3). The difference that occurred (digestible hemicellulose intake) was sufficiently small to be of no biological importance. Harvest date influenced ($P < 0.01$) DMI, DM digestion, and cellulose digestion (Table 3). The significant LOF ($P = 0.02$) for DMI was the result of similar intakes for the July and August harvests but an increased intake for the September harvest. The lack of significance for the linear harvest effect and with a significant LOF ($P = 0.09$) for hemicellulose was the result of a higher hemicellulose digestion in the August

Table 3. Average dry matter intake, apparent digestion coefficients, and digestible intakes for dry matter, crude protein, neutral detergent fiber, and constituent fiber fractions from alfalfa hays fed to sheep (DM basis)

	Time of cut (TC)[a]		Harvest date (HD)[b]				Effect[c]		
								HD	
Item	PM	AM	July	August	September	SE	TC	L	LOF
							– Signficance ($P > F$) –		
Intake, kg/100 kg BW									
DM	2.50	2.54	2.43	2.36	2.77	0.102	0.59	<0.01	0.02
Digestion coefficients									
DM	0.690	0.683	0.679	0.677	0.703	0.008	0.25	<0.01	0.05
CP	0.806	0.797	0.806	0.799	0.799	0.008	0.20	0.63	0.67
NDF	0.605	0.606	0.600	0.605	0.612	0.014	0.89	0.69	0.99
ADF	0.592	0.589	0.589	0.582	0.601	0.015	0.83	0.49	0.36
HEMI[d]	0.638	0.649	0.627	0.661	0.642	0.017	0.41	0.17	0.09
CELL[d]	0.682	0.684	0.671	0.679	0.700	0.012	0.86	0.07	0.54
Digestible intake, kg/100 kg BW									
DM	1.72	1.74	1.65	1.60	1.94	0.067	0.77	<0.01	<0.01
CP	0.46	0.47	0.44	0.45	0.52	0.020	0.50	<0.01	0.05
NDF	0.56	0.58	0.57	0.56	0.58	0.027	0.29	0.72	0.45
ADF	0.40	0.41	0.41	0.39	0.42	0.021	0.68	0.31	0.17
HEMI	0.15	0.17	0.16	0.17	0.16	0.007	0.01	0.42	0.33
CELL	0.35	0.36	0.35	0.35	0.38	0.017	0.47	0.14	0.21

[a]Each value is the mean of 18 observations (six animals and three harvest dates). AM = harvested at sunrise; PM = harvested at sunset.
[b]Each value is the mean of 12 observations (six animals and two time of cuts).
[c]L = linear contrast; LOF = lack of fit.
[d]HEMI = hemicellulose; CELL = cellulose.

harvest relative to the other two harvests. The digestion of cellulose increased linearly ($P = 0.07$) with harvest. Intakes of digestible DM and CP had significant ($P \leq 0.05$) linear and LOF effects of harvest date (Table 3). In both cases, the digestible intakes were similar in July and August but greater in September. The digestible intake of cellulose ($P = 0.14$) exhibited a small linear increase over the three harvests.

Steers consumed more DM ($P = 0.11$) from the PM-cut hay than from the AM-cut hay (Table 4). With the exception of CP digestion, all variables showed a significant ($P \leq 0.10$) TC × HD interaction. In the case of CP digestion (only the HD main effect was significant [$P = 0.13$] and reported), a significant LOF ($P \leq 0.01$) was noted (not shown in Table 4) as a result of similar CP digestion in July and August but a greater CP digestion in September. The TC × HD interaction for the other digestion coefficients was associated with the July harvest date in which the PM-cut hay had lower digestion coefficients than AM-cut hay for all variables measured, as opposed to greater values for the PM hay at the other harvest dates (Table 4). For example, the NDF fraction in PM-cut hay harvested in July was digested less (0.526) than the AM-cut hay (0.595), whereas PM-cut hays harvested in August and September had greater NDF digestion (0.597 and 0.618, respectively) than AM-cut hays (0.582 and 0.583, respectively).

Digestible DMI was not calculated and analyzed statistically as in the goat and sheep trials because intake estimates and digestion coefficients were obtained in separate experiments using different animals. An estimate of digestible DMI may be obtained, however, by multiplying mean DMI by mean DM digestion coefficients for the PM (2.90 kg/100 kg of BW × 0.662 = 1.92 kg/100 kg of BW) and AM (2.62 kg/100 kg of BW × 0.659 = 1.73 kg/100 kg of BW) cut hays. Based on these estimates, steers may have consumed 11% more digestible DM when consuming PM-cut hay, which might influence daily animal response (NRC, 1981, 1996) and have potential economic value. The benefit from producing PM-cut hay occurs at no additional monetary cost, but it does have a risk-cost associated with the loss of 1 d of drying time.

Fecal Composition. As potential indicators of variation in the animal's diet and digestion process, fecal concentrations of CP, NDF, and ADF were determined. Because the goat, sheep, and steer trials were conducted separately, no statistical test was made among the ruminant species. Information, however, can be obtained from within each animal species trial to determine whether the six experimental hays were ingested and digested similarly. Feces from goats showed no difference in the concentrations of CP, NDF, and ADF for the TC main effect but showed a HD effect for each and significant ($P \leq 0.05$) TC × HD interactions (Table 5). These interactions, resulting from different slopes for AM and PM cuts at different harvest dates, indicate that the hays were not utilized similarly. The interaction for all these variables was associated mainly with the July harvest, in which PM-cut hay resulted in feces with less CP and

Table 4. Average dry matter intake, apparent digestion coefficients, and digestible intakes for dry matter, crude protein, neutral detergent fiber, and constituent fiber fractions from alfalfa hays fed to steers (DM basis)

Item	Time of cut (TC)[a]		Harvest date (HD)[b] July	August	September	SE	Effect TC	HD	TC × HD
							— Significance ($P > F$) —		
Intake, kg/100 kg BW									
DM	PM	2.90	2.74	2.58	2.96	0.210	0.11	0.22	0.64
	AM	2.62	—	—	—				
Digestion coefficients									
DM	PM	—	0.628	0.657	0.701	0.012	0.75	<0.01	0.10
	AM	—	0.657	0.637	0.683				
CP	PM and AM	—	0.774	0.771	0.791	0.010	0.59	0.13	0.54
NDF	PM	—	0.526	0.597	0.618	0.017	0.63	0.08	0.02
	AM	—	0.595	0.582	0.583				
ADF	AM	—	0.503	0.570	0.588	0.016	0.53	0.14	0.02
	PM	—	0.574	0.556	0.557				
HEMI[c]	PM	—	0.579	0.660	0.684	0.020	0.93	0.05	0.04
	AM	—	0.644	0.641	0.642				
CELL[c]	PM	—	0.584	0.652	0.670	0.014	0.11	<0.01	0.03
	AM	—	0.651	0.649	0.664				

[a]Each value is the mean of 18 observations (six animals and three harvests). AM = harvested at sunrise; PM = harvested at sunset.
[b]Each value is the mean of six animals except for DMI and CP which is the mean of 12 observations (six animals and two time of cuts).
[c]HEMI = hemicellulose; CELL = cellulose.

greater NDF and ADF concentrations than with the AM-cut hay. A shift to greater fecal CP and lesser fecal NDF and ADF occurred in the PM-cut hays harvested in August and in September.

Fecal concentrations of CP, NDF, and ADF from sheep also showed significant ($P \leq 0.04$) interactions between the main effects of TC and HD (Table 5). Crude protein was greater in the July AM treatment than the PM, but CP within the August and September harvests showed no difference between the AM and PM hays. The interaction for NDF and ADF was similar to the interaction detected in the composition of the goat feces with the

Table 5. Average crude protein, neutral detergent fiber, and acid detergent fiber concentrations in feces from goats, sheep, and steers fed alfalfa hays (DM basis)

Item	Time of cut (TC)[a]	Harvest date (HD)[b] July	August	September	SE	Effect TC	HD	TC × HD
		— g/kg —				— Significance ($P > F$) —		
Goat trial								
CP	PM	133	152	155	2	0.60	<0.01	0.05
	AM	139	146	151				
NDF	PM	516	479	468	8	0.56	0.03	0.01
	AM	482	486	484				
ADF	PM	386	363	353	5	0.62	0.04	<0.01
	AM	361	369	365				
Sheep trial								
CP	PM	128	144	153	2	0.08	<0.01	0.02
	AM	137	144	153				
NDF	PM	508	481	468	5	0.59	<0.01	0.01
	AM	488	487	476				
ADF	PM	380	367	355	4	0.95	<0.01	0.04
	AM	369	372	362				
Steer trial								
CP	PM and AM	136	143	154	2	0.10	<0.01	0.27
NDF	PM	549	539	506	7	0.06	<0.01	0.03
	AM	522	522	516				
ADF	PM	406	403	376	5	0.06	<0.01	0.03
	AM	386	392	383				

[a]Each value is the mean of six animals, except for CP in the steer trial which is the mean of 12 observations (two times of cut and six animals). AM = harvested at sunrise; PM = harvested at sunset.

July harvest response to time of cutting differing from the effect in the August and September harvests.

There was no interaction of TC and HD in the concentration of CP in steer feces, but HD was associated with a linear ($P < 0.01$) increase in CP from July to September (Table 5). Fecal concentrations of NDF and ADF showed an interaction of TC and HD ($P = 0.03$), being greater in the feces from the PM hay harvested in July and decreasing to be least in the feces from the PM hay harvested in September. The NDF and ADF concentration in feces from the AM-cut hay changed little from July to September.

Hay Composition. Both IVTDMD and the soluble carbohydrates (TNC and its four fractions) were greater ($P < 0.01$) in PM-cut hay than in AM-cut hay (Table 6). The greater IVTDMD is consistent with greater TNC concentrations. In addition, the greater TNC concentrations are consistent with published literature for PM samples of alfalfa (Plhak, 1989) and ryegrass (Orr et al., 2001). Also, the greater TNC concentrations in the PM-cut hays are consistent with hays from the same treatment lot used in previous preference trials (Fisher et al., 2002). In those trials, TNC in PM-cut hays averaged 54 g/kg compared with 43 g/kg for AM-cut hays. Fiber fractions, on the other hand, were not altered by time of cut. The elevated TNC and IVTDMD in the PM-cut hays may be responsible for the increased DMI by both goats and steers. In the experiment with goats, the PM-cut hays had greater DM digestion and, consequently, digestible DMI, as well as greater digestion coefficients for the fiber fractions (Table 3) than the AM-cut hays.

In vitro true DM disappearance, CP, fiber fractions, and soluble carbohydrates were all altered ($P < 0.01$) by harvest date (Table 6). With the exception of CP and starch, all variables showed a significant ($P < 0.01$) lack of fit. The LOF to the linear contrast occurred because the July and August harvests were similar, whereas the September harvest had lower concentrations of fiber and greater concentrations of sugars and TNC. The means for IVTDMD were also similar for the July and August harvests and greater for the September harvest.

The small difference in DMI by steers compared with goats between the PM and AM hays and the lack of difference in the digestion coefficient for steers, as well as the lack of significant responses by sheep to PM hay compared with goats, is not clearly explained by the composition data. There was a similarity between sheep and goats in the variation in fecal concentrations of CP and fiber fractions. The composition of the offered feed from the same treatment lot sampled for each animal fed in the separate animal trials showed that differences existed. The hay treatment × animal trial interaction was not significant for any of the variables analyzed (Table 6). This indicates that the relative differences among the hays were similar among trials, but that the mean concentrations between trials varied. Examination of the means by animal trial (Table 6) showed that the forage offered in the goat and sheep trials was nearly identical in composition. The forage offered in the steer trial had small but significant decreases in IVTDMD, CP, and monosaccharides, and small increases in the fiber fractions and starch. The similarity in the composition of the offered feed between the goat and sheep trials could, in part, be accounted for by the fact that the trials were conducted concurrently and the length of the trials were appreciably shorter than the steer trials. The decreased quantity of hay required for the goat and sheep trials, compared with the steer trials, decreased the opportunity for variation to occur in the offered feed. Further explanation may reside with the degree of selectivity exhibited by the different animal species in obtaining their diets from the offered forage. Generally, ruminants select the leafy tissue over stems when given the opportunity (Minson, 1981). Selectivity can be examined indirectly in these trials by analyzing the difference in IVTDMD, CP, and NDF concentrations between the offered hays and the orts sampled during each experiment. Selection of higher quality portions of the feed over lower quality portions results in decreased IVTDMD and CP but increased NDF in the orts. The calculated difference values (Table 6) indicate that selection occurred ($P < 0.01$) in all trials, and the magnitude was similar for sheep and goats. Difference values from the steer trial, however, were much smaller, indicating that steers consumed a diet of less nutritive value. Because TNC accumulates during the day in leaf tissue (Lechtenberg et al., 1971), a lower proportion of leaf in the consumed forage may partially explain the lack of response exhibited by steers in digestion coefficients for DM and the fiber fractions.

Harvest date effects ($P < 0.01$) also were observed for the differences between the forage offered and the orts (Table 6). Difference values were of similar magnitude for the means reported for the July and August harvested hays. In all cases, animals showed decreased difference values in the higher quality September-harvested hays (Table 6).

Dry Matter Intake, Digestion, and Preference

The same six experimental hays evaluated for DMI and digestibility in this study were evaluated previously for preference (Fisher et al., 2002). In that preference trial, MDS was used to develop a spatial arrangement representing the differences expressed as selective forage intake by the animal. For MDS, the difference in preference between a pair of hays was expressed by subtracting the amount of the least preferred hay from the most preferred hay and dividing by the sum of the two intakes. In this way, preference was expressed numerically as a relative difference or distance. If the animal consumes equal quantities of the hays in the pair, then the difference ratio is equal to zero and no preference or distance between the hays is expressed. If only one of the pair is consumed, then the difference ratio is equal to one and the maximum difference in preference between hays is expressed (Buntinx et al., 1997). The PROC MDS of SAS (SAS Inst., Inc., Cary, NC) is an iterative fitting

Table 6. Average composition of alfalfa hays fed and difference values (composition of offered feed minus composition of orts) for time of cut and harvest date in all three animal intake trials (DM basis)

	Time of cut (TC)[b]		Harvest date (HD)[c]			Animal trial (AT)[d]				Effect			
											HD[e]		
Item[a]	PM	AM	July	Aug.	Sept.	Goats	Sheep	Steers	SE	TC	L	LOF	AT
	g/kg									Significance ($P > F$)			
IVTDMD	767	758	751	747	789	767	768	752	2.1	<0.01	<0.01	<0.01	<0.01
CP	213	217	210	217	219	217	218	211	1.8	0.06	<0.01	0.18	0.04
Fiber fractions													
NDF	417	421	430	437	390	406	403	447	3.3	0.36	<0.01	<0.01	<0.01
ADF	305	306	314	316	287	299	299	319	2.8	0.88	<0.01	<0.01	<0.01
HEMI	111	115	116	120	103	108	104	128	1.2	0.14	<0.01	<0.01	<0.01
CELL	234	235	240	244	220	229	229	246	2.1	0.61	<0.01	<0.01	<0.01
Lignin	63	68	69	70	62	65	64	73	0.6	0.63	<0.01	<0.01	<0.01
Soluble carbohydrates													
MS	13	11	11	10	14	13	13	10	0.3	<0.01	<0.01	<0.01	<0.01
DS	17	11	9	9	25	14	14	14	0.6	<0.01	<0.01	<0.01	0.79
SP	10	9	9	9	11	9	9	9	0.1	<0.01	<0.01	<0.01	0.01
Starch	6	5	5	6	6	6	5	7	0.2	<0.01	<0.01	0.76	<0.01
TNC	46	36	34	34	56	42	41	40	0.8	<0.01	<0.01	<0.01	0.17
Difference value (composition of offered feed minus composition of orts)													
IVTDMD	121	124	139	137	91	154	155	59	8.9	0.11	<0.01	<0.01	<0.01
CP	73	80	82	87	58	94	101	32	5.2	0.12	<0.01	<0.01	<0.01
NDF	149	154	165	170	120	185	196	73	10.4	0.43	<0.01	<0.01	<0.01

[a]IVTDMD = in vitro true DM disappearance; HEMI = hemicellulose; CELL = cellulose; MS = monosaccharides; DS = disaccharides; SP = short-chained polysaccharides; ST = starch; and TNC = total nonstructural carbohydrates.
[b]Each value is the mean of 54 observations (six animals × three harvest × three experiments). AM = harvested at sunrise; PM = harvested at sunset.
[c]Each value is the mean of 36 observations (six animals × two times of cut × three experiments).
[d]Each value is the mean of 36 observations (six animals × six treatments).
[e]L = linear contrast; LOF = lack of fit.

procedure for data assumed to express distances or relative differences between stimuli (e.g., feeds) in an unknown number of orthogonal dimensions. After specifying the assumed number of dimensions, a least squares fit is approximated using an array of points representing stimuli. The coordinates of the points are adjusted iteratively until the reduction in residual sum of squares is below a specified level. The residual sum of squares is calculated by comparing the "distance" between the points representing the stimuli and the observed distances or differences between the stimuli. In effect, a map is developed with points representing each stimulus. The positions are adjusted until the maximum sum of squares is explained given the limitation of the specified number of dimensions. The order of fit is first dimension 1, which will generally include the most important variables (most sums of squares), followed by dimension 2, which will generally include the second most important variables (second most sums of squares), then dimension 3, and so on. In the previous study, MDS identified the variables assigned to the first two dimensions (dimension 1 and 2) to explain the preference difference observed for steers, sheep, and goats. Associating the short-term preference and the coordinates for dimension 1 and 2 from the previous trials with DMI and digestion from this study reveals several points of interest. First, DMI by steers estimated in this study was well correlated with the preference (≤2.0 h intake) of steers estimated in the previous trial ($r = +0.83$; $P < 0.05$). Also, DMI by steers estimated in this study was well correlated with stimuli coordinates for dimension 1 from the preference trial ($r = +0.90$; $P \leq 0.05$). Second, only sheep DM digestion estimated in this study was associated with any of the sheep measurements from the preference trial, and this was with stimuli coordinates for dimension 1 ($r = +0.84$; $P \leq 0.05$). Third, neither goat DMI nor DM digestion from this study was related to the measurements made with goats in the preference trial.

Despite the small compositional differences between the PM- and AM-cut forage, it seems that hays that were preferred by steers were likely to be consumed daily by steers in greater quantities. Sheep and goats responded differently than steers. Neither DMI nor DM digestion by sheep or goats in this study was well associated with any of the measurements from the preference trial. These differences relative to preference and DMI between steers and the small ruminants may be partly related to the differences in the diet they selected from the offered forage.

Implications

The management strategy of harvesting hay at sunset provides an opportunity to increase total nonstructural carbohydrate concentrations of the forage. This increase in carbohydrates is associated with improved in vitro true dry matter disappearance and deceased fiber concentrations and has the potential to improve daily dry matter intake of more digestible forage and result in improved daily animal responses.

Literature Cited

AOAC. 1990. Official Methods of Analysis. 15th ed. Assoc. Off. Anal. Chem., Arlington, VA.

Bowden, D. D., K. Taylor, and W. E. P. Davis. 1968. Water soluble carbohydrates in orchardgrass and mixed forages. Can. J. Plant Sci. 48:9–15.

Buntinx, S. E., K. R. Pond, D. S. Fisher, and J. C. Burns. 1997. The utilization of multidimensional scaling to identify forage characteristics associated with preference in sheep. J. Anim. Sci. 75:1641–1650.

Burns, J. C., R. F Barnes, W. F. Wedin, C. L. Rhykerd, and C. H. Noller. 1970. Nutritional characteristics of forage sorghum and sudangrass after frost. Agron. J. 62:348–350.

Burns, J. C., K. R. Pond, and D. S. Fisher. 1994. Measurement of intake. Pages 494–532 in Forage Quality, Evaluation and Utilization. G. C. Fahey, ed. Am. Soc. Agron., Madison, WI.

Burns, J. C., K. R. Pond, D. S. Fisher, and J. M. Luginbuhl. 1997. Changes in forage quality, ingestive mastication, and digesta kinetics resulting from switchgrass maturity. J. Anim. Sci. 75:1368–1379.

Fisher, D. S., and J. C. Burns. 1987. Quality of summer annual forages. I. Sample preparation methods and chemical characterization of forage types and cultivars. Agron. J. 79:236–242.

Fisher, D. S., H. F. Mayland, and J. C. Burns. 1999. Variation in ruminant preference for tall fescue hays cut at either sundown or sunup. J. Anim. Sci. 77:762–768.

Fisher, D. S., H. F. Mayland, and J. C. Burns. 2002. Variation in ruminant preference for alfalfa hays cut at sunup and sundown. Crop Sci. 42:231–237.

Gordon, A. J. 1996. Diurnal patterns of photosynthate allocation and partitioning among sinks. Pages 499–517 in Phloem Transport. J. Cronshaw, W. J. Lucas, and R. T. Giaquinta, ed. Liss, New York.

Lechtenberg, V. L., D. A. Holt, and H. W. Youngberg. 1971. Diurnal variation in nonstructural carbohydrates in vitro digestibility, and leaf to stem ratio of alfalfa. Agron. J. 63:719–724.

Minson, D. J. 1981. Effects of chemical and physical composition of herbage eaten upon intake. Pages 167–182 in Nutrient Limits to Animal Production from Pastures. J. B. Hacker, ed. CAB, Slough, U.K.

NRC. 1981. Nutrient Requirements of Goats. Natl. Acad. Press, Washington, DC.

NRC. 1996. Nutrient Requirements of Beef Cattle. 7th ed. Natl. Acad. Press, Washington, DC.

Orr, R. J., S. M. Rutter, P. D. Pennings, and A. J. Rook. 2001. Matching grass supply to grazing patterns for dairy cows. Grass Forage Sci. 56:352–361.

Plhak, F. 1991. Differences in nutritive value of lucerne cut in morning and afternoon hours. Pages 817–818 in Proc. XVI Int. Grassl. Cong., Nice, France. Assoc. Franç. Prod. Four., Versailles, France.

Smith, D. 1969. Removing and analyzing non-structural carbohydrates from plant tissue. Res. Rep. 41, College of Agric. and Life Sciences, Univ. of Wisconsin, Madison.

Steel, R. G. D., and J. H. Torrie. 1980. Principles and Procedures of Statistics: A Biometrical Approach. 2nd ed. McGraw-Hill Publ. Co., New York.

Van Soest, P. J., and J. B. Robertson. 1980. Systems of analysis for evaluating fibrous feeds. Pages 49–60 in Proc. Int. Development Res. Ctr., Ottawa, Canada. W. J. Pigden, C. C. Balch, and M. Graham, ed. Unipub, New York.