Dry Matter Intake and Digestibility of 'Coastal', 'Tifton 44', and 'Tifton 85' Bermudagrass Hays Grown in the U.S. Upper South

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ABSTRACT

'Coastal' bermudagrass [*Cynodon dactylon* (Pers.) L.] is the major warm-season grass grown across the U.S. upper south. More recent hybrids of 'Tifton 44' (T44) and 'Tifton 85' (T85) (*Cynodon* sp.) offer improved nutritive value. Compared are dry matter (DM) intake and digestion of Coastal bermudagrass (CB), T44, and T85 hays grown under different soil and climate conditions and harvested at either the same or different maturities. In the comparison of CB and T44 with steers (*Bos taurus* L.), DM intake was greater for CB in one of three experiments, whereas intakes did not differ in the other two. Greater intake for CB was associated with greater DM digestion. In the other two experiments, T44 had greater DM digestion than did CB in one trial but did not differ in the other. Hays of CB, T44, and T85, harvested in 2 yr, were compared by means of sheep (*Ovis aries* L.). In Year 1, sheep consumed more CB than either T44 or T85, whereas in Year 2, no differences in intake were detected. Coastal was digested least in both experiments compared with T44 and T85, and T85 had greatest DM digestion in one of the two years. Samples of masticate of CB had the least in vitro true dry matter disappearance (IVTDMD) with T44 intermediate and T85 generally greatest. In general, animal response data showed little advantage of T44 in comparison with CB; however, Tifton 85 appears to have greater digestible fiber and offers potentially greater DM digestion and digestible intake compared with CB.

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Abbreviations: ADF, acid detergent fiber; CB, Coastal bermudagrass; CP, crude protein; DM, dry matter; IVDMD, in vitro dry matter disappearance; IVTDMD, in vitro true dry matter disappearance; LOF, lack of fit; NDF, neutral detergent fiber; NIRS, near-infrared reflectance spectroscopy; T44, Tifton 44 bermudagrass; T85, Tifton 85 bermudagrass.

Perennial warm-season grasses are the major forages that sustain ruminant production systems across the southeastern and mid-South regions of the USA (Burns et al., 2004). In the southeastern USA, hybrid bermudagrass cultivars have dominated, but they have adaptation limits above the southern boundaries of the North–South transition zone (Burton and Hanna, 1995). Coastal, one of the earliest hybrid cultivars developed (1943), has been successfully grown through the central Piedmont of North Carolina, although occasional winter kill has occurred even in well established stands. Bermudagrass can be either grazed or cut and stored as hay. When grazed, CB has had high productivity but often only supports modest daily animal gains (Gross et al., 1966; Burns et al., 1973, 1984). When fed as hay, CB was readily consumed, but digestion of DM and fiber fractions was relatively low compared with other warm-season grasses (Burns et al., 1985).

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Tifton 44 bermudagrass has improved nutritive value and cold tolerance compared with CB (Burton and Monson, 1978) and has been successfully grown through central North Carolina (Rakes et al., 1988; Burns et al., 1992). Spring growth has been observed to begin several weeks earlier in T44 compared with CB, with grazing possible 10 to 14 d earlier in the season than CB and somewhat later into the early fall, thereby extending the grazing season by 2 to 3 wk (Rakes et al., 1988).

Tifton 85 bermudagrass has been shown to have improved DM yield and digestion but less winter hardiness than T44 (Burton et al., 1993; Burton, 2001). A 10-yr-old planting of T85 (made in 1995), however, has demonstrated acceptable winter hardiness in the Raleigh, NC, area. This cultivar warrants further assessment for use in production systems in this region.

Intake and digestion trials comparing CB with T44 or T85, although limited, indicate that CB has comparable or superior daily DM intake, but DM digestion is usually inferior (Mandebvu et al., 1999a). Reduced in vitro dry matter disappearance (IVDMD) was also reported from masticate of steers grazing CB pastures compared with masticate from pastures of T44 and T85 (Hill et al., 1993). Tifton 85 masticate was greatest in IVDMD with T44 intermediate and not different from CB. The merits of either T44, T85, or both to replace CB predicated on daily animal response have not been adequately addressed. This study consisted of five related but different experiments comparing the quality of CB with either T44 or both T44 and T85. The overall objective of all five experiments was to compare DM intake, DM digestion, and masticate characteristics between CB and T44 or among CB, T44, and T85. Specific objectives are stated below for each experiment.

MATERIALS AND METHODS

Experimental Hays

Hays harvested and fed in all experiments were obtained from well established stands that had been fertilized and limed according to soil tests. Forages compared within an experiment were managed similarly. Initial growth in all experiments was removed from the harvest site and discarded. The first and subsequent regrowths, depending on the experiment, were used for the experimental hays. After removal of the preceding growth, stands were top-dressed with 78 kg N ha^{-1} as ammonium nitrate in preparation for the production of the subsequent experimental hays. Forages were either field cured or artificially dried, depending on experiment (see below). If field cured, the forage was cut with a mower-conditioner set to a 10-cm height and baled with a conventional square baler. Forages to be artificially dried were harvested one treatment at a time with a flail chopper (cut into 8- to 15-cm lengths) set to leave a 10-cm stubble, blown into a self-unloading wagon, unloaded into a metal bulk drying barn (described by Burns et al., 1997), and dried overnight (18 h) by forced air (88°C at inlet). After drying, the hay was baled as noted for field-cured hay. The bales were transported either from the field or dryer and stored on wooden pallets in a well ventilated building designed for hay storage until used in the experiments.

At initiation of each experiment, field cured hays were passed through a hydraulic bale press (Van Dale 5600, J. Starr Industries, Fort Atkins, WI) with stationary knives spaced at 10 cm. This process reduces hay into 7- to 13-cm lengths with essentially no leaf loss and aids in feeding and minimizes the potential for the hay to be tossed out of the manger. The cut hay was stored in carts for later feeding. Hays that were artificially dried had been flail chopped and no additional chopping was required before feeding.

Evaluation Using Steers

Intake and Digestion Phases

In Exp. 1 through 4, forages were evaluated in an animal facility consisting of a metal structure partitioned into a feed preparation area on one end, an enclosed, but well ventilated middle area equipped with digestion crates with moderate temperature control (ambient air maintained >10°C and <24°C), and a third section equipped with a raised, basket weave, metal platform fitted with electronic (Calan) gates (American Calan Inc., Northwood, NH) and used to control animal access to mangers for individual intake measurements. The intake area was beneath an extension of the roof with three open sides. In the intake phase, each animal was electronically keyed to allow access to only one manger but had free access to trace mineralized salt and water and could lounge with other animals. Before each experiment, animals were conditioned to the gates before random assignment to the appropriate forage treatment.

The intake phase of each experiment consisted of a 21-d period with the first 7 d used for adjustment and the last 14 d to estimate daily DM intake (Burns et al., 1994). A recorded weight of hay was fed twice daily allowing a 15% excess that was based on the previous day's intake. A daily sample of the fed hay was obtained for each animal and composites made on a weekly basis. Orts were weighed twice daily, saved separately for each animal × treatment combination, and composited each week.

The digestion phase immediately followed each intake period. The animals were moved from the intake area into digestion crates. The digestion phase consisted of a 7-d adjustment period followed by a 5-d total fecal collection (12 d). A recorded weight of forage was fed twice daily at 15% excess (except were noted below) of the previous day's intake. A daily sample of the fed hays was obtained and orts saved separately for each animal × treatment combination and composited for the 5-d collection period.

Feces were collected on a plastic sheet placed on the floor immediately in back of each digestion crate. Feces were removed periodically throughout the day and the daily total weighed for each of five consecutive days. Feces were thoroughly mixed daily, and 5% of the fresh weight was placed in a freezer (−15°C). When part of the experimental objectives, a second sample was obtained and placed in a freezer for particle size determination.

The weekly hay samples from the 14-d intake phase, the 5-d composite hay and fecal samples from the digestion phase, and the associated ort samples from the intake and digestion phases were oven-dried (55°C) and weighed for DM determination, thoroughly mixed, and a 300- to 500-g subsample ground in a Wiley Mill to pass a 1-mm screen and stored at room temperature until analyzed. The samples for fecal particle size determination remained in the freezer (−15°C) until freeze dried and were dry sieved as noted below for masticates.

In experiments using a randomized complete block design, the digestion phase followed the intake phase and completed the experiment for each animal. However, in Latin square-designs, animals returned to the intake facility following the digestion phase to begin the next period.

Masticate Phase

Mature, esophageally cannulated, Angus steers (>590 kg) were fed a standard CB hay about 5 d before initiation of the experiment. After adjustment to treatments (offered the previous PM), collections occurred about 0900 and 1500 h on two consecutive days. Animals were offered about 1.2 kg of hay at each collection. The esophageal cannulas were removed and boli collected by hand to ensure complete collection. The first five to six boli were discarded and the following 10 to 15 were collected. They were placed on a large plastic tray, gently mixed, placed into two plastic bags, immediately quick-frozen in liquid nitrogen (−195°C), and stored in a freezer (−15°C) until freeze dried and then stored in the freezer until analyzed. The dried boli were sampled for chemical analyses and for particle size determination.

Particle size estimates of the boli and feces were obtained by passing two 15-g samples through a Fritsch Vibrator system (Fritsch Analysette, the Tekmor Co., Cincinnati, OH). Nine particle sizes were weighed consisting of DM retained on 5.60-, 4.00-, 2.80-, 1.70-, 1.00-, 0.50-, 0.25-, and 0.125-mm sieves and that which passed through the 0.125-mm sieve (<0.125 mm). The dry weight was recorded for the material retained on each sieve and that which passed through the 0.125-mm sieve. Samples were composited across days and feeding times for each sieve size. Sieved samples were stored either separately by individual sieve size or, in the case of the masticate samples, composites were made to form three particle-size classes of large (≥1.7 mm), medium (<1.7 and ≥0.50 mm), and small (<0.50 mm) before chemical analyses. The composite samples were ground in a cyclone mill (Udy Corp., Fort Collins, CO) to pass a 1-mm screen and stored in a freezer until analyzed.

Experiment 1

Hays of CB and T44 were produced in the Coastal Plain on a fine loamy, kaolinitic, thermic Typic Kandiudults near Clayton, NC. A 6-wk regrowth of both CB and T44 harvested 1 August and a 12-wk regrowth of CB, from delaying harvest until 11 September, constituted the experimental hays. Hays were evaluated by means of Hereford steers in three sets of a 3 × 3 Latin square design. Intake estimates were repeated in all three squares, whereas digestibility was measured in two of the three squares. The intakes of 12 steers of similar body weight were standardized for 14 d on locally produced CB hay. Of these 12 animals, nine with similar daily DM intake were grouped by three and randomly assigned to treatments. The initial weight of the steers in Square I averaged 184 kg (range = 164–197 kg), in Square II, 187 kg (range = 178–200 kg), and in Square III, 197 kg (range = 186–207). Digestion was estimated after the intake phase of the third period of Squares I and II only, resulting in two replicates for each of the three treatments. During the digestion phase, each animal was fed at 90% of its previous week's average ad libitum daily DM intake.

Experiment 2

Coastal and T44 were grown in the Piedmont on a fine, kaolinitic, thermic Typic Kanhapludults at the North Carolina State University Reedy Creek Road Field Laboratory, Raleigh, NC. Two 5-wk regrowths of each cultivar, the first harvested on 15 July and the second on 24 August, constituted the four hay treatments. All were evaluated with Angus steers using a randomized complete block design. Four steers within each of the three animal replicates (blocks) were grouped by body weight (mean weight = 254 kg; range = 216–276 kg), and each steer assigned at random, within the group, to the four treatments. A separate masticate study was conducted using esophageally cannulated steers in a randomized complete block design with four animal replicates (blocks) per treatment. The whole masticate was analyzed for percent DM, median particle size, IVTDMD, crude protein (CP), and neutral detergent fiber (NDF). Subsamples of the whole masticate DM were sieved for particle size distribution and the DM recombined into particle-size classes giving the proportion of large, medium, and small particles. The DM of each particle-size class was analyzed for IVTDMD, CP, and NDF, but results are not reported in this paper.

Experiment 3

Coastal and T44 bermudagrasses were grown in the Piedmont on a fine, kaolinitic, thermic Typic Kanhapludults at the North Carolina State University Reedy Creek Road Field Laboratory, Raleigh, NC. Initial growth was removed 9 May and three subsequent regrowths of both cultivars were harvested 15 June, 20 July, and 10 August constituting six experimental hays. The hays were direct cut with a flail harvester and artificially dried. The hays were evaluated by means of 24 Angus steers in a randomized complete block design with four animal replicates (blocks). Steers were blocked on body weight (mean = 274 kg; range = 227–335 kg) and assigned at random, within block, to the six forage treatments. A mastication study was also conducted using esophageally cannulated steers in a 6 × 6 Latin square design. Each day constituted a period. Whole masticate samples were analyzed for median particle size and concentrations of DM, IVTDMD, CP, and NDF. Subsamples of the whole masticate and feces were sieved to determine particle size distribution of the six experimental hays. The masticate DM was recombined into particle-size classes giving the proportion of large, medium, and small particles as described previously. The DM of each particle-size class was analyzed for IVTDMD, CP, and NDF, but results are not reported in this paper.

Experiment 4

Coastal, T44, and T85 bermudagrasses were grown in the Piedmont on a fine, kaolinitic, thermic Typic Kanhapludults at the North Carolina State University, Lake Wheeler Road Field Laboratory, Raleigh, NC. Hays were harvested 7 July after 4 wk of regrowth and constituted the three experimental treatments. The hays were evaluated for masticate characteristics using esophageally cannulated steers in a randomized complete block design with six animals per treatment. Masticates were analyzed for median particle size and concentrations of DM, IVTDMD, CP, and NDF. Subsamples of the whole masticate were sieved to determine particle size distribution of the three cultivars. The masticate DM was recombined into particle-size classes giving the proportion of large, medium and small particles. The DM of each particle-size class was analyzed for IVTDMD, CP, and NDF, but results are not reported in this paper.

Evaluations using Sheep

Experiment 5 was conducted with sheep in a building constructed for small-ruminant research with moderate temperature control (ambient air maintained >13 and <24°C). The animals were held in digestion crates with free access to salt and water. When animals were initially placed in crates, they were fitted with a collection harness for future fecal collections. After an initial standardization period (14 d), allowing conditioning to the crates and harness, each animal was randomly assigned to a treatment. At initiation of the digestion phase, a canvas collection bag was positioned on the harness and fitted with a plastic insert for total fecal collection. During collection, the fecal bags were emptied daily and feces processed as described previously above for steers.

Year 1

Well established stands of CB, T44, and T85 were located on a fine, kaolinitic, thermic, Typic Kanhapludults at the North Carolina State University, Lake Wheeler Road Field Laboratory, Raleigh, NC. Hays from the three cultivars were harvested 7 July after 4 wk of regrowth and constituted the three experimental hays. The hays were evaluated with Katahdin wether sheep using a randomized complete block design with six sheep per treatment. The sheep were blocked into six replicates on the basis of body weight (mean = 35.1 kg; range = 29.0–40.9 kg) and assigned at random, within block, to the three hay treatments. These same experimental hays were evaluated for masticate characteristics using steers in Exp. 4 above.

Table 1. The number of samples and range for each forage constituent† predicted by near-infrared reflectance spectrophotometry, its SE of calibration (SEC), and its SE of cross-validation (SECV) for both the intake and digestion and the masticate experiments.

Item	*N*	Range	SEC	R^2	SECV	R^2
Masticate:		g kg^{-1}	g kg^{-1}		g kg^{-1}	
IVTDMD	166	549–851	13.5	0.97	17.0	0.96
CP	113	55–195	2.2	0.99	3.8	0.99
NDF	224	525–764	10.9	0.94	13.0	0.91
Forage:						
IVTDMD	71	528–793	25.2	0.87	27	0.85
CP	164	53–227	3.5	0.98	4.4	0.97
NDF	165	654–780	5.3	0.96	7.7	0.92
ADF	163	292–455	5.3	0.96	6.5	0.94
CELL	164	244–383	3.1	0.98	4.0	0.97
Lignin	162	37–76	2.3	0.91	3.2	0.84

†IVTDMD = in vitro true dry matter disappearance; CP = crude protein; NDF = neutral detergent fiber; ADF = acid detergent fiber; CELL = cellulose.

Year 2

Coastal, T44, and T85 hays were harvested during a second year from the same fields described for Year 1. A 4-wk regrowth was cut 7 July and evaluated with Katahdin wether sheep using a randomized complete block design with six sheep per treatment. The sheep were blocked by weight into six replicates (mean = 35 kg; range = 28–41 kg) and assigned at random, within block, to the three experimental hay treatments.

Laboratory Analysis

All feed and ort samples from the intake and digestion phases of each experiment were ground in a Wiley mill to pass a 1-mm screen and nutritive value estimated with a near infrared reflectance spectrophotometer (NIRS). All samples were scanned in a model 5000 NIRS with WinISI, version 1.5 software (Foss North America, Inc., Eden Prairie, MN). The "H" statistic (0.6) was used to identify samples with different spectra which were subsequently analyzed by wet chemistry to develop NIRS calibration equations to predict the various estimates of nutritive value for all samples (Table 1).

In vitro true dry matter disappearance was determined by 48-h fermentation in a batch fermentation vessel (Ankom Technology Corp., Fairport, NY) with artificial saliva and rumen inoculum according to Burns and Cope (1974). In vitro fermentation was terminated with neutral detergent solution in the Ankom 200 fiber analyzer to remove the residual microbial dry matter. Ruminal inoculum was obtained from a mature Hereford steer fed a mixed alfalfa (*Medicago sativa* L.)-orchardgrass (*Dactylis glomerata* L.) hay. Total N was determined colorimetrically (AOAC, 1990) with a Technicon Autoanalyzer (Bran and Luebbe, Buffalo, IL) and CP was estimated as 6.25 times total N. Fiber fractions, consisting of NDF, acid detergent fiber (ADF), sulfuric acid lignin, and acid detergent insoluble ash were estimated in a batch processor (Ankom Technology Corp., Fairport, NY) using reagents according to Van Soest and Robertson (1980). Hemicellulose was determined by difference (NDF − ADF) as was cellulose [ADF – (lignin + ash)].

Statistical Analyses

The data from the intake and digestion phases were analyzed on the basis of the experimental designs for the particular studies. In Exp.1, the intake data were analyzed as a repeated 3 × 3 Latin square design using a mixed model. The statistical model included terms for animal, period, treatments, and squares. Animal, periods, and squares were random effects and treatments fixed (Steel and Torrie, 1980; SAS, 2004). The digestion data were analyzed as a randomized complete block design. The mixed model included a random term for animals and a fixed term for treatments. In Exp. 2 through 5, data were analyzed as randomized complete block designs. The mixed model included a random term for animals and a fixed term for treatments. Particle sizes, when determined, were expressed as percentage of cumulative particle weight oversize (sum of DM weight on each sieve vs. weight from all larger sieves) and were used to determine mean and median particle size (Fisher et al., 1988). Means for all variables found significant in all experiments were compared by a set of meaningful contrasts (Exp. 1, 2, 4, and 5) or trend analysis (Exp. 3) within the analysis of variance, depending on the structure of the experimental treatments. In the case of Exp. 3, which included three harvests, the harvest sum of squares were partitioned between two contrasts; one accounted for the proportion of the sum of squares explained by a linear response and the rest of the sum of squares to the quadratic component or more appropriately lack of fit (LOF) since there are only 2 degrees of freedom available. A significant LOF indicates a deviation from a simple linear fit since only three observations exist. Consequently, the second harvest is either greater or lesser than expected from a linear interpolation of the first and third harvests. A decision was made a priori to consider differences in all animal responses significant with statistical test at $P \leq 0.10$. All forage composition data were considered significant at $P \leq 0.05$.

For the summary discussion, a meta analysis of all the daily intake and digestion data was conducted by Proc Mixed of SAS (SAS, 2004). Each harvest from each year was considered as a random effect along with replication within the harvest and year. Fixed effects were animal species and bermudagrass cultivar.

RESULTS AND DISCUSSION

Steer Experiments

Experiment 1

Bermudagrass is a preferred receiver of waste from swine-confinement systems in the Southeast, but its harvest to remove nutrients from waste spray fields is often viewed as a liability with infrequent harvest preferred. However, a 3- to 5-wk harvest interval is recommended to maintain acceptable forage quality (Mueller et al., 1993). The objective of this experiment was to determine if differences in forage quality exists (i) between CB and T44 when harvested at 6 wk of regrowth and (ii) when the harvest of CB regrowth was delayed from 6 to 12 wk.

At 6 wk of regrowth, the consumption, by steers, of CB and T44 did not differ, averaging 2.48 kg 100^{-1} kg body weight (Table 2). Bermudagrass is readily consumed by ruminants, even when mature, with intakes generally greater than other warm-season grasses with comparable NDF concentrations (Burns et al., 1985). The coefficient of digestion for T44 was greater ($P = 0.02$) than CB, but digestible DM intakes did not differ and is reflected in short-term steer daily gains of 0.69 vs. 0.59 kg ($P = 0.39$). The daily gain for T44 (0.69 kg) was consistent with NRC, level 1 model (1996) predictions, with forage DM consumed at about 2.7 kg 100^{-1} kg of body weight with a total digestible nutrient concentration of 630 g kg^{-1}.

Delaying the harvest of CB from 6 to 12 wk reduced DM intake approximately 5% (2.49 vs. 2.40 kg 100^{-1} kg body weight), but digestibility was reduced nearly 20% (Table 2; 506 vs. 408 g kg^{-1}). Short-term daily gains also reflected this difference, averaging 0.59 kg for the 6-wk CB hay vs. 0.39 kg ($P = 0.08$) for the 12-wk CB hay. These data are consistent with forage maturity affects (Coleman et al., 2004) and indicate that there would be little advantage to replace CB stands with T44 and that the quality of CB continues to decline when harvest is delayed from 6 to 12 wk but that digestibility declines more rapidly than intake

Experiment 2

The objective of this experiment was to compare the quality of CB and T44 when grown under two climate conditions represented by 5-wk regrowth harvested in July and August. Growth harvested in July received 118 mm of rainfall (major events of 33 mm occurred in Week 1 of regrowth and 52 mm in Week 3) compared with growth in August which received 229 mm of rainfall (major events of 30 mm occurred in Week 1 of regrowth and 160 mm in Week 4). Both regrowths were produced with similar mean maximum temperature (July = 29.7°C and August = 29.5°C). With few exceptions, no cultivar × harvest interactions were noted for the variables analyzed. Consequently, only the cultivar and harvest main effects are reported, but exceptions are noted as appropriate.

Dry Matter Intake and Digestion

At 5 wk of regrowth, CB and T44 hays did not differ in intake or in apparent DM digestion, although digestion of the cell wall and constituent fiber fractions were greater for T44 than CB (Table 3). This apparent discrepancy is, in part, attributed to less variation (smaller SE) associated with digestibility estimates for NDF and its fiber constituents then noted for apparent DM digestion. The greater apparent digestibility of the NDF and constituent fiber fractions, compared with apparent DM digestion, is primarily due to the removal of microbial biomass when detergent solution is used to extract feces. Therefore, reduced total fecal content (5-d collection) used in subsequent digestion calculations resulted in greater digestibilities for the fiber fractions than reported for apparent DM digestion.

Table 2. Dry matter intake and digestion of mature Coastal and Tifton 44 bermudagrass hays, Exp. 1 (oven-dry basis).

Bermudagrass	Intake[†]	Dry matter Digestion	DI[‡]
	kg 100^{-1} kg	g kg^{-1}	kg 100^{-1} kg
Coastal (CB):			
6 wk	2.49[§]	506[¶]	1.31[¶]
12 wk	2.40	408	1.09
Tifton 44 (T44):			
6 wk	2.46	632	1.59
Significance (P):	0.23	0.01	0.11
Maturity (CB)			
6 vs. 12 wk	0.10	0.03	0.22
Cultivar (6 wk)			
CB vs. T44	0.50	0.02	0.15

[†] Body weigh basis.

[‡] DI = digestible intake.

[§] Each value is the mean of nine animals.

[¶] Each value is the mean of two animals. DI based on the dry matter intake of the two animals used in the digestion phase.

Table 3. Dry matter intake, apparent dry matter digestion, digestion of fiber fractions and digestible intake of Coastal and Tifton 44 bermudagrass hays harvested in July and August, Exp. 2 (oven-dry basis).

		Digestion[†]					Digestible intake				
Bermudagrass	**Intake[‡]**	**DM**	**NDF**	**ADF**	**HEMI**	**CELL**	**DM**	**NDF**	**ADF**	**HEMI**	**CELL**
	kg 100^{-1} kg	g kg^{-1}					kg 100^{-1} kg				
Cultivar:											
Coastal	2.21[§]	572[§]	599	577	621	632	1.28[§]	1.02	0.48	0.54	0.45
Tifton 44	1.87	580[¶]	638	611	661	670	1.01[¶]	0.85	0.38	0.47	0.36
Harvest:											
July	2.50[#]	614[††]	682	665	696	717	1.46[††]	1.19	0.55	0.64	0.51
August	1.58	544[#]	556	523	586	585	0.86[#]	0.68	0.32	0.37	0.30
SE	0.25	20	14	13	18	12	0.16	0.12	0.06	0.07	0.05
Significance (*P*):											
Cultivar (CL)	0.23	0.34	0.02	0.01	0.04	<0.01	0.08	0.16	0.09	0.28	0.08
Harvest (H)	0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
CL × H	0.79	0.17	0.20	0.08	0.36	0.25	0.84	0.76	0.65	0.86	0.58

[†] DM = dry matter; NDF = neutral detergent fiber; ADF = acid detergent fiber; HEMI = hemicellulose; CELL = cellulose.

[‡] Body weight basis.

[§] Each value is the mean of two harvests and three animals (***n*** = 6).

[¶] Each value is the mean of two animals in the July harvest and three animals in the August harvest (*n* = 5).

[#] Each value is the mean of two cultivars and three animals (*n* = 6).

[††] Each value is the mean of three animals for Coastal and two animals for Tifton 44 (*n* = 5).

Table 4. In vitro true dry matter disappearance (IVTDMD) and nutritive value[†] of Coastal and Tifton 44 bermudagrass hays harvested in July and August and fed to steers in Exp. 2 (oven-dry basis).

Bermudagrass	**IVTDMD**	**CP**	**NDF**	**ADF**	**HEMI**	**CELL**	**Lignin**
	g kg^{-1}						
Cultivar:							
Coastal	614[‡]	148	755	371	386	316	56
Tifton 44	621	145	769	363	408	313	52
Harvest:							
July	681[§]	194	752	355	397	305	49
August	554	100	773	380	396	323	59
SE	9	5	3	5	6	4	3
Significance (*P*):							
Cultivar (CL)	0.43	0.61	<0.01	0.11	<0.01	0.40	0.18
Harvest (H)	<0.01	<0.01	<0.01	<0.01	0.86	<0.01	<0.01
CL × H	0.01	0.06	0.37	0.37	0.86	0.73	0.25

[†] CP = crude protein; NDF = neutral detergent fiber; ADF = acid detergent fiber; HEMI = hemicellulose; CELL = cellulose.

[‡] Each value is the mean of two harvests and three animals (*n* = 6).

[§] Each value is the mean of two cultivars and three animals (*n* = 6).

Composition of the hays showed that CB and T44 did not differ in IVTDMD and CP (Table 4), which is consistent with the observed steer intake and DM digestion (Table 3). Neutral detergent fiber and constituent hemicellulose were greater in T44 than in CB, whereas cellulose and lignin concentrations did not differ. Digestible intake, a product of DM intake and digestion for the variable of interest, was greater for CB in DM ($P = 0.08$), ADF ($P = 0.09$), and cellulose ($P = 0.08$).

The influence of harvest was large as steers consumed less ($P = 0.01$) and digested less of the DM and the fiber fractions of the August, compared with the July hays ($P = < 0.01$; Table 3). A significant cultivar × harvest interaction occurred only for ADF digestion, which was attributed to a proportionally larger difference in favor of T44 in the July harvest than noted for T44 in the August harvest (data not shown).

Hays harvested in August had lesser IVTDMD and CP and greater NDF and constituent fiber fractions (Table 4), except for hemicellulose, which was similar for both harvests. A significant cultivar × harvest interaction was noted for IVTDMD ($P = 0.01$), which was attributed to a change in rank from the July harvest (CB: IVTDMD = 662 g kg^{-1}; T44: IVTDMD = 701 g kg^{-1}) to the August harvest (CB; IVTDMD = 566 g kg^{-1}; T44: IVTDMD = 542 g kg^{-1}). As expected, the composition data generally support the observed steer DM intake and digestion. Digestible intake of DM and the fiber fractions were also greater for July- than for August-harvested hays ($P < 0.01$).

The large difference in both the nutritive value of the hay and animal responses between the July and August harvest is attributed primarily to the more favorable moisture status during the August regrowth (229 mm) compared with July (118 mm). This resulted in more robust forage growth in August and a taller sward which contributed more stem material to the hay crop, consequently, lowering nutritive value and quality (Buxton and Fales, 1994; Coleman et al., 2004). The general lack of interaction (cultivar × harvest) indicates that both cultivars were influenced similarly.

Diet Characteristics

Masticate collected of offered hays permitted characterization of the ingested diet. The whole masticate showed that saliva incorporation was not different between cultivars (DM = 178 g kg^{-1}; Table 5), but particle size differed with T44 particles larger and indicates that steers may have chewed the hay differently to arrive at a common saliva concentration, or the hays of the two cultivars may have fractured differentially. Both the IVTDMD and the NDF of the masticate were greater for T44 than CB, and both

IVTDMD and NDF were altered by harvest with IVTDMD lower and NDF greater in the August hay (Table 5). The cultivar × harvest interaction for CP resulted from the disproportionate decline between cultivars for the July and August harvests (CB declined from 188–88 g kg^{-1} and T44 from 183–95 g kg^{-1}). Because particle size is associated with intake regulation (Fisher et al., 1987) through particle-size reduction and rate of escape from the rumen (Kennedy and Doyle, 1993) and because small and large particles from leaves and stems have different retention times (Mertens, 1993), the masticate DM was separated into particle sizes. Recombining the particle DM into particle-size classes showed no difference between cultivars in the proportion of the DM composing the medium particle-size class. However, T44 contained a greater proportion of large particles (P = 0.09) and a lesser proportion of small particles (P = 0.02). Concentrations of IVTDMD, CP, and NDF of the three particle-size classes were determined and are generally reflected in the whole masticate. Consequently, these data are not reported.

Table 5. Dry matter (DM), particle size (PS), and nutritive value[†] of whole masticate and particle-size classes of Coastal and Tifton 44 bermudagrass hays harvested in July and August and fed to steers in Exp. 2 (oven-dry basis).

	Whole masticate					Particle-size classes[‡]		
Bermudagrass	DM	PS	IVTDMD	CP	NDF	Large	Medium	Small
	g kg^{-1}	mm		g kg^{-1}			%	
Cultivar:								
Coastal	179[§]	1.17	674	13.8	710	26.4	62.3	11.3
Tifton 44	176	1.26	700	13.9	737	30.3	60.5	9.2
Harvest:								
July	170[¶]	1.21	764	186	712	29.3	60.6	10.1
August	185	1.22	610	91	734	27.4	62.2	10.4
SE	5	0.06	6	2	5	3	3	0.9
Significance (P):								
Cultivar (CL)	0.47	0.05	<0.01	0.72	<0.01	0.09	0.28	0.02
Harvest (H)	<0.01	0.86	<0.01	<0.01	<0.01	0.40	0.35	0.69
CL × H	0.14	0.88	0.63	0.03	0.57	0.42	0.11	0.19

[†] IVTDMD = in vitro true dry matter disappearance; CP = crude protein; NDF = neutral detergent fiber.

[‡] Proportion of dry matter in large (≥1.7 mm), medium (<1.7 and ≥0.50 mm) and small (<0.50 mm) particles.

[§] Each value is the mean of two harvest dates and four animals (n = 8).

[¶] Each value is the mean of two cultivars and four animals (n = 8).

The influence of rainfall (harvest) altered the amount of saliva incorporated with less incorporation (greater DM) in the August-harvested hays (Table 5). Hays from the two harvests did not differ in how they were masticated, as indicated by particle-size, but the August grown hay receiving greater rainfall, had reduced nutritive value, and is consistent with resulting animal responses (Table 3). These results are consistent with the literature, which shows that favorable moisture status (August growth) promotes growth with more carbon diverted to cell wall formation, whereas water stress (July growth) reduces growth with less carbon incorporated into cell walls but the carbon accumulates as soluble carbohydrates (Buxton and Casler, 1993; Buxton and Fales, 1994). The latter situation favors forage quality. Further, rainfall status showed little influence on how the hays fractionated on ingestion because no difference occurred in the proportion of the masticate DM contained in each particle-size class.

Experiment 3

The objective of this experiment was to compare variation in the quality of CB and T44 hays when harvested in June, July, and August with growth occurring under differing moisture and temperature conditions. The 5-wk regrowth harvested in June received 109 mm of rainfall (major events of 62 mm occurred in Week 3 of regrowth and 36 mm in Week 5) compared with 76 mm when harvested in July (major events of 14 mm occurred in Week 1 of regrowth, 34 mm in Week 4, and 28 mm in Week 5) and 197 mm when harvested in August (major events of 68 mm occurred in Week 1 of regrowth, 50 mm in Week 2, and 79 mm in Week 3). The respective mean maximum temperatures were 28, 34, and 31°C. Because a number of variables showed a significant cultivar × harvest interaction, the data are presented by cultivar and harvest. When no interaction is present, only the main effects are discussed.

Dry Matter Intake and Digestion

Daily DM intake was greater for CB compared with T44, but a significant cultivar × harvest interaction was present (Table 6 significant interaction LOF). This interaction was attributed to the large reduction in DM intake of T44 hay harvested in July compared with the small increase in intake noted for CB from June to July. Dry matter digestion was not different between cultivars, but a cultivar × harvest interaction occurred, as noted for DM intake, and was also associated with the July harvest in which DM digestion of T44 decreased more compared with CB (Table 6).

The July-harvested forage received less rainfall compared with the harvests made in June and August, but moisture stress was not evident in July because effective rain events occurred in Weeks 1, 4, and 5. Mean maximum temperature, however, was greater during the July growth (34°C) than during the June (28°C) and August (31°C) growths. Stress from high temperature is associated with reduced nonstructural carbohydrates and increased NDF concentrations, resulting in reduced DM digestion (Buxton and Fales, 1994). This is consistent with the results obtained in this study. Further, the significant cultivar × harvest interactions indicated that T44 was more sensitive to the adverse influence of temperature stress than CB.

Table 6. Dry matter intake, apparent dry matter digestion, digestion of fiber fractions and digestible intake of Coastal and Tifton 44 bermudagrass hays harvested in June, July, and August and fed to steers in Exp. 3 (oven-dry basis).

		Digestion[†]					Digestible intake[‡]				
Bermudagrass	Intake[‡]	DM	NDF	ADF	HEMI	CELL	DM	NDF	ADF	HEMI	CELL
	kg 100^{-1} kg	g kg^{-1}					kg 100^{-1} kg				
Coastal (CB):											
June	2.23[§]	605	603	552	645	658	1.35	0.98	0.41	0.57	0.40
July	2.30	584	588	532	635	637	1.34	1.00	0.43	0.57	0.42
August	2.20	568	562	505	615	604	1.25	0.90	0.40	0.50	0.38
Mean	2.24	586	584	530	632	633	1.31	0.96	0.41	0.55	0.40
Tifton 44 (T44):											
June	2.02	592	612	573	645	672	1.20	0.94	0.40	0.54	0.40
July	1.79	544	571	519	616	627	0.98	0.79	0.34	0.45	0.34
August	2.06	577	583	532	629	623	1.19	0.90	0.40	0.50	0.38
Mean	1.96	571	588	541	630	641	1.12	0.88	0.38	0.50	0.37
SE	0.11	12	12	15	10	13	0.07	0.05	0.02	0.03	0.02
Significance (*P*):											
Contrasts:											
CB vs. T44	<0.01	0.15	0.66	0.35	0.86	0.49	<0.01	0.07	0.13	0.05	0.15
Harvest:											
June	2.13	598	607	562	645	665	1.28	0.96	0.41	0.55	0.40
July	2.05	564	579	526	625	632	1.16	0.89	0.38	0.51	0.38
August	2.13	572	572	518	622	614	1.22	0.90	0.40	0.50	0.38
Linear	0.99	0.05	0.01	0.01	0.04	<0.01	0.38	0.24	0.66	0.08	0.47
LOF[¶]	0.40	0.06	0.32	0.27	0.37	0.53	0.15	0.43	0.37	0.48	0.54
Interaction:											
Linear	0.73	0.38	0.62	0.83	0.49	0.85	0.48	0.72	0.88	0.60	0.99
LOF	0.09	0.09	0.14	0.17	0.16	0.28	0.04	0.05	0.06	0.04	0.06

[†] DM = dry matter; NDF = neutral detergent fiber; ADF = acid detergent fiber; HEMI = hemicellulose; CELL = cellulose.

[‡] Body weight basis.

[§] Each value is the mean of four animals.

[¶] LOF = lack of fit (significance designates that the July harvest differs from either or both the June and August harvests).

The digestion of NDF and its constituent fiber fractions did not differ between cultivars, but the digestion of each fraction declined from the June to the August harvest (Table 6, significant linear component). For example, NDF digestion averaged 607 g kg^{-1} in June, 579 g kg^{-1} in July, and 572 g kg^{-1} in August. This is consistent with seasonal trends of reduced forage quality as the growing season progresses through late summer (Coleman et al., 2004).

Digestible intakes of DM, NDF, and its constituent fiber fractions interacted between cultivar and harvest. The interactions were due to only slight changes in digestible intakes among the three harvests for CB but a large reduction for T44 harvested in July (Table 6) and is consistent with DM intake and apparent DM digestion trends noted above.

The composition of the fed hays, except hemicellulose, showed significant cultivar × harvest interactions (Table 7). These resulted primarily from disproportionate changes between cultivars among harvests and not from a change in the rank order of the treatments. Presentation of the composition data by individual harvest and cultivar was retained to permit comparisons with DM intake and digestion (Table 6). Greater concentrations of IVTDMD and CP, but lesser concentrations of NDF and its constituent fiber fractions, occurred for CB compared with T44. The exception was lignin, which did not differ between cultivars (Table 7).

The different rainfall and temperature environments for the three regrowths altered IVTDMD, CP and NDF, and all fiber constituents. As noted for animal responses, differences were mainly associated with variable rainfall and high growing temperatures (mean maximum temperature >30°C), which occurred for the July and August harvest and which showed least IVTDMD and CP and greatest concentrations of NDF (Table 7) and were consistent with reduced nutritive value of forage at increasing air temperature (Buxton and Casler, 1993; Buxton and Fales, 1994; Coleman et al., 2004; DaSilva et al., 1987).

Diet Characteristics

The difference between the fed-hay IVTDMD, CP, and NDF and ort concentrations indicates that some selective feeding may have occurred (Table 7). Generally, selective feeding involves animal preference for the leaf fraction, which results in lesser concentrations in the orts of IVTDMD and CP and greater concentrations of NDF. With bermudagrass, however, the NDF concentrations may not be indicative because NDF concentrations of leaves and stems are frequently not different (Fisher et al., 1991). This is contrary to most warm-season grasses. At early head emergence (4- to 5-wk regrowth of bermudagrass), stems generally have greater NDF concentrations compared with leaves (Griffin and Jung, 1983). The "difference" (ort composition minus "as fed" composition) values for IVTDMD and CP showed the expected response for selective consumption for CB and were different from T44 but not altered by harvest (Table 7). A cultivar × harvest interaction occurred for IVTDMD and was attributed to the July harvest for T44 in which the difference value (−57) was greater than reported for either the June or August harvest and of the magnitude noted for CB.

Evaluation of the animal's diet, using collected masticates, showed cultivars to differ for all variables analyzed (Table 8). Cultivar and harvest interacted for masticate DM and this was attributed to a gradual decrease of DM in CB masticate (increase in saliva incorporation) because harvest occurred later in the summer but an increase in DM (reduced

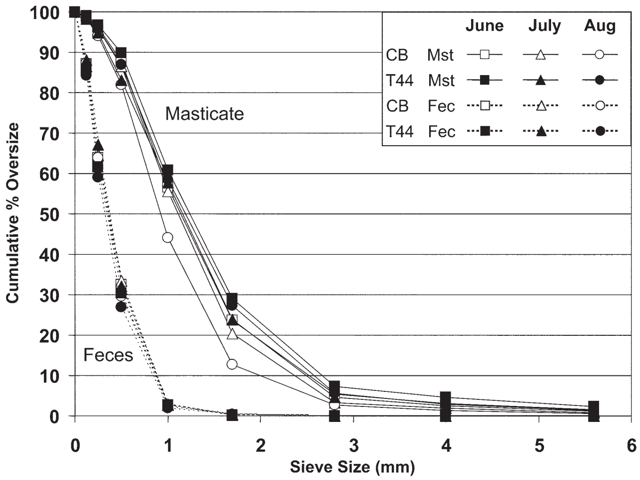

Figure 1. Dry matter cumulative percent oversize of particles from masticate (Mst) and feces (Fec) from Coastal (CB) and Tifton 44 (T44) hays harvested in June, July, and August.

Table 7. In vitro true dry matter disappearance (IVTDMD) and nutritive value† of Coastal and Tifton 44 bermudagrass hays harvested in June, July, and August and fed to steers in Exp. 3 (oven-dry basis).

Bermudagrass	IVTDMD		CP		NDF		ADF	HEMI	CELL	Lignin
	AF‡	DF‡	AF	DF	AF	DF				
	g kg^{-1}									
Coastal (CB):										
June	682§	–57	144	–5	725	–2	334	392	268	54
July	666	–52	131	–8	738	+1	350	388	283	57
August	674	–53	137	–10	731	+7	361	370	288	65
Mean	674	–54	137	–8	731	+2	348	383	280	59
Tifton 44 (T44):										
June	633	–33	126	+1	760	–4	349	411	288	53
July	615	–57	116	–1	771	–6	367	404	297	58
August	664	–27	129	+1	750	–2	363	387	296	60
Mean	638	–39	124	+1	760	–4	360	401	294	57
SE	7	8	3	3	3	3	2	3	2	1
Significance (*P*):										
Contrasts:										
CB vs. T44	<0.01	0.04	<0.01	0.01	<0.01	0.03	<0.01	<0.01	<0.01	0.07
Harvest:										
June	659	–45	135	–2	743	–4	341	402	278	54
July	641	–54	123	–5	754	–3	358	396	290	57
August	669	–39	133	–5	741	+2	362	379	292	62
Linear	0.20	0.48	0.42	0.41	0.44	0.08	<0.01	<0.01	<0.01	<0.01
LOF¶	<0.01	0.11	<0.01	0.68	<0.01	0.41	<0.01	<0.01	<0.01	0.52
Interaction:										
Linear	0.03	0.92	0.07	0.47	<0.01	0.22	<0.01	0.51	<0.01	0.06
LOF	0.09	0.05	0.57	0.99	0.20	0.80	0.03	0.64	0.96	0.04

†CP = crude protein; NDF = neutral detergent fiber; ADF = acid detergent fiber; HEMI = hemicellulose; CELL = cellulose.

‡AF = as fed and DF = difference value (concentrations in orts minus concentrations in the fed forage.).

§Each value is the mean of four animals.

¶LOF = lack of fit (significance designates that the July harvest differs from either or both the June and August harvests).

Table 8. Dry matter (DM), median particle size (PS), and nutritive value† of whole masticate and particle-size classes of Coastal and Tifton 44 bermudagrass hays harvested in June, July, and August and fed to steers in Exp. 3 (dry matter basis).

	Whole masticate					Particle-size classes‡		
Bermudagrass	DM	PS	IVTDMD	CP	NDF	Large	Medium	Small
	g kg^{-1}	mm	———— g kg^{-1} ————			———— % ————		
Coastal (CB):								
June	200§	1.13	665	138	655	24.5	63.2	12.3
July	184	1.08	672	125	675	20.3	66.2	13.5
August	175	0.93	685	134	675	12.8	69.2	18.1
Mean	186	1.05	674	132	668	19.2	66.2	14.6
Tifton 44 (T44):								
June	177	1.24	641	123	689	29.1	60.6	10.3
July	167	1.14	630	115	701	24.8	61.7	13.6
August	180	1.14	669	127	707	28.9	59.2	12.0
Mean	175	1.17	647	122	699	27.6	60.5	11.9
SE	6	0.06	6	3	7	4	3	1.0
Significance (*P*):								
Contrasts:								
CB vs. T44	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Harvest:								
June	189	1.19	653	130	672	26.8	61.9	11.3
July	175	1.11	651	120	688	22.5	64.0	13.5
August	178	1.03	677	130	691	20.8	64.2	15.0
Linear	0.03	<0.01	<0.01	0.95	<0.01	0.03	0.28	<0.01
LOF¶	0.05	0.98	0.01	<0.01	0.28	0.58	0.61	0.59
Interactions:								
Linear	<0.01	0.30	0.52	0.08	0.88	0.04	0.08	0.02
LOF	0.31	0.22	0.06	0.79	0.53	0.21	0.62	<0.01

†IVTDMD = in vitro true dry matter disappearance; CP = crude protein; NDF = neutral detergent fiber.

‡Proportion of masticate dry matter as Large (≥1.7 mm), Medium (<1.7 and ≥0.50 mm), and Small (<0.50 mm) particles.

§Each value is the mean of six steers.

¶LOF = lack of fit (significance designates that the July harvest differs from either or both the June and August harvests).

saliva incorporation) for T44 in August-harvested hay. This, along with the differences noted for whole masticate particles, indicates that CB and T44 were being processed relatively differently. Particles from the sieved masticate showed variation among the hays across sieve size when expressed as cumulative percent oversize (Fig. 1). These differences, however, were not present in the distribution of particle sizes of fecal DM. Combining the masticate DM into particle-size classes showed that the hays were processed differently because the DM composed of large particles was greater for T44 but a lesser proportion of medium and small particles (Table 8). The influence of growing conditions was evident with harvests being different, showing a linear decrease for large particles and linear increase for small particles. However, changes between cultivars among harvests resulted in cultivar × harvests interactions for all three particle sizes. These were attributed to differences that occurred in hay harvested after the July regrowth period.

The whole masticate IVTDMD, CP, and NDF differed between cultivars with CB greater in IVTDMD and CP but lesser in NDF. This is consistent with greater DM intake noted for CB (Table 6). All three variables also varied by harvest and cultivar with IVTDMD and CP showing different relative changes especially in the July harvest for T44 and CB, while NDF concentrations increased from June to August. The IVTDMD, CP, and NDF concentrations of each particle-size class were determined and reflected the same changes noted for the whole masticate and are consequently not reported.

Experiment 4

The objective of this experiment was to compare masticate characteristics of CB with T44 and T85 when steers are offered hay harvested at 4-wk regrowth. Differences in masticate characteristics will warrant a subsequent intake and digestion study. Apparent relationships have been noted between particle size characteristics of the masticate DM of the grazing animal and forage quality (Burns and Sollenberger, 2002). For example, daily gains of steers grazing C_4 and C_3 grass pastures were positively associated with the proportion of the masticate DM that was composed of large particles ($r = 0.94$) but negatively associated with medium

Table 9. Dry matter (DM), median particle size (PS), and nutritive value† of whole masticate and particle-size classes of Coastal, Tifton 44, and Tifton 85 bermudagrass hays fed to steers in Exp. 4 (dry matter basis).

						Particle-size classes‡											
	Whole masticate					Large				Medium				Small			
Bermudagrass	DM	PS	IVD	CP	NDF	Prop§	IVD	CP	NDF	Prop.	IVD	CP	NDF	Prop.	IVD	CP	NDF
	g kg^{-1}	mm	—— g kg^{-1} ——			%	—— g kg^{-1} ——			%	—— g kg^{-1} ——			%	—— g kg^{-1} ——		
Cultivar:																	
Coastal (CB)	183¶	1.09	688	73	658	20.2	658	58	661	66.7	681	74	666	13.2	741	97	614
Tifton 44 (T44)	175	1.19	751	144	652	24.8	728	123	671	64.2	748	146	658	11.0	821	180	580
Tifton 85 (T85)	181	1.62	777	139	664	45.8	738	117	686	45.5	802	153	659	8.8	843	176	585
SE	15	0.09	6	1	7	3	6	2	5	2	6	2	6	1.2	9	2	15
Significance (*P*):	0.13	<0.01	<0.01	<0.01	0.04	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	0.27	<0.01	<0.01	<0.01	<0.01
Cultivars:																	
CB vs. (T44+T85)	0.15	<0.01	<0.01	<0.01	0.94	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	0.12	<0.01	<0.01	<0.01	<0.01
T44 vs. T85	0.14	<0.01	<0.01	0.01	0.02	<0.01	0.15	0.05	0.01	<0.01	<0.01	0.02	0.96	<0.01	<0.01	0.08	0.30

†IVD = IVTDMD = in vitro true dry matter disappearance; CP = crude protein; NDF = neutral detergent fiber.

‡Large = ≥1.7 mm; Medium <1.7 and ≥0.50 mm; Small = <0.50 mm.

§Prop. = proportion of masticate dry matter.

¶Each value is the mean of six animals.

($r = -0.89$) and small particles ($r = -0.95$). These relationships indicate that particle breakdown during mastication is reflected in subsequent rumination and nutrient conversion. To examine the relationship between masticate characteristics and associated animal response in hay, the masticate IVTDMD, CP, and NDF concentrations from Exp. 2 and 3 and the associated animal responses from each hay were correlated. Masticate IVTDMD, CP, and NDF were generally significantly associated with steer DM intake ($r = 0.81$, $P < 0.01$; $r = 0.86$; $P < 0.01$, and $r = -0.55$; $P = 0.10$, respectively), digestion ($r = 0.78$, $P < 0.01$; $r = 0.82$, $P < 0.01$; $r = -0.27$, $P = 0.45$, respectively), and digestible DM intake ($r = 0.72$, $P = 0.02$; $r = 0.81$, $P < 0.01$; $r = -0.64$, $P = 0.05$, respectively). The exception was the relationship between DM digestion and NDF concentration of masticate. Although the correlation was negative, as expected, variation in NDF relative to the associated estimate of digestion (IVTDMD) reduced the magnitude of the correlation. These relationships, however, generally support the value of using masticate characteristics to initially assess the quality potential among cultivars.

The incorporation of saliva by steers into the three hays did not differ, as noted by whole-masticate DM concentrations, but particle size did (Table 9). The smallest particles occurred for CB and largest for T85 with T44 intermediate. Examining the distribution of the masticate DM as cumulative percent oversize showed distributions for CB and T44 similar to that noted in Exp. 3, but distribution for T85 was markedly different (Fig. 2). Because of particle size differences, relative to animal DM intake and digestion (Fisher et al., 1987), the particles were combined into particle-size classes (Table 9). The results showed CB to have the least proportions of large particles and the greatest proportion of medium and small particles. On the other hand, T85 had the greatest proportion of large particles and the least of medium and small particle with T44 intermediate.

Because particles have different composition (Chesson, 1993) and their degradation is related to rate of passage, the whole-masticate and constituent particle sizes were analyzed for IVTDMD, CP, and NDF. Whole masticate DM of CB analyzed least in IVTDMD and CP, whereas T85 was greatest in IVTDMD with T44 intermediate. This indicates that T85 would favor both DM intake and digestion over CB or T44. Greater NDF concentration, usually associated with reduced DM intake and digestion, was noted for T85 with T44 less, but not different from CB. Further, because the nutritive value of particles affect animal utilization of DM through nutrient concentration and rate of release (Chesson, 1993), IVTDMD, CP, and NDF concentrations of each particle-size class were determined. Both IVTDMD and CP were least for CB in all three masticate particle-size classes. On the other hand, T85 had greatest IVTDMD but was not different from T44 for large particles and greatest IVTDMD and

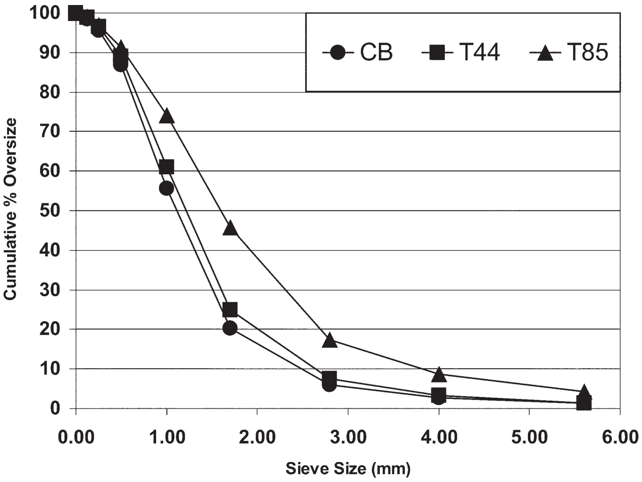

Figure 2. Dry matter cumulative percent oversize of particles from masticates of Coastal (CB), Tifton 44 (T44), and Tifton 85 (T85) bermudagrass hays.

CP for medium particles and greatest IVTDMD for small particles. The relatively high NDF concentrations for T85 in large particles with greatest IVTDMD indicate a relatively digestible fiber. No differences were noted in NDF among cultivars for medium particles, whereas CB was greatest in NDF in the small particles.

The greatest IVTDMD in the T85 whole-masticate DM and in all three of its particle-size classes indicate that T85 would favor in vivo DM intake, DM digestion, and digestible DM intake over CB and perhaps T44. The high proportion of DM present as large particles in the masticate of T85 (45.5%), however, may not favor DM intake. These differences among the three cultivars warrant further evaluation regarding their influence on subsequent animal daily DM intake and digestion.

Sheep Experiment

Sheep were used to compare the quality of CB, T44, and T85. The objectives were to determine (i) if the masticate characteristics observed among the three cultivars in Exp. 4 would be reflected in animal DM intake and apparent digestion and (ii) if differences found among cultivars were of sufficient magnitude to consider T85 as an alternative to CB or T44.

Experiment 5

A 4-wk regrowth of CB, T44, and T85 was harvested in July in two consecutive years. In the first year (Year 1), forage regrowth received 86 mm of rainfall (major events were 20 mm in Week 2 of regrowth, 17 mm in Week 3, and 39 mm in Week 4) with a mean maximum temperature of 32°C. In the second year (Year 2), forage regrowth received only 37 mm of rainfall (the major event was 20 mm in Week 2 of regrowth) with a mean maximum temperature of 29°C. Each year's harvest was evaluated in separate trials using different animals and was conducted the winter following the summer of harvest.

Year 1

Dry matter intake was greatest for CB compared with the mean of T44 and T85, and the latter two did not differ (Table 10). The apparent digestion of DM was least for CB and greatest for T85 with T44 intermediate. This is an agreement with the masticate data from Exp. 4 (Table 9). The digestion of NDF and its constituent fiber fractions was least for CB and greatest for T85 with T44 intermediate. The greater digestion of NDF for T85 explains, in part, the masticate anomaly in Exp. 4 of both greatest IVTDMD and NDF for T85 compared with CB or T44 and supports the finding by Mandebvu et al. (1999a, 1999b) of different cell wall chemistry between T85 and CB.

The IVTDMD and CP concentrations were least and NDF, HEMI, and Lignin concentrations greatest for CB compared with the mean of T44 and T85 (Table 11). Further, T85 had the greatest IVTDMD, ADF, and cellulose concentrations compared with T44. The greatest IVTDMD for T85 and least for CB is consistent with

Table 10. Dry matter intake, digestion, and digestible intakes of Coastal, Tifton 44, and Tifton 85 bermudagrass hays fed to sheep in Exp. 5 (oven-dry basis).

		Digestion[†]					Digestible intake[†]				
Cultivar	Intake[‡]	DM	NDF	ADF	HEMI	CELL	DM	NDF	ADF	HEMI	CELL
	$\text{kg } 100^{-1}\text{ kg}$	g kg^{-1}					$\text{kg } 100^{-1}\text{ kg}$				
Year 1:											
Coastal (CB)	2.05[§]	573	584	560	607	632	1.17	0.88	0.41	0.47	0.38
Tifton 44 (T44)	1.70	609	641	627	656	675	1.03	0.79	0.40	0.39	0.36
Tifton 85 (T85)	1.71	666	703	695	711	755	1.14	0.87	0.45	0.42	0.42
SE	0.14	9	11	11	10	10	0.08	0.06	0.03	0.03	0.03
Significance (*P*):	0.15	<0.01	<0.01	<0.01	<0.01	<0.01	0.40	0.46	0.43	0.16	0.24
CB vs. (T44 + T85)	0.06	<0.01	<0.01	<0.01	<0.01	<0.01	0.36	0.44	0.75	0.08	0.80
T44 vs. T85	0.96	<0.01	<0.01	<0.01	<0.01	<0.01	0.32	0.33	0.22	0.50	0.10
Year 2:											
Coastal	2.57	637	630	609	651	652	1.63	1.11	0.54	0.58	0.47
Tifton 44	2.62	696	697	694	700	730	1.82	1.23	0.61	0.62	0.54
Tifton 85	2.65	705	718	716	720	757	1.86	1.28	0.65	0.62	0.58
SE	0.13	13	14	15	13	15	0.08	0.06	0.03	0.03	0.03
Significance (*P*):	0.77	<0.01	<0.01	<0.01	<0.01	<0.01	0.08	0.10	0.02	0.35	<0.01
CB vs. (T44 + T85)	0.52	<0.01	<0.01	<0.01	<0.01	<0.01	0.03	0.04	0.01	0.16	<0.01
T44 vs. T85	0.79	0.59	0.28	0.28	0.28	0.17	0.68	0.52	0.23	0.99	0.14

[†] DM = dry matter; CP = crude protein; NDF = neutral detergent fiber; ADF = acid detergent fiber; HEMI = hemicellulose; CELL = cellulose.

[‡] Body weight basis.

[§] Each value is the mean of six animals.

the apparent DM digestion obtained for sheep (Table 10). Some selective consumption was evident as noted by the difference (ort composition minus as fed composition) values with lower concentrations of IVTDMD and CP in the orts but increased concentrations of NDF (Table 11). No difference was noted in selectivity between CB and the mean of T44 and T85 for IVTDMD and NDF, but the difference value was least for CB. The difference values were consistently greater, however, for T85 compared with T44 for all three variables, indicating that animals were able to more effectively select material with greater nutritive value when consuming T85 (Table 11).

Digestible intakes were generally not different among the three cultivars and attributed mainly to the greater DM intake of CB, which off set, in part, the greater digestion of DM and constituent fiber fractions noted for T44 and T85 (Table 10).

Year 2

Dry matter intake of the three cultivars did not differ, whereas apparent DM digestion was least for CB and greatest for T85 and not different from T44. Similarly, the digestion of NDF and constituent fiber fractions were least for CB and greatest for T85 and not different from T44. The lack of difference between T85 and T44 for these variables, as noted in Year 1, is in part, due to apparently greater variation among animals as indicated by the larger SEs reported in Year 2 vs. Year 1. Such variation is attributed to the fact that different animals were used in the Year 1 and Year 2 trials and that the hays produced in Year 1 were of lower quality (both reduced intake and apparent DM digestion) than in Year 2. Although both hays were grown for the same interval each year, the growth in Year 1 had an adequate water supply, resulting in more robust growth of each cultivar compared with Year 2. Further, hays in Year 1 were produced with greater mean maximum air temperature than in Year 2 (32 vs. 29°C). The presence of adequate moisture for good growth and the influence of high air temperatures are associated with reduced nutritive value and reduced forage quality (Buxton and Casler, 1993; Buxton and Fales, 1994; DaSilva et al., 1987) as reported in this study.

As noted in Year 1, the IVTDMD and CP concentrations of the fed hays were least and NDF and constituent fiber fractions (except cellulose) greatest for CB (Table 11). Greatest IVTDMD was noted for T85, but CP and NDF concentrations were not different between T85 and T44. Tifton 85 had greatest concentrations of ADF and cellulose but least hemicellulose and lignin compared with T44. Selective consumption, as noted in Year 1, is again evident by the difference values (Table 11) and occurred for all three cultivars, but in Year 2, the greatest selection occurred for CB (larger difference values) compared with the mean of T44 and T85. On the other hand, selective consumption of T85 vs. T44 is evident since difference values were greatest in all cases for T85 but only significant for CP and NDF.

Table 11. In vitro dry matter disappearance (IVTDMD) and nutritive value[†] of Coastal, Tifton 44, and Tifton 85 bermudagrass hays fed to sheep in Exp. 5 (oven-dry basis).

	IVTDMD		CP		NDF					
Cultivar	AF[‡]	DF[‡]	AF	DF	AF	DF	ADF	HEMI	CELL	Lignin
	g kg^{-1}									
Year 1:										
Coastal (CB)	593[§]	–54	77	–7	741	+17	361	380	295	56
Tifton 44 (T44)	685	–33	153	–12	728	+13	373	355	311	54
Tifton 85 (T85)	734	–98	158	–32	726	+28	382	344	332	45
SE	2	7	2	3	1	3	1	1	1	1
Significance (*P*):	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
CB vs. (T44 + T85)	<0.01	0.21	<0.01	<0.01	<0.01	0.35	<0.01	<0.01	<0.01	<0.01
T44 vs. T85	<0.01	<0.01	0.07	<0.01	0.16	<0.01	<0.01	<0.01	<0.01	<0.01
Year 2:										
Coastal (CB)	690	–62	154	–31	693	+29	347	346	283	55
Tifton 44	709	–23	164	–9	676	+7	335	341	282	51
Tifton 85	744	–45	160	–22	677	+26	349	328	294	47
SE	4	9	1	5	1	4	1	2	2	1
Significance (*P*):	<0.01	0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
CB vs. (T44 + T85)	<0.01	0.01	<0.01	0.01	<0.01	0.02	<0.01	<0.01	0.02	<0.01
T44 vs. T85	<0.01	0.06	0.07	0.04	0.67	<0.01	<0.01	<0.01	<0.01	<0.01

[†] CP = crude protein; NDF = neutral detergent fiber; ADF = acid detergent fiber; HEMI = hemicellulose; CELL = cellulose.

[‡] AF = as fed and DF = difference values (concentrations in orts minus concentrations in the fed forage).

[§] Each value is the mean of six sheep.

Digestible intakes were least for CB compared with the mean of T44 and T85, whereas T44 and T85 did not differ (Table 10). This is different than noted in Year 1 and can be attributed primarily to no difference among cultivars in DM intake, thereby allowing the expression of greater digestion of all fractions for T44 and T85. The latter was noted in both years.

General

In the comparisons between CB and T44 (Exp. 1, 2, 3, and 4), which involved multiple harvests, DM intake (Exp. 1, 2, and 3) was significantly greater for CB only in Exp. 1. The relatively high daily consumption of CB, in spite of generally lower nutritive value at various maturities, is consistent with the literature in comparisons with other bermudagrass cultivars (Mandebvu et al., 1999a) or other warm-season grasses (Burns et al., 1985; Arthington and Brown, 2005). Comparisons between harvests (Exp. 2) were consistent because DM intake did not differ between cultivars, but DM digestion and digestible DM intake was greater for July- vs. August-harvested hays. In comparisons among harvests (Exp. 3), however, the two cultivars interacted with harvests. This was attributed mainly to the disproportional changes between CB and T44 from the July to the August harvest. This type of response was also reported by Adeli et al. (2005) for ‘Alicia’ bermudagrass and by Henderson and Robinson (1982) when comparing several warm-season grasses including bermudagrass. Upon examining maturity and harvest date influences on bermudagrass, there is general agreement in the literature that nutritive value and hence quality declines with increased maturity and varies widely among harvest dates with forage of similar maturity (Faix et al., 1981; Monson and Burton, 1982; Holt and Conrad, 1986; Hill et al., 1993; Mandebvu, 1998, 1999a, 1999b; Arthington and Brown, 2005). These changes, however, were cultivar specific (Jolliff et al., 1979; Monson and Burton, 1982; Holt and Conrad, 1986; Mandebvu et al., 1999a, 1999b) and consistent with the differences reported for CB and T44 in this study showing different responses among the hays produced during June, July, and August, even though regrowth interval was the same for each.

Comparisons of CB, T44, and T85 (Exp. 5) showed CB to have the least digestible DM, NDF, and constituent fiber fraction of the three, whereas T85 was greatest. The greater concentration in IVTDMD of the fed T85 hay vs. CB (difference of 141 g kg^{-1} in Year 1 and 54 g kg^{-1} in Year 2) compared with only slightly (but significant) lesser concentrations of NDF (difference of 15 g kg^{-1} in Year 1 and 16 g kg^{-1} in Year 2) is also consistent with the literature (Mandebvu et al., 1998, 1999a, 1999b). Characterization of the NDF fraction in CB and T85 by Mandebvu et al. (1999a, 1999b) showed that CB had a greater concentration of ether-linked ferulic acid. Ferulic acid has been proposed by Jung and Allen (1995) to cross-link lignin with the cell wall polysaccharides making them less available for microbial breakdown. This phenomenon has been associated with the reduced digestion of the DM and fiber fractions of CB compared with T85 (Mandebvu et al., 1999a, 1999b).

Digestible intake of DM, NDF, and constituent fiber fractions reflected the greater DM intake for CB in Year 1 compared with the greater digestion of DM and of the fiber for T85 in Year 2. Year differences were attributed mainly to greater air temperature during growth in Year 1, resulting in reduced DM intake.

Examination of the whole-masticate in experiments comparing CB and T44 showed that T44 had greater median particle size and greater IVTDMD. Further, T44 had a greater proportion of its DM as large particles and the least as small particles and greater IVTDMD of all particles. Comparing the whole masticates of CB, T44, and T85 showed the masticate of T85 had the largest median particle size with the greatest IVTDMD and CB the least median particle size with the least IVTDMD. This is consistent with Hill et al. (1993) in a similar comparison. Examining the particle-size classes of masticates showed T85 to have the greatest proportion of large particles and the least of small particles with CB having the converse and T44 intermediate. This differential mastication of the tissue between CB and T85 on ingestion supports the suggestion by Mandebvu et al. (1999a) that the chemical nature of T85 cell walls have been altered in its development. Correlation analysis showed the masticate characteristics of hays were well associated with animal DM intake, digestion, and digestible intake and consistent with the relationship between masticate characteristics and performance of grazing animals (Burns and Sollenberger, 2002).

A meta analysis of the intake trials across animals species was used to examine overall least squares means. Sheep and cattle estimates of DM digestibility and intake on a body weight basis did not vary significantly. Cultivar effects were detected with the greatest estimated intake for CB (2.27 kg 100^{-1} kg) compared with intakes of 2.10 kg 100^{-1} kg for T85 and 2.03 kg 100^{-1} kg for T44. However, as was discussed previously, while the small particle size may support higher rates of passage and intakes, the overall digestibility of CB (596 g kg^{-1}) was found to be less than either T44 (612 g kg^{-1}) or T85 (661 g kg^{-1}). The digestibility of T85 was greater than either of the other cultivars and would support high intakes of digestible dry matter and performance. Detailed studies to examine further the extent to which changes in environmental factors alter cell wall chemistry among forage cultivars relative to particle-size breakdown, rumen fill, passage rate (retention time), and subsequent animal daily performance appear warranted. The animal response and masticate data obtained in this study do not support the replacement of CB with

T44 in production systems for the upper south. On the other hand, data support the replacement of CB with T85 and, where T85 is adapted, merits consideration.

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