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Ruminant Selection among Switchgrass Hays Cut at Either Sundown or Sunup

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ABSTRACT

As a result of photosynthesis, plants typically have greater concentrations of nonstructural carbohydrates at the end of the photoperiod. The preference of ruminants for hays harvested within the same 24-h period can be greater for plants harvested late in the photoperiod with increased soluble carbohydrate. To test for variation in ruminant preference for afternoon versus morning harvested hays in a C_4 grass harvested in the humid east, established fields of 'Kanlow' and 'Alamo' switchgrass (*Panicum virgatum* L.) were used to produce hays in 1998, 1999, and 2000 near Raleigh, NC. Harvests were paired so that each cutting in the evening (PM) was followed by a cutting the next morning (AM). We harvested in this manner three times in 1998 to produce six Kanlow hays; twice with Kanlow and once with Alamo at two levels of nitrogen fertility in 1999 to produce eight hays; and three times in 2000 to produce six Alamo hays. The hays were field-dried, baled, and passed through a hydraulic bale processor. Hays from each year were tested with cattle (*Bos taurus* L.), goats (*Capra hircus* L.), and sheep (*Ovis aries* L.). During an adaptation phase, hays were offered individually. In the experimental phase, all possible pairs of hays were presented. Data were analyzed by multidimensional scaling and by traditional analyses. Multidimensional scaling indicated that selection was based on multiple criteria. The suite of improvements associated with PM-harvested hays in fiber content, digestibility, and nonstructural carbohydrate observed for alfalfa and fescue hays in the western USA was difficult to reproduce with switchgrass hay in the southeastern USA. This difficulty is likely related to the less favorable environment for haymaking as well as the physiology, anatomy, and morphology of this C_4 grass.

Plants vary diurnally in concentrations of nonstructural carbohydrates with greatest concentrations observed in the afternoon (Bowden et al., 1968; Lechtenberg et al., 1971; Gordon, 1996). Observations of diurnal variation of intake rates of sheep coincide with increases in nonstructural carbohydrates (Orr et al., 1997). Variation in fiber concentration and in vitro dry matter disappearance have also been observed in experiments in which ruminants preferred fescue and alfalfa hays harvested in the PM over those harvested in the AM (Fisher et al., 1999; Fisher et al., 2002). In these cases, food preferences were altered by subtle changes in forage structural and nonstructural carbohydrate composition with measurable changes in the in vitro dry matter disappearance. Forage composition is modified without the use of supplements and provides a rigorous test of the ruminant's ability to learn that the nutritive value or taste of one feed varies slightly from another (Provenza and Balph, 1987). In the procedure utilized by Fisher et al. (1999, 2002), to express a positive preference for PM hay, the ruminant must recognize the hay from a previous meal, associate the forage with a feedback experience, and select the hay when it is paired with another feed harvested from the same field 12 h later. The objective of this study was to test for variation in short-term preference for switchgrass hays harvested only 12 to 14 h apart. The harvested switchgrass included Kanlow harvested in 1997, Kanlow and Alamo harvested in 1998, and Alamo harvested in 2000. In 1998, Alamo was produced at two levels of nitrogen fertility. This selection of hays produced over three years allowed for a wide range of significant variation in forage composition (or nutritive value) and environmental conditions within which to test for the impact of PM and AM hay mowing in the humid southeastern USA.

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MATERIALS AND METHODS

Field Procedures

All hays for the experiments reported were harvested from well established stands of switchgrass grown on a Cecil clay loam (fine, kaolinitic, thermic Typic Kanhapludults) soil near Raleigh, NC. The hay cuts were paired at each harvest so that each cut in the evening (PM) was followed by another cut the next morning (AM) at sunup.

Hay Harvested 1997

We harvested Kanlow hays in the vegetative stage at three dates resulting in six hays. The first harvest occurred in July (14 July, Cut 1-PM; 15 July, Cut 2-AM), the second in August (1 August, Cut 1-PM; 2 August, Cut 2-AM), and the third in October (1 October, Cut 1-PM; 2 October, Cut 2-AM). Weather during hay making was variable with precipitation occurring during hay drying for the July harvest (Table 1). Total radiation was low for the August harvest but conditions were good during the October harvest.

Hay Harvested 1998

Initial growth of both Kanlow and Alamo switchgrass was removed in 1998. Two regrowth harvests of Kanlow were obtained with the first harvest taken in July (20 July, Cut 1-PM; 21 July, Cut 2-AM) and the second in August (4 August, Cut 1-PM; 5 August, Cut 2-AM). The Alamo regrowth was harvested only once but it was produced at two levels of nitrogen fertility by applying either 75 or 150 kg N ha^{-1}. The harvests occurred in August (20 August, Cut 1-PM low N and PM high N; 21 August, Cut 2 AM low N and AM high N).

Abbreviations: ADF, acid detergent fiber; AM, morning; ADIA, acid detergent insoluble ash; CP, crude protein; DM, dry matter; IVTD, in vitro true dry matter disappearance; MDS, multidimensional scaling; NDF, neutral detergent fiber; PM, evening; TNC, total nonstructural carbohydrate.

Table 1. Hay sources, harvest dates, mean maximum and minimum temperatures during hay drying, total radiation on the day of each PM harvest, and total precipitation for each of the hays used in the nine experiments.†

Hay sources	Harvest dates	Maximum temp.	Minimum temp.	Total radiation	Precipitation
		°C		MJ m^{-2} d^{-1}	cm
Harvests for Exp. 1, 2, and 3 in 1997	14 July (PM), 15 July (AM)	35	22	13.6	1.9
	1 Aug (PM), 2 Aug (AM)	31	18	15.4	0.5
	1 Oct (PM), 2 Oct (AM)	24	11	9.5	0.2
Harvests for Exp. 4, 5, and 6 in 1998	20 July (PM), 21 July (AM)	35	24	13.3	0.0
	4 Aug (PM), 5 Aug (AM)	30	18	14.5	0.0
	20 Sep (PM), 21 Sep (AM)	32	17	14.2	0.4
Harvests for Exp. 7, 8, and 9 in 2000	23 Jun (PM), 24 Jun (AM)	33	21	11.0	0.0
	30 Jun (PM), 1 Jul (AM)	30	18	11.6	0.0
	16 Jul (PM), 17 Jul (AM)	32	21	9.4	0.0

† Weather data collected at NCSU Turfgrass Field Laboratory (approximately 4.5 km from the experiment) with the exception of the 23 and 24 June 2000 harvests which were estimated using the Reedy Creek Field Laboratory (approximately 3 km from the experiment).

Conditions during hay curing were excellent with low precipitation and high radiation before harvest (Table 1).

Hay Harvested 2000

We harvested Alamo switchgrass three times with the first harvest taken in June (23 June, Cut 1-PM; 24 June, Cut 2-AM), the second harvest in June/July (30 June, Cut 1-PM; 1 July, Cut 2-AM), and the third harvest in July (16 July, Cut 1-PM; 17 July, Cut 2-AM). Weather during the haymaking was good but lower in total radiation than in 1998 (Table 1).

Hay Handling for All Years

All the hays for all the production years were field dried, baled, and stored in an enclosed barn before use in preference trials. No significant differences in dry matter were observed among the hays at feeding (data not shown). Just before feeding, and to assist animal consumption and avoid leaf loss, all hays were passed through a hydraulic Van Dale 5600 Bale Processor (J. Star Industries, Fort Atkinson, WI) with stationary knives spaced 10 cm apart.

Design of Preference Trials

With the hays produced in each year we conducted three preference experiments that differed in the animal species used. Using the hays produced in 1997 we conducted Experiment 1 utilizing cattle (Exp. 1), Experiment 2 utilizing goats (Exp. 2), and Experiment 3 utilizing sheep (Exp. 3). In the October harvest of 1997 hay production was limited and only permitted the inclusion of those six treatments in the sheep trial. Using the hays produced in 1998 we conducted Experiment 4 utilizing cattle (Exp. 4), Experiment 5 utilizing goats (Exp. 5), and Experiment 6 utilizing sheep (Exp. 6). Using the hays produced in 2000 we conducted Experiment 7 utilizing cattle (Exp. 7), Experiment 8 utilizing goats (Exp. 8), and Experiment 9 utilizing sheep (Exp. 9). In each of the three cattle experiments (Exp. 1, 4, and 7) different Hereford steers were used. In each of the three experiments with goats (Exp. 2, 5, and 8) different Spanish doe goats were used and in each of the three experiments with sheep (Exp. 3, 6, and 9) different Katahdin ewe sheep were used. Each experiment required six animals.

The protocol for animal care and health was approved by the North Carolina State University Institutional Animal Care and Use Committee (03-047-A). During an adaptation or training period (Kyriazakis et al., 1990), meals of individual hays were offered to allow the animal to associate the hay with post-ingestive consequences produced by the forage. We randomized the order in which the forages were offered to each animal. During each experimental phase, we presented all possible pairs of the hays for meals. The order of presentation of the pairs and the left–right position of the hays in the pair were randomized. The weight of hay was determined before and after feeding. This permitted calculation of dry matter (DM) consumed after adjusting for the DM concentration of the hay. Animals were individually penned in all three experiments. Sheep and goat pens were approximately 1.5 by 2 m. Cattle pens were approximately 2.5 by 4 m. We presented each pair of forages side by side with sheep and goats offered approximately 0.75 kg of each hay and allowed approximately 2.5 h to feed. At approximately 30 min after offering the feed, an intermediate forage weight was collected for the sheep and goats. This was used to calculate an initial intake rate by dividing hay disappearance over the first 30 min by the time in minutes. The cattle were led into the pens, offered approximately 2 kg of each hay, and allowed approximately 30 min to feed. Only two pens were available for cattle so approximately 2 h was required to finish each morning's pairs. Cattle were housed and fed in stalls for the remainder of the day. For the experiments with cattle, a time-lapse video recorder (Panasonic, Matsushita Electric Corp., Secaucus, NJ) was used to estimate the total time spent at each feeder to calculate intake rate by dividing hay disappearance by minutes at the feeder.

In all three experiments we took care to prevent consumption of all of the preferred hay and therefore to always offer a choice between the two hays in the pair. Each day, after the preference trial, sheep and goats were given ad libitum access to hays not included in the trials along with a trace mineralized salt block.

Sampling and Estimation of Forage Nutritive Value

In each experiment, forage samples were analyzed that were comprised of subsamples collected each time a hay was fed in a pair ($n = 5$). Samples were then composited for each animal and represented the forage offered to each animal. This included variation within the hay source as well as laboratory variation in our estimates of means ($n = 6$). The composite sample was dried at 55°C in a forced draft oven (Hot Pack Inc., Philadelphia, PA) and composition values were reported on a DM basis. Samples were ground to pass a 1-mm screen in a Wiley mill (Thomas Scientific, Swedesboro, NJ).

We utilized filter bag technology with a batch processor to estimate in vitro true dry matter disappearance (IVTD) of the hay samples (Ankom Technology Corp., Fairport, NY). Rumen inoculum was collected from a cannulated mature Hereford steer fed a mixed alfalfa (*Medicago sativa* L.) and orchardgrass (*Dactylis glomerata* L.) hay. After incubating for 48 h in a batch fermenter with ruminal inoculum the samples were extracted with neutral detergent solution for estimation of IVTD.

Neutral detergent fiber (NDF), acid detergent fiber (ADF), hemicellulose, cellulose, acid detergent lignin (ADL), and acid detergent insoluble ash (ADIA) were estimated according to Van Soest and Robertson (1980) in a batch processor (Ankom Technology Corp., Fairport, NY). Crude protein was estimated as 6.25 times the percentage of N determined with an AutoAnalyzer (Technicon Industrial Systems, Tarrytown, NY) (AOAC, 1990).

The total nonstructural carbohydrates (TNC) of the forage samples were analyzed by an adaptation (Fisher and Burns, 1987) of the method described by Smith (1969). The TNC were fractionated by differential solubility into soluble carbohydrate and starch. Starch was determined by digesting to glucose with amyloglucosidase and estimating the monomer concentration on a YSI Model 27 Industrial Analyzer utilizing an immobilized enzymatic membrane and a sensor (Yellow Springs Instrument Co., Yellow Springs, OH).

All samples were scanned for near-infrared reflectance spectroscopy (Foss Tecator, Eden Prairie, MN) and the observed values of a representative population were used to develop a prediction equation for all variables using the Modified Partial Least Squares procedure (Infrasoft Int., Foss Tecator, Eden Prairie, MN). The prediction equation was then used to predict each observation.

Statistical Analysis

The experimental design allowed statistical analysis by multidimensional scaling (Buntinx et al., 1997; Fisher et al., 1999, 2002; SAS, 1999) as well as by analysis of variance. The use of multidimensional scaling (MDS) makes it possible to develop the number of criteria (dimensions) that the subjects (animals) are using to judge the differences between stimuli (hays) (Buntinx et al., 1997). In this case, MDS is used to develop the dimensions that represent the differences among the treatments that were expressed as selective forage intake by the animals. To utilize MDS, preference is estimated as a difference ratio between each pair of hays by subtracting the amount consumed of the less preferred hay from the amount consumed of the more preferred hay and dividing by the sum of the two intakes. In this way, preference is expressed numerically as a number between zero and one. If the animal consumed equal quantities of the hays in the pair, then the difference ratio is equal to zero and no preference is expressed. If only one of the pair was consumed then the difference ratio is equal to one and the maximum difference in preference between hays is expressed. The statistical procedure (Proc MDS, SAS, Cary, NC) produces a spatial arrangement of the forages in a specified number of dimensions. Forages judged to be similar by the animals are close together in the dimensional space while those judged to be dissimilar are far apart in the dimensional space.

The MDS dimensions are orthogonal but the sign or orientation and relationship with measured explanatory variables must be developed by comparing the dimensions with other data and using correlation and regression for statistical description. As an example, MDS could be used to analyze a triangular matrix representing all the possible distances between a set of cities. The results could be used to determine if all the cities were located along a transect (one dimension) or were scattered in a two-dimensional space. The MDS dimensions would recreate a map of the city locations but the orientation and relationship to explanatory variables such as latitude and longitude could be a mirror image or reversed and it is sometimes convenient to change the signs of the MDS dimensions to make them easier to interpret.

The dimensions resulting from preferences expressed by the animals allows us to test for the number of dimensions being used as criteria but those dimensions must then be tested for relationship to observed forage parameters. It is also possible that the selection criteria used by the animal and elucidated by MDS are unrelated to the particular observations of forage composition selected by the experimenter. The experimenter may have overlooked a variable that was at least correlated with one or more of the criteria relevant for explaining the animal behavior. In these experiments, simple linear correlation was used to examine the relationship of DM intake and MDS dimensions to estimates of nutritive value. In this way we were able to describe intake in one (DM intake) and multiple (MDS) dimensions and we attempted to relate those dimensions to the nutritive value of the hay.

Each experiment was also tested by analysis of variance after averaging hay intake across all pairs by each animal. The analysis of variance included terms for animals and hays (Proc GLM, SAS, Cary, NC). Means were separated using the minimum significant difference (MSD) from the Waller–Duncan k-ratio *t* test (k = 100) and contrast statements were also used for specific planned comparisons. Within analysis of variance and correlations statistical significance was assumed to be associated with probabilities less than or equal to 0.05.

RESULTS AND DISCUSSION

Analysis of the hays from the three harvest years and three animal species (nine experiments) utilizing multi dimensional scaling indicated that all three animal species were basing selection on multiple dimensions (criteria). The numbers of stimuli (hay sources) in these experiments ranged from four to eight and all nine experiments were scaled with two dimensions (Buntinx et al., 1997).

Cattle 1997 Kanlow Hays–Experiment 1

Although cattle had a strong preference for the first harvest of the Kanlow hays over the second harvest there was no significant preference for the PM hays when compared to the AM hays ($P = 0.26$; Table 2). Dimension 1 from the MDS analysis separated the harvests and Dimension 2 described variation within a harvest.

The PM effect was not significant for the fiber fractions but the PM harvest had lower crude protein and starch and higher soluble carbohydrate and TNC (Table 2). The sum of starch and soluble carbohydrate makes up TNC. The level of soluble carbohydrate in the PM hays was great enough to result in a greater TNC (sum of soluble carbohydrate and starch) even though the PM hays had less starch than the AM hays. The lower level of crude protein is likely the result of dilution by nonstructural carbohydrate. Both hays from the more preferred first harvest were lower in NDF, ADF, hemicellulose, lignin, and ADIA and higher in IVTD than the less preferred harvest. Increased TNC may contribute to the decreased fiber fractions by dilution. However, the observed changes in fiber fractions are not explained simply by dilution by TNC.

The first MDS dimension was closely associated with harvest and strongly correlated with the fiber fractions

Table 2. Intake, intake rate, dimensional coordinates (Dim1 and Dim2), and composition of two harvests (H1 and H2) of 'Kanlow' switchgrass hay cut either in the afternoon (PM) or morning (AM) as fed to cattle (Exp. 1; 1997 hays).†

Forage	Int.	Int. rate	Dim1	Dim2	NDF	ADF	Cell	Hemi	Lig	ADIA	IVTD	CP	Starch	Sol. CHO	TNC
	g	g min^{-1}			g kg^{-1}										
Kanlow H1-PM	862	53	1.40	0.31	722	372	334	349	36	1.6	648	59	27	57	84
Kanlow H1-AM	852	50	1.40	−0.31	721	373	334	348	36	1.4	661	70	28	46	75
Kanlow H2-PM	150	24	−1.40	−0.01	745	387	341	358	42	2.7	584	57	22	50	73
Kanlow H2-AM	248	62	−1.40	0.01	747	387	341	360	41	2.4	588	56	27	41	68
MSD‡	104	NA	–	–	11	11	9	2	2	0.2	12	3	2	4	5
Mean PM	506	38	–	–	733	380	338	353	39	2.2	616	58	25	53	78
Mean AM	550	56	–	–	734	380	338	354	39	1.9	631	63	28	43	71
PM vs. AM§	0.26	0.24	–	–	0.82	0.89	0.96	0.60	0.63	<0.01	0.06	<0.01	<0.01	<0.01	0.01

† Values are means of six subsamples collected during feeding of six animals. Int., intake; Int. rate, intake rate; Dim1 and Dim2, coordinates from multidimensional scaling; NDF, neutral detergent fiber; ADF, acid detergent fiber; Cell, cellulose; Hemi, hemicellulose; Lig, sulfuric acid lignin; ADIA, acid detergent insoluble ash; IVTD, in vitro true dry matter disappearance; CP, crude protein; Sol. CHO, soluble carbohydrate; TNC, total nonstructural carbohydrate.

‡ MSD, minimum significant difference from Waller–Duncan k-ratio *t* test with k-ratio = 100.

§ Results of orthogonal contrast; $P > F$.

NDF ($P < 0.01$), ADF ($P < 0.01$), cellulose ($P < 0.01$), hemicellulose ($P = 0.01$), lignin ($P < 0.01$), ADIA ($P = 0.03$), and IVTD ($P < 0.01$). The relationship with IVTD was positive but all other relationships were negative. None of the variables collected to describe nutritive value were correlated with the second MDS dimension. The high rainfall during haymaking for the first harvest and the low level of total radiation before the PM harvest for the second harvest may have affected the criteria used by the cattle to select hays. Even with the higher than desirable rainfall, the first harvest produced hay of good nutritive value. However, crude protein was low in both harvests. The low total radiation before the second harvest may have resulted in the low TNC observed for both the PM and AM harvest.

Goats 1997 Kanlow Hays–Experiment 2

Goats had a strong preference for the first harvest of the Kanlow hays over the second harvest in addition to a preference for the PM hays when compared to the AM hays (Table 3). Once again, Dimension 1 from the MDS analysis separated the harvests and Dimension 2 described variation within a harvest.

The PM effect was significant for hemicellulose, crude protein, and the nonstructural carbohydrate fractions (Table 3). As in the samples collected during the feeding of cattle (Exp. 1), the PM harvested hays as fed to the goats had lower crude protein and starch but higher soluble carbohydrate and TNC (Table 3). Also, the two hays from the more preferred harvest were lower in NDF, ADF, hemicellulose, lignin, and ADIA and higher in IVTD.

In the MDS analysis of the preferences expressed by goats, we found the first MDS dimension to be closely associated with harvest and strongly correlated with the constituent fiber fractions of NDF ($P < 0.01$), ADF ($P = 0.01$), cellulose ($P = 0.02$), hemicellulose ($P = 0.04$), lignin ($P = 0.02$), and with IVTD ($P < 0.01$). The relationship with IVTD was positive but all other relationships were negative. None of the variables collected to describe nutritive value were correlated with the second MDS dimension.

Sheep 1997 Kanlow Hays–Experiment 3

The sheep preferred the first and third harvests of the Kanlow hays over the second harvest. However, there was no significant preference for the PM hays when compared with the AM hays ($P = 0.59$; Table 4). Dimension 1 from the MDS analysis separated the first and second harvests but Dimension 2 was important in describing differences between the third harvest and the other harvests.

The PM hays were significantly lower in hemicellulose, ADIA, crude protein, and starch but higher in soluble carbohydrate and TNC (Table 4). The hays from the more preferred first and third harvests were lower in NDF, ADF, cellulose, and lignin and higher in IVTD than the hays from the less-preferred second harvest.

Table 3. Intake, intake rate, dimensional coordinates (Dim1 and Dim2), and composition of two harvests (H1 and H2) of 'Kanlow' switchgrass hay cut either in the afternoon (PM) or morning (AM) as fed to goats (Exp. 2; 1997 hays).†

Forage	Int.	Int. rate	Dim1	Dim2	NDF	ADF	Cell	Hemi	Lig	ADIA	IVTD	CP	Starch	Sol. CHO	TNC
	g	g min^{-1}			g kg^{-1}										
Kanlow H1-PM	351	6.4	1.19	−0.83	717	370	332	347	36	1.6	656	60	28	60	88
Kanlow H1-AM	325	5.8	0.91	1.06	720	370	331	350	37	1.6	653	70	27	48	75
Kanlow H2-PM	182	1.6	−1.16	0.80	745	388	341	357	43	2.8	587	59	22	49	71
Kanlow H2-AM	164	1.5	−0.94	−1.03	747	387	342	360	41	2.4	586	55	27	43	71
MSD‡	23	0.9	–	–	9	11	9	3	2	0.1	19	5	2	4	4
Mean PM	266	4.0	–	–	731	379	336	352	40	2.2	622	60	25	54	80
Mean AM	244	3.6	–	–	734	378	336	355	39	2.0	620	62	27	46	73
PM vs. AM§	0.02	0.28	–	–	0.55	0.84	0.96	0.03	0.46	0.46	0.79	0.05	0.02	<0.01	<0.01

† Values are means of six subsamples collected during feeding of six animals. Int., intake; Int. rate, intake rate; Dim1 and Dim2, coordinates from multidimensional scaling; NDF, neutral detergent fiber; ADF, acid detergent fiber; Cell, cellulose; Hemi, hemicellulose; Lig, sulfuric acid lignin; ADIA, acid detergent insoluble ash; IVTD, in vitro true dry matter disappearance; CP, crude protein; Sol. CHO, soluble carbohydrate; TNC, total nonstructural carbohydrate.

‡ MSD, minimum significant difference from Waller–Duncan k-ratio *t* test with k-ratio = 100.

§ Results of orthogonal contrast; $P > F$.

Table 4. Intake, intake rate, dimensional coordinates (Dim1 and Dim2), and composition of three harvests (H1, H2, and H3) of 'Kanlow' switchgrass hay cut either in the afternoon (PM) or morning (AM) as fed to sheep (Exp. 3; 1997 hays).†

Forage	Int.	Int. rate	Dim1	Dim2	NDF	ADF	Cell	Hemi	Lig	ADIA	IVTD	CP	Starch	Sol. CHO	TNC
	g	$g\ min^{-1}$			$g\ kg^{-1}$										
Kanlow H1-PM	309	4.3	1.24	−0.69	719	372	333	347	36	1.8	648	58	27	61	88
Kanlow H1-AM	287	4.7	1.01	0.98	716	367	330	349	36	1.7	656	70	27	48	76
Kanlow H2-PM	142	1.0	−1.68	0.32	746	393	345	354	43	2.8	584	54	22	52	74
Kanlow H2-AM	166	1.6	−1.14	−1.03	756	399	352	357	44	2.6	583	56	25	40	64
Kanlow H3-PM	234	3.1	−0.15	1.23	713	358	320	355	39	3.4	628	81	20	71	91
Kanlow H3-AM	255	3.2	0.72	−0.81	715	357	319	358	39	3.1	633	88	24	56	80
MSD‡	42	0.8	–	–	6	7	6	2	1	0.1	9	2	2	3	3
Mean PM	228	2.8	–	–	726	374	333	352	39	2.7	620	64	23	61	84
Mean AM	236	3.2	–	–	729	374	334	355	40	2.5	624	71	25	48	73
PM vs. AM§	0.59	0.11	–	–	0.11	0.86	0.60	<0.01	0.81	<0.01	0.19	<0.01	<0.01	<0.01	<0.01

† Values are means of six subsamples collected during feeding of six animals. Int., intake; Int. rate, intake rate; Dim1 and Dim2, coordinates from multidimensional scaling; NDF, neutral detergent fiber; ADF, acid detergent fiber; Cell, cellulose; Hemi, hemicellulose; Lig, sulfuric acid lignin; ADIA, acid detergent insoluble ash; IVTD, in vitro true dry matter disappearance; CP, crude protein; Sol. CHO, soluble carbohydrate; TNC, total nonstructural carbohydrate.

‡ MSD, minimum significant difference from Waller–Duncan k-ratio *t* test with k-ratio = 100.

§ Results of orthogonal contrast; $P > F$.

When compared to the third harvest, the two hays from the first harvest were higher in ADF, cellulose, and IVTD and lower in hemicellulose, lignin, ADIA, and crude protein than the two hays from the third harvest.

The first MDS dimension was associated with harvest and correlated with NDF ($P = 0.05$), lignin ($P < 0.01$), and IVTD ($P < 0.01$). The relationship with IVTD was positive but the other two relationships were negative. None of the variables collected to describe nutritive value were correlated with the second MDS dimension.

Cattle 1998 Kanlow and Alamo Hays–Experiment 4

In the comparison of the harvests of Kanlow switchgrass with a harvest of two N levels in the production of Alamo switchgrass the cattle did not prefer the PM harvest over the AM harvest ($P = 0.51$; Table 5). The later harvests of Alamo were preferred over the earlier harvests of Kanlow and the higher N Alamo treatment was preferred over the lower N Alamo treatment. Dimension 1 from the MDS analysis separated the Kanlow harvests from the Alamo harvest and the second dimension described differences in preference within a cultivar.

The PM hays were significantly lower in NDF, ADF, cellulose, hemicellulose, lignin, and crude protein but higher in soluble carbohydrate and TNC (Table 5). The more preferred Alamo harvests had reduced NDF, ADF, cellulose, and lignin with increased ADIA, IVTD, crude protein, starch, soluble carbohydrate, and TNC. It is important to note that cultivar comparison is confounded with harvest. The hays were selected to provide a range of hay preferences in the ruminants for a background on which to test the PM and AM harvest effects. The Alamo hays from the lower N fertility treatment had greater NDF, ADF, cellulose, starch, soluble carbohydrate, and TNC but reduced ADIA, IVTD, and crude protein.

The first MDS dimension was associated with the com-

Table 5. Intake, intake rate, dimensional coordinates (Dim1 and Dim2), and composition of 'Kanlow' and 'Alamo' switchgrass at three harvests (H1, H2, and H3) with the Alamo harvest at both low (LN) and high (HN) nitrogen cut either in the afternoon (PM) or morning (AM) and fed to cattle (Exp. 4; 1998 hays).†

Forage	Int.	Int. rate	Dim1	Dim2	NDF	ADF	Cell	Hemi	Lig	ADIA	IVTD	CP	Starch	Sol. CHO	TNC
	g	$g\ min^{-1}$			$g\ kg^{-1}$										
Kanlow H1-PM	344	37	−1.05	−1.12	740	397	353	343	42	2.6	627	68	21	41	62
Kanlow H1-AM	323	52	−1.01	−1.09	747	398	354	349	42	2.6	615	69	20	32	52
Kanlow H2-PM	108	33	−1.14	0.85	756	400	354	356	46	3.0	549	55	16	44	60
Kanlow H2-AM	75	28	−1.23	1.13	757	402	354	355	45	3.0	555	57	19	35	54
Alamo H3-LN-PM	948	61	1.10	−0.37	698	346	310	352	33	3.0	688	85	26	58	84
Alamo H3-LN-AM	885	76	1.18	−0.22	720	366	328	354	37	3.0	678	86	26	43	68
Alamo H3-HN-PM	1066	62	1.21	0.07	698	349	310	349	34	3.4	710	101	24	53	76
Alamo H3-HN-AM	1099	65	1.13	0.76	707	353	315	354	35	3.2	718	111	20	41	61
MSD‡	112	24	–	–	5	5	4	3	1	0.1	10	3	2	2	3
Mean PM	616	48	–	–	723	373	332	350	39	3.0	643	77	22	49	71
Mean AM	596	55	–	–	733	380	338	353	40	3.0	641	80	21	38	59
PM vs. AM§	0.51	0.22	–	–	<0.01	<0.01	<0.01	<0.01	<0.01	0.09	0.49	<0.01	0.26	<0.01	<0.01
Kanlow H1 and H2	212	38	–	–	750	399	354	351	44	2.8	586	62	19	38	57
Alamo H3	1000	66	–	–	706	353	316	352	35	3.1	698	96	24	49	72
Variety effect§	<0.01	<0.01	–	–	<0.01	<0.01	<0.01	0.09	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Alamo LN	916	68	–	–	709	356	319	353	35	3.0	683	85	26	51	76
Alamo HN	1082	64	–	–	703	351	312	352	35	3.3	714	106	22	47	69
N effect§	<0.01	0.55	–	–	<0.01	0.02	<0.01	0.30	0.41	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01

† Values are means of six subsamples. Treatments include two harvests (H1 and H2) for Kanlow and two N fertility levels (LN = 50 kg ha^{-1} and HN = 150 kg ha^{-1}) for Alamo cut at sundown (PM) and sunup (AM). Int., intake; Int. rate, intake rate; Dim1 and Dim2, first and second MDS dimensions; NDF, neutral detergent fiber; ADF, acid detergent fiber; Cell, cellulose; Hemi, hemicellulose; Lig, sulfuric acid lignin; ADIA, acid detergent insoluble ash; IVTD, in vitro true dry matter disappearance; CP, crude protein; Sol. CHO, soluble carbohydrate; TNC, total nonstructural carbohydrate.

‡ MSD, minimum significant difference from Waller–Duncan k-ratio *t* test with k-ratio = 100.

§ Results of orthogonal contrasts; $P > F$.

Table 6. Intake, intake rate, dimensional coordinates (Dim1 and Dim2), and composition of 'Kanlow' and 'Alamo' switchgrass at three harvests (H1, H2, and H3) with the Alamo harvest at both low (LN) and high (HN) nitrogen cut either in the afternoon (PM) or morning (AM) and fed to goats (Exp. 5; 1998 hays).†

Forage	Int.	Int. rate	Dim1	Dim2	NDF	ADF	Cell	Hemi	Lig	ADIA	IVTD	CP	Starch	Sol. CHO	TNC
	g	g min^{-1}			g kg^{-1}										
Kanlow H1-PM	91	0.92	−0.79	−1.16	736	388	346	347	42	2.5	630	75	17	43	60
Kanlow H1-AM	59	0.55	−1.28	−0.77	751	402	356	349	45	2.6	616	79	16	32	48
Kanlow H2-PM	29	0.23	−1.47	0.46	757	402	354	355	46	3.0	546	55	14	45	59
Kanlow H2-AM	24	0.21	−1.24	1.29	758	400	351	357	46	3.1	548	57	16	38	55
Alamo H3-LN-PM	218	2.40	1.21	−0.09	699	353	314	346	36	2.8	670	87	23	65	88
Alamo H3-LN-AM	200	2.24	0.94	−0.42	711	360	320	351	37	3.0	665	91	22	54	76
Alamo H3-LN-PM	227	2.87	1.29	0.46	694	348	310	346	34	3.4	698	99	21	68	90
Alamo H3-LN-AM	252	2.96	1.34	0.21	705	357	320	348	37	3.2	719	117	18	49	67
MSD‡	24	0.36	–	–	3	4	3	2	1	0.1	8	4	2	2	2
Mean PM	141	1.60	–	–	722	373	331	349	40	3.0	636	79	19	55	74
Mean AM	134	1.49	–	–	731	380	337	351	41	3.0	637	86	18	43	62
PM vs. AM§	0.26	0.24	–	–	<0.01	<0.01	<0.01	<0.01	<0.01	0.69	0.80	<0.1	0.06	<0.01	<0.01
Kanlow H1 and H2	51	0.48	–	–	750	398	352	352	45	2.8	585	67	16	40	56
Alamo H3	224	2.62	–	–	702	355	316	348	36	3.1	688	98	21	59	80
Variety effect§	<0.01	<0.01	–	–	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Alamo LN	209	2.32	–	–	705	356	317	349	37	2.9	668	89	22	59	82
Alamo HN	240	2.92	–	–	700	353	315	347	36	3.3	708	108	20	59	78
N effect§	<0.01	<0.01	–	–	<0.01	0.03	0.11	0.02	<0.01	<0.01	<0.01	<0.01	<0.01	0.60	<0.01

† Values are means of six subsamples. Treatments include two harvests (H1 and H2) for Kanlow and two N fertility levels (LN = 50 kg ha^{-1} and HN = 150 kg ha^{-1}) for Alamo cut at sundown (PM) and sunup (AM). Int., intake; Int. rate, intake rate; Dim 1 and Dim 2, first and second MDS dimensions; NDF, neutral detergent fiber; ADF, acid detergent fiber; Cell, cellulose; Hemi, hemicellulose; Lig, sulfuric acid lignin; ADIA, acid detergent insoluble ash; IVTD, in vitro true dry matter disappearance; CP, crude protein; Sol. CHO, soluble carbohydrate; TNC, total nonstructural carbohydrate.
‡ MSD, minimum significant difference from Waller–Duncan k-ratio *t* test with k-ratio = 100.
§ Results of orthogonal contrasts; $P > F$.

bination of cultivar and harvest. It was correlated with NDF ($P < 0.01$), ADF ($P < 0.01$), cellulose ($P < 0.01$), lignin ($P < 0.01$), IVTD ($P < 0.01$), crude protein ($P < 0.01$), starch ($P = 0.02$), and TNC ($P = 0.04$). The relationships between the first MDS dimension and IVTD, crude protein, starch, and TNC were positive but the relationships with the fiber fractions were negative. Hemicellulose was positively correlated with the second MDS dimension.

Goats 1998 Kanlow and Alamo Hays–Experiment 5

As was the case for the cattle in Exp. 4, in the comparison of the harvests of Kanlow switchgrass with a harvest of two N levels in the production of Alamo switchgrass, the goats did not have a greater intake ($P = 0.26$) or intake rate ($P = 0.24$) for the PM harvest over the AM harvest (Table 6). The later harvests of Alamo were preferred over the earlier harvests of Kanlow and the higher N Alamo treatment was preferred over the lower N Alamo treatment as expressed by total intake and intake rate. Dimension 1 from the MDS analysis separated the Kanlow harvests from the Alamo harvest and the second dimension described differences within a cultivar.

The PM hays were lower in NDF, ADF, cellulose, hemicellulose, lignin, and crude protein but higher in soluble carbohydrate and TNC (Table 6). The more preferred Alamo harvests had reduced NDF, ADF, cellulose, hemicellulose, and lignin with increased ADIA, IVTD, crude protein, starch, soluble carbohydrate, and TNC. The Alamo hays from the low N fertility treatment had increased NDF, ADF, hemicellulose, lignin, starch, and TNC but decreased ADIA, IVTD, and crude protein.

The first MDS dimension was associated with the combination of cultivar and harvest. It was correlated with NDF ($P < 0.01$), ADF ($P < 0.01$), cellulose ($P < 0.01$), lignin ($P < 0.01$), IVTD ($P < 0.01$), crude protein ($P = 0.01$), starch ($P = 0.01$), soluble carbohydrate ($P = 0.01$), and TNC ($P = 0.01$). The relationships between the first MDS dimension and IVTD, crude protein, starch, soluble carbohydrate, and TNC were positive but the relationships with the fiber fractions were negative. The second MDS dimension was positively correlated with ADIA ($P = 0.03$).

Sheep 1998 Kanlow and Alamo Hays–Experiment 6

In contrast to the cattle (Exp. 4) and goats (Exp. 5), the sheep preference for the PM harvested hays was expressed in both increased intake and intake rate in this collection of hays. The later harvests of Alamo were preferred over the earlier harvests of Kanlow and the higher N Alamo treatment was preferred over the low N Alamo treatment as expressed by total intake and intake rate (Table 7). Dimension 1 from the MDS analysis separated the Kanlow harvests from the Alamo harvest and the second dimension principally described differences within a cultivar.

The PM hays had decreased NDF, ADF, cellulose, hemicellulose, lignin, and crude protein but higher in soluble carbohydrate and TNC (Table 7). The more preferred Alamo harvests had reduced NDF, ADF, cellulose, hemicellulose, and lignin with increased ADIA, IVTD, crude protein, starch, soluble carbohydrate, and TNC. The Alamo hays from the low N fertility treatment had increased NDF, ADF, cellulose, hemicellulose, lignin, starch, and TNC but increased ADIA, IVTD, and crude protein.

The first MDS dimension was associated with the combination of cultivar and harvest. It was correlated with NDF ($P < 0.01$), ADF ($P < 0.01$), cellulose ($P <$

Table 7. Intake, intake rate, dimensional coordinates (Dim1 and Dim2), and composition of 'Kanlow' and 'Alamo' switchgrass at three harvests (H1, H2, and H3) with the Alamo harvest at both low (LN) and high (HN) nitrogen cut either in the afternoon (PM) or morning (AM) and fed to sheep (Exp. 6; 1998 hays).†

Forage	Int.	Int. rate	Dim1	Dim2	NDF	ADF	Cell	Hemi	Lig	ADIA	IVTD	CP	Starch	Sol. CHO	TNC
	g	g min^{-1}			g kg^{-1}										
Kanlow H1-PM	109	1.0	−1.39	0.05	738	392	349	346	43	2.6	628	77	15	46	61
Kanlow H1-AM	93	0.8	−1.27	−0.84	752	401	356	351	44	2.6	614	76	15	35	50
Kanlow H2-PM	71	0.4	−1.43	−0.21	757	402	356	355	46	3.1	551	55	13	47	60
Kanlow H2-AM	68	0.4	−1.22	1.03	758	399	351	358	45	3.2	548	57	16	39	55
Alamo H3-LN-PM	343	3.7	1.30	−0.08	702	349	311	352	34	2.9	683	87	22	63	85
Alamo H3-LN-AM	308	3.4	1.32	0.05	716	357	317	359	36	3.0	676	90	20	52	72
Alamo H3-HN-PM	400	5.2	1.36	−0.11	697	343	305	354	33	3.4	705	101	20	65	85
Alamo H3-HN-AM	385	4.8	1.34	0.10	709	355	316	354	35	3.1	733	115	18	47	65
MSD‡	23	0.4	–	–	4	4	4	2	1	0.1	9	3	1	2	2
Mean PM	231	2.6	–	–	724	372	330	352	39	3.0	642	80	17	56	73
Mean AM	214	2.4	–	–	734	378	335	355	40	3.0	643	85	17	43	61
PM vs. AM§	<0.01	0.06	–	–	<0.01	<0.01	<0.01	<0.01	<0.01	0.03	0.65	<0.01	0.83	<0.01	<0.01
Kanlow H1 and H2	85	0.6	–	–	751	399	353	353	45	2.9	585	66	15	42	57
Alamo H3	359	4.3	–	–	706	351	312	355	35	3.1	699	98	20	57	77
Variety effect§	<0.01	<0.01	–	–	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Alamo LN	326	3.6	–	–	709	353	314	356	35	3.0	680	88	21	58	79
Alamo HN	392	5.0	–	–	703	349	311	354	34	3.2	719	108	19	56	75
N effect§	<0.01	<0.01	–	–	<0.01	0.02	0.03	0.04	<0.01	<0.01	<0.01	<0.01	<0.01	0.04	<0.01

† Values are means of six subsamples. Treatments include two harvests (H1 and H2) for Kanlow and two N fertility levels (LN = 50 kg ha^{-1} and HN = 150 kg ha^{-1}) for Alamo cut at sundown (PM) and sunup (AM). Int., intake; Int. rate, intake rate; Dim1 and Dim2, first and second MDS dimensions; NDF, neutral detergent fiber; ADF, acid detergent fiber; Cell, cellulose; Hemi, hemicellulose; Lig, sulfuric acid lignin; ADIA, acid detergent insoluble ash; IVTD, in vitro true dry matter disappearance; CP, crude protein; Sol. CHO, soluble carbohydrate; TNC, total nonstructural carbohydrate.
‡ MSD, minimum significant difference from Waller–Duncan k-ratio *t* test with k-ratio = 100.
§ Results of orthogonal contrasts; $P > F$.

0.01), lignin ($P < 0.01$), IVTD ($P < 0.01$), crude protein ($P = 0.01$), starch ($P < 0.01$), soluble carbohydrate ($P = 0.03$), and TNC ($P = 0.01$). The relationships between the first MDS dimension and IVTD, crude protein, starch, soluble carbohydrate, and TNC were positive but the relationships with the fiber fractions were negative. The second MDS dimension was not correlated with any of the estimates of nutritive value that we measured.

Cattle 2000 Alamo Hays–Experiment 7

Within the collection of six Alamo hays representing three paired PM and AM harvests cattle did not prefer the PM harvest over the AM harvest as expressed by intake. Intake rate was higher in the AM hays (Table 8). The results of the MDS analysis indicate that the selection was based on more than one dimension but they were not as simply related to the harvests as in the previous six experiments. Note that there were no differences between the six hays as expressed in cattle intake (MSD = 215). Based on the results of the intake measurements and the MDS analysis, these hays were particularly difficult for the cattle to rank.

The PM effect was not significant for the fiber fractions with the exception of a small decrease in lignin. The PM harvest had decreased ADIA and crude protein but increased starch, soluble carbohydrate and TNC (Table 8). The first MDS dimension was not correlated with any of the estimates of nutritive value and the second MDS dimension was only correlated with lignin ($P = 0.05$).

Goats 2000 Alamo Hays–Experiment 8

In contrast to the cattle, the goats preferred the PM harvested Alamo hays as expressed by both intake and intake rate (Table 9). As was the case with the cattle, the results of the MDS analysis indicate that the selection was based on more than one dimension but they were not as simply related to the harvests as in the

Table 8. Intake, intake rate, dimensional coordinates (Dim1 and Dim2), and composition of three harvests (H1, H2, and H3) of 'Alamo' switchgrass hay cut either in the afternoon (PM) or morning (AM) as fed to cattle (Exp. 7; 2000 hays).†

Forage	Int.	Int. rate	Dim1	Dim2	NDF	ADF	Cell	Hemi	Lig	ADIA	IVTD	CP	Starch	Sol. CHO	TNC
	g	g min^{-1}			g kg^{-1}										
Alamo H1-PM	870	66	−1.31	0.23	718	365	318	353	45	4.4	650	65	17	68	85
Alamo H1-AM	679	77	1.26	−0.74	724	371	324	352	47	4.7	639	72	15	53	68
Alamo H2-PM	876	123	0.15	1.44	715	357	313	358	42	4.6	670	77	18	61	79
Alamo H2-AM	848	155	1.07	0.91	713	355	311	358	43	5.4	679	95	15	55	70
Alamo H3-PM	766	164	0.17	−1.42	717	353	309	365	45	5.3	658	78	18	62	80
Alamo H3-AM	741	185	−1.35	−0.42	722	357	311	364	45	5.5	658	82	17	54	71
MSD‡	215	26	–	–	10	6	5	2	1	0.3	10	4	1	4	5
Mean PM	837	118	–	–	717	358	313	358	44	4.8	659	73	18	64	81
Mean AM	756	139	–	–	720	361	315	358	45	5.2	659	83	16	54	70
PM vs. AM§	0.10	0.01	–	–	0.21	0.12	0.18	0.86	<0.01	<0.01	0.82	<0.01	<0.01	<0.01	<0.01

† Values are means of six subsamples collected during feeding of six animals. Int., intake; Int. rate, intake rate; Dim1 and Dim2, coordinates from multidimensional scaling; NDF, neutral detergent fiber; ADF, acid detergent fiber; Cell, cellulose; Hemi, hemicellulose; Lig, sulfuric acid lignin; ADIA, acid detergent insoluble ash; IVTD, in vitro true dry matter disappearance; CP, crude protein; Sol. CHO, soluble carbohydrate; TNC, total nonstructural carbohydrate.
‡ MSD, minimum significant difference from Waller–Duncan k-ratio *t* test with k-ratio = 100.
§ Results of orthogonal contrast; $P > F$.

Table 9. Intake, intake rate, dimensional coordinates (Dim1 and Dim2), and composition of three harvests (H1, H2, and H3) of 'Alamo' switchgrass hay cut either in the afternoon (PM) or morning (AM) as fed to goats (Exp. 8; 2000 hays).†

Forage	Int.	Int. rate	Dim1	Dim2	NDF	ADF	Cell	Hemi	Lig	ADIA	IVTD	CP	Starch	Sol. CHO	TNC
	g	g min^{-1}			g kg^{-1}										
Alamo H1-PM	160	2.12	1.40	0.35	710	362	316	347	43	5.6	664	69	16	65	81
Alamo H1-AM	102	0.86	−1.26	−0.93	731	380	330	352	46	5.2	650	66	15	48	63
Alamo H2-PM	208	2.87	−0.82	1.39	716	364	320	352	43	5.7	673	82	14	55	69
Alamo H2-AM	144	1.59	0.65	−1.36	733	372	324	361	44	5.9	671	83	13	43	56
Alamo H3-PM	157	1.95	0.97	0.68	722	358	312	364	44	5.8	669	78	15	54	69
Alamo H3-AM	154	1.65	−0.91	−0.24	727	365	319	372	45	6.0	659	79	15	50	65
MSD‡	23	0.51	–	–	10	8	7	4	2	0.2	13	4	1	6	6
Mean PM	175	2.31	–	–	716	362	316	354	43	5.7	668	76	15	58	73
Mean AM	133	1.37	–	–	730	372	324	358	45	5.7	660	76	15	47	62
PM vs. AM§	<0.01	<0.01	–	–	<0.01	<0.01	<0.01	<0.01	<0.01	0.40	0.03	0.93	0.18	<0.01	<0.01

† Values are means of six subsamples collected during feeding of six animals. Int., intake; Int. rate, intake rate; Dim1 and Dim2, coordinates from multidimensional scaling; NDF, neutral detergent fiber; ADF, acid detergent fiber; Cell, cellulose; Hemi, hemicellulose; Lig, sulfuric acid lignin; ADIA, acid detergent insoluble ash; IVTD, in vitro true dry matter disappearance; CP, crude protein; Sol. CHO, soluble carbohydrate; TNC, total nonstructural carbohydrate.
‡ MSD, minimum significant difference from Waller–Duncan k-ratio *t* test with k-ratio = 100.
§ Results of orthogonal contrast; $P > F$.

previous six experiments. The goats did have significant variation among the intakes of the six hays (MSD = 23) but these hays were more similar and difficult to rank since no harvest had both hays either higher or lower in intake than any other harvest. For example, even though the AM cut of the first harvest had a lower intake than any other harvest (102 g) the PM cut of the same harvest had an intake (160 g) that was only significantly lower than the PM cut of the second harvest.

In contrast to the results of the analysis of the hay as fed to the cattle, for the goats the PM harvested hays had reduced NDF, ADF, cellulose, hemicellulose, and lignin as well as increased IVTD, soluble carbohydrate, and TNC (Table 9).

The first MDS dimension was correlated with ADF ($P = 0.03$), cellulose ($P = 0.03$), and lignin ($P = 0.04$). These relationships were negative and none of our observed estimates of composition were correlated with the second MDS dimension.

Sheep 2000 Alamo Hays–Experiment 9

In contrast to the cattle and similar to the results using goats, the sheep preference for the PM harvested Alamo hays was expressed by both intake and intake rate (Table 10). However, the results of the MDS analysis indicate that the selection was based on more than one dimension without a simple relationship. For example, the PM hays from the second and third harvest are judged to be similar and placed near each other in the dimensional space. The coordinates for the PM hay of the second harvest are 1.15 and 0.64. The coordinates for the third PM harvest are 1.27 and 0.24. In contrast, the first harvest PM hay was also a preferred hay and the coordinates were −1.22 and −0.13. As was the case for the goats (Exp. 8), the sheep had significant variation among the intakes of the six hays (MSD = 46) but the hays were apparently too complex to rank based on the results of MDS.

In contrast to the hay composition fed to the cattle and similar to the results for the goats the PM harvested hays, as fed, had less NDF, ADF, cellulose, hemicellulose, and lignin as well as greater ADIA, IVTD, soluble carbohydrate, and TNC (Table 10).

The first MDS dimension was correlated with crude protein ($P < 0.01$). None of our observed estimates of composition were correlated with the second MDS dimension.

SUMMARY

The effect of the PM harvested hays was much less robust with switchgrass hays harvested in the humid

Table 10. Intake, intake rate, dimensional coordinates (Dim1 and Dim2), and composition of three harvests (H1, H2, and H3) of 'Alamo' switchgrass hay cut either in the afternoon (PM) or morning (AM) as fed to sheep (Exp. 9; 2000 hays).†

Forage	Int.	Int. rate	Dim1	Dim2	NDF	ADF	Cell	Hemi	Lig	ADIA	IVTD	CP	Starch	Sol. CHO	TNC
	g	g min^{-1}			g kg^{-1}										
Alamo H1-PM	266	3.57	−1.22	−0.13	708	359	313	350	42	5.7	666	71	16	66	82
Alamo H1-AM	157	1.57	−1.25	−0.86	733	378	329	354	46	5.1	645	67	14	51	65
Alamo H2-PM	294	4.40	1.15	0.64	712	360	317	353	42	5.8	678	86	15	53	68
Alamo H2-AM	220	2.64	−0.57	1.48	733	373	325	360	43	5.6	669	84	14	41	55
Alamo H3-PM	264	3.89	1.27	0.24	725	362	316	363	45	5.9	663	81	15	54	69
Alamo H3-AM	219	3.24	0.63	−1.37	729	366	319	363	44	5.8	656	78	16	49	65
MSD‡	46	1.26	–	–	10	10	8	4	1	0.3	9	6	1	5	5
Mean PM	275	3.95	–	–	715	360	315	355	43	5.8	669	79	15	58	73
Mean AM	199	2.48	–	–	732	372	324	359	44	5.5	657	76	15	47	62
PM vs. AM§	<0.01	<0.01	–	–	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	0.1	0.23	<0.01	<0.01

† Values are means of six subsamples collected during feeding of six animals. Int., intake; Int. rate, intake rate; Dim1 and Dim2, coordinates from multidimensional scaling; NDF, neutral detergent fiber; ADF, acid detergent fiber; Cell, cellulose; Hemi, hemicellulose; Lig, sulfuric acid lignin; ADIA, acid detergent insoluble ash; IVTD, in vitro true dry matter disappearance; CP, crude protein; Sol. CHO, soluble carbohydrate; TNC, total nonstructural carbohydrate.
‡ MSD, minimum significant difference from Waller–Duncan k-ratio *t* test with k-ratio = 100.
§ Results of orthogonal contrast; $P > F$.

South than reported for fescue and alfalfa in the western USA (Fisher et al. (1999, 2002). Preference for PM harvested hays over AM harvested hays was only detected in four of nine experiments. However, one or both of the small ruminant species expressed a preference for the PM hays in each of the three collections of hays. Cattle did not express any significant preference for the PM hays with increased intake and in one case expressed no preferences among any of the hays presented along with a higher intake rate for the AM harvested hays. The more difficult drying conditions of the Southeast compared with the northwestern USA may account for the lower success rate in altering animal preference. However, this was the first research using these procedures with switchgrass. The physiology, anatomy, and morphology of this C_4 grass may have contributed to the reduced effect of PM and AM harvest management. In particular, the role of the bundle sheath in carbohydrate accumulation and export may have altered animal response to carbohydrate accumulation.

In Experiments 4, 5, and 6 the variation in nitrogen fertility permitted a comparison of hays containing increased crude protein (CP) and reduced soluble and structural carbohydrate to hays with lower CP and increased soluble and structural carbohydrate. In this comparison, the animals preferred the hays with increased CP even though they had reduced soluble carbohydrate. In each of the nine experiments we were able to deliver PM feeds, as fed, with TNC greater than the AM feeds. The differences we observed in the composition of hays harvested at the same time and fed to cattle, sheep, and goats illustrates the importance of sampling the feed as delivered to the animal. Variation within the hay supply and over time are often not accounted for by sampling schemes that only sample the supply as harvested. The procedure used in these nine experiments allowed for variation in composition of hays actually delivered at the feed bunk to be represented within the error term.

The PM feeds were only 7 to 12 g kg^{-1} of TNC greater than the AM feeds. This range in TNC between PM and AM is similar to the range reported from fescue (10–18 g kg^{-1}) and alfalfa (10–19 g kg^{-1}). However, in the case of both fescue and alfalfa we were able to deliver hays "as fed" with higher IVTD. The IVTD of the PM hays was only higher in Exp. 8 and 9. In these experiments significant preferences for the PM hays were expressed by goats and sheep as increased intake and intake rate. The IVTD of the "as fed" material for the cattle was never higher for the PM harvested hays than the AM harvested hays and the cattle did not express a preference for the PM harvested hays. In comparison of previously published studies, the fiber fractions in these experiments were often similar for the AM and PM harvested hays. For example, the NDF of the PM harvested hay was lower than the AM hay in only five of nine experiments.

The results of MDS analysis indicated the importance of fiber content and digestibility as selection criteria. Fiber and digestibility were important in explaining the first dimension of Experiments 1 through 6. Soluble carbohydrate was also important in Experiments 4 though 5. In six out of nine experiments we did not have a composition variable correlated with the second dimension of MDS. This would indicate that the animals were basing selection on a variable that was not even correlated with one of our composition variables. The suite of improvements associated with PM harvested hays in fiber content, nonstructural carbohydrate, and particularly digestibility observed previously for alfalfa and fescue hays in the western USA (Fisher et al. (1999, 2002) were difficult to reproduce with switchgrass hay in the southeastern USA. This difficulty is likely related to the less favorable environment for haymaking as well as the physiology, anatomy, and morphology of this C_4 grass.

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