'Coastal' and 'Tifton 44' Bermudagrass Availability on Animal and Pasture Productivity

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ABSTRACT

Hybrid cultivars of bermudagrass [*Cynodon dactylon* (L.) Pers.] are a major feed source for ruminants across the southeastern United States. This 4-yr experiment compared animal and pasture performance of 'Coastal' and 'Tifton 44' bermudagrasses over three canopy heights designated as short (5.6 cm), medium (10.1 cm), and tall (13.1 cm). The relationship of canopy height to ingestive mastication and canopy characteristics was also studied. Soil was a Cecil clay loam (clayey, Kaolinitic thermic Typic Hapludult). Pastures were continuously stocked using variable stocking to maintain the targeted canopy heights. Herbage mass (to soil surface) was similar between Coastal and Tifton 44 (T44) within each canopy height averaging 2.36, 4.08, and 5.25 Mg ha^{-1}. Steer average daily gain (ADG) was greater ($P = 0.09$) from T44 than Coastal (0.58 vs. 0.51 kg) but no differences were noted in pasture productivity. Increasing herbage mass linearly increased ($P < 0.01$) ADG (0.40–0.59 kg) but reduced ($P < 0.01$) stocking rate (16.1–11.2 steers ha^{-1}), which influenced animal days (1810–1079 d ha^{-1}), weight gain (1057–786 kg ha^{-1}), and effective feed units (6392–4452 kg ha^{-1}). Steer ADG increased ($P = 0.01$) from short to medium canopy height (0.40–0.64 kg) with little change between medium and tall canopy height (0.64–0.59 kg). Tifton 44 pasture is of greater quality than Coastal giving greater ADG but both were productive producing about 1100 kg of gain ha^{-1} when effectively managed and utilized.

Hybrid bermudagrass is the major perennial warm-season forage grown across the upper South (Burns et al., 2004). 'Coastal' bermudagrass is widely distributed across the Coastal Plain and into the Central Piedmont Region of North Carolina (Gross et al., 1966; Burns et al., 1984). Periodic low temperatures during the winter in the Piedmont, however, can cause severe stand thinning resulting in weedy-grass invasion and reduced summer production. The release of 'Tifton 44' bermudagrass (T44) provided a perennial hybrid with improved cold tolerance (Burton and Monson, 1978) and with good winter survival reported as far north as northern Illinois (Faix et al., 1981). When established in the Piedmont of North Carolina, T44 initiated spring growth earlier than Coastal and continued growth later in the summer (Rakes et al., 1988).

Generally, T44 has been shown to be equal to, or greater than Coastal in dry matter digestion when harvested as hay (Burns and Fisher, 2007) and provided greater animal daily gains when grazed (Utley et al., 1978). Improved quality in bermudagrass selections has been attributed, in part, to altered cell wall composition despite greater NDF concentrations (Mandebvu et al., 1999). Warm-season grasses have inherently greater NDF concentration than cool-season grasses (>700 g kg^{-1}), but the digestibility of the NDF in Coastal (486 g kg^{-1}) is considerably less than other warm-season grasses such as switchgrass (*Panicum virgatum* L.) (650 g kg^{-1}) or flaccidgrass (*Pennisetum flaccidum* Griseb.) (681 g kg^{-1}), with respective NDF concentrations of 731, 735, and 682 g kg^{-1} (Burns et al., 1985).

The productivity of pastures is partly dependent on the degree of utilization imposed by grazing management practices. Generally, as pasture utilization increases, animal daily gains as well as gain ha^{-1}, increases up to the point that animal daily dry matter intake becomes restricted (Mott and Lucas, 1952; Riewe et al., 1963; Blaser et al., 1981). Thereafter, animal production ha^{-1} may continue to increase until animal daily response is sufficiently reduced to result in reduced animal gain ha^{-1} (Mott, 1960), but even in a specific location the curve will be dependent on the forage species and cultivar. When considering the replacement of an established cultivar with an improved one, differing nutritive value, growth rate, and yield may alter the relationship between herbage mass and subsequent animal responses. This is the situation facing producers considering the establishment of a new bermudagrass pasture or even replacement of Coastal with T44 in the Mid-Atlantic Region. The objectives of this study were to compare steer daily gain and pasture productivity from Coastal and T44 bermudagrasses over a range of herbage mass and to relate ingestive behavior and pasture canopy characteristics to animal performance to establish the appropriate herbage-mass allowance to optimize gain animal^{-1} and gain ha^{-1}.

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Abbreviations: ADF, acid detergent fiber; ADG, average daily gain, CELL, cellulose; CP, crude protein; EFU, effective feed unit, HM, herbage mass; HEMI, hemicellulose; IVTOD, in vitro true organic matter digestion; LAI, leaf area index; LOF, lack of fit; M, medium; NDF, neutral detergent fiber; NIRS, near-infrared reflectance spectroscopy; OM, organic matter; S, short; T, tall; T44, Tifton 44 bermudagrass.

MATERIALS AND METHODS

The experiment was conducted for 5 yr consisting of a preliminary year (1993) followed by a 4-yr experiment at the North Carolina Agricultural Research Service Reedy Creek Road Field Laboratory located on the west edge of Raleigh, NC. The soil at the experimental site was a Cecil clay loam, typical of much of the Piedmont Region. Twelve pastures (0.24 ha each) were established vegetatively in late March 1991, to provide 12 paddocks for a randomized complete block design with two replicates. Certified Coastal and Tifton 44 bermudagrass sprigs were placed into a prepared seed bed in 51-cm rows. The plots were cultipacked immediately after sprigging and initially irrigated to aid establishment. The emerging stands were top dressed with granular ammonium nitrate at 67 kg N ha^{-1} in August and top growth clipped periodically to encourage stolon and rhizome development.

The year following establishment, (1992), forage was removed uniformly from the experimental area at approximately 4-wk intervals and conserved as hay. The grazing experiment was initiated in 1994 with excellent bermudagrass stands present.

Pastures

Pasture Management

Treatments consisted of Coastal and T44 each managed to maintain three canopy heights and subsequently three levels of herbage mass (HM) throughout the grazing season (six treatments). A canopy height target of 2 to 5 cm was considered as short (S), 10 to 13 cm as medium (M), and 15 to 20 cm as tall (T). Stocking was used to generate canopy characteristics representative of each HM treatment and mowing was not used to create the canopies. For example, the SHM treatment was stocked first based on the target canopy height. Initial stocking was dependent on environmental conditions and occurred 20 April in Year 1, 28 April in Year 2, 27 May in Year 3, and 4 May in Year 4. Stocking of the MHM and THM treatments occurred in that order as they attained their target height. Termination of grazing was based on reduced pasture growth rates in late summer. Bermudagrass growth in the Mid-Atlantic Region declines rapidly (approximately late August) as minimum temperatures fall below 16°C and when moisture is limiting. Consequently, grazing was terminated 9 September in Year 1, 22 August in Year 2, 2 September in Year 3, and 25 August in Year 4.

Because of the similarity between cultivars, canopy height was used as an index to maintain the appropriate spread in HM. Pastures were generally scored using random height measurements three times weekly by two independent observers. Variable stocking was used to maintain the designated HM with extra animals added or removed from the appropriate pasture treatment as needed.

Soil pH was maintained between 5.8 to 6.4 with P and K applied annually according to soil test. Nitrogen, as ammonium nitrate, was applied uniformly and at a high rate to all treatments. Nitrogen was applied at initial green-up (about 1 April) at 78 kg ha^{-1} and at 90 kg N ha^{-1} in the third week of May, last week of June, and first week of August totaling 347 kg ha^{-1} for the season (Thom et al., 1990).

Pasture Measurements

Herbage mass measurements were initiated each year by late June to early July after appropriate pasture canopy heights were obtained and were continued at 3- to 4-wk intervals during the trial. Eighty canopy and compressed heights measurements were obtained per pasture at each sampling time using a falling plate (Plexiglass) 0.5 m in diameter by walking in a serpentine pattern that covered the entire pasture. Regions within each pasture selected as representing close grazed, average grazed, and lax grazed were harvested and used for calibration of the 80 falling plate observations. After the canopy and compressed heights of the three selected sites were determined, the area (0.20 m^2) was clipped to the soil surface, the sample placed in a plastic bag, and transported on ice to the field laboratory. The dry matter concentration was determined by lyophilization and used to calculate actual HM dry matter harvested from each site. The HM was regressed on compressed canopy height to develop a calibration equation. An overall equation for the 4-yr trial was developed (r^2 among years ranged from 0.72 to 0.89) and used to predict HM for the trial having an $r^2 = 0.81$. Stepwise regression was used to test for modification of the equation by years and/or experimental treatments but the fit of the overall equation was not improved by adjusting either intercepts or slopes.

Detailed canopy characterization was conducted in August of Year 1 and July of Year 2 in concert with HM determinations. At this sampling six quadrats 0.2 m^2 were harvested to the soil surface from sites within each pasture of areas visually estimated to be representative of the pasture treatment. The samples were separated into bermudagrass and weeds (designated other). Twenty tillers were randomly selected from the bermudagrass component from each quadrat, placed between moist paper towels and onto ice, and immediately transported to the laboratory for leaf area measurements and specific leaf weight determinations. Leaves were quickly removed from each tiller, scanned on a leaf area meter (Delta-T Devises LTD, Burwell, Cambridge, UK), placed in a tray and green weight recorded, then dried at 75°C for 24 h and reweighed, giving dry weight (g) per square meter of leaf area or specific leaf weight (g m^2). The remainder of the bermudagrass tillers from each quadrat was separated into leaf, stem (includes sheath), dead and head fractions, and weighed. The leaf area of the whole sample was determined by dividing the total leaf weight by the leaf weight of the 20 tillers. Leaf area index (LAI) was determined by dividing the leaf area of the whole sample by the land area (0.2 m^2) sampled. All fractions (except the leaves from the 20 tillers) were lyophilized, weighed to constant weight, and each expressed as a proportion of the whole canopy on a freeze-dried basis. The samples were all ground through an Udy Mill (Udy Corp. Fort Collins, CO) to pass a 1-mm screen and stored in air-tight containers in a freezer (−16°C) for laboratory analysis.

Animal

Management

Grade Angus steers (*Bos taurus*) obtained through North Carolina graded spring feeder-calf sales served as the experimental animals. Steers were treated with prophylactics for internal parasites before the initiation of grazing and again in

July. Each year, at the beginning of grazing, a uniform set of steers were grouped by weight into uniform sets and a lighter and heavier steer paired and designated as Tester 1 and Tester 2 and the tester pair was then randomly assigned to each pasture. This equalized animal weight per pasture treatment and aided grazing management. All steers were sprayed to control flies at each weighing during the season (every 2 wk). Animals had free access to trace mineralized salt blocks, fresh water, and artificial shade within each pasture.

Weight and Body Condition

Unshrunk weights of the tester steers were obtained initially, averaging 277 kg (±30 kg) for the 4-yr experiment. All animals were weighed at 2-wk intervals on the same morning schedule for the duration of the trial. Body condition scores were assigned to each animal at the initiation of grazing, midsummer, and at termination of grazing. Animal body weights were used to determine daily performance and weight changes, and body condition scores were used to calculate EFU as an estimate of pasture productivity (Petersen and Lucas, 1968; Petersen, 1994).

Grazing Time

Estimates of time spent grazing each 24 h was determined for a 5-d period in mid-July to August in Year 1 and in mid July in Year 2 just before canopy characterization and masticate collection (see below). Data were obtained using a Vibracorder (Kienzle Apparaten, GmbH. Villingen/Schwartzwald, Germany) attached to a leather collar and fitted onto the neck of a tester steer. The Vibracorder was attached on one side of a large leather collar with a counterweight on the other side to prevent rotation of the collar. The leather collar was placed over the animal's neck behind the ears and the leading edge was fastened to a conventional leather halter. The Vibracorder was mounted such that it was vertical when the animal was grazing. This permitted a stylus attached to a pendulum to scribe on a waxed chart, with a 5-d capacity, when the animal was grazing (Stobbs, 1970). Because of the social instincts of cattle, only one animal required monitoring to obtain grazing time for the treatment (two to four steers per paddock). Further, because animals adjust quickly (~30 min) to the collar, the use of a tester is feasible and avoids the need for preconditioning of any extraneous animals to the specific treatment canopy. Grazing time during the 5-d collection period was summarized in 30-min increments initially and then totaled for early morning, midday, and for each of the five, 24-h periods.

Masticate Collection and Characterization

Seven Angus steers (average body weight >450 kg) fitted with esophageal cannula (Ellis et al., 1984) and maintained on Coastal bermudagrass before sampling were used for diet collection. Each collection was in concert with HM determination, canopy characterization, and grazing time determination. Masticate collections occurred by field replicate, with all pasture treatments within a replicate, sampled concurrently on 2 consecutive days. Masticate collections consisted of two sequential sampling days for two sampling times each year (July and August in Year 1 and in early and late July in Year 2). Six steers from the seven-steer pool were randomly assigned to treatments on Day 1 and Day 2. A constraint was that no pasture was sampled by the same steer on consecutive days. Masticate collection was initiated about 0600 h and was completed by about 0900 h. The masticate was collected by first removing the cannula, discarding the first 6 to 8 boli, then walking beside the animal with a plastic lined butterfly net and catching the subsequent extrusa. After adequate collection (about 20 min), including the retention of saliva, the sample was thoroughly mixed, placed in a plastic bag, sealed, flattened, and placed on a metal rack and submerged in liquid N (−195°C). The samples were subsequently stored in a freezer (−16°C) until lyophilized.

After lyophilization, the sample was split with approximately half used to analyze the nutritive value of the whole masticate and the other half for particle-size determination. Particle-size determination was achieved by dry sieving a 15-g sample through eight screens in a Fritsch vibrator system (Fritsch Analysette 3, Tekmar, Cincinnati, OH) set on 3000 oscillation min^{-1}. The nine particle sizes obtained were those retained on a 5.6, 4.0, 2.8, 1.7, 1.0, 0.5, 0.25 and 0.12.5-mm sieves and that which passed through the 0.125-mm sieve. Percentage of cumulative particle weight oversize was used to determine median and mean particle sizes (Fisher et al., 1988). Particles greater than 1.7 mm were classified as large, those <1.7 and ≥0.5 mm as medium, and particles that passed the 0.5-mm screen as small. The whole masticate and sieved fractions were ground in a cyclone mill (Udy Corp. Prod. no. 3010-014, Ft. Collins, CO) to pass a 1.0-mm screen and stored in a freezer (−16°C) until laboratory analysis. After laboratory analyses were completed, the data from the 2 consecutive days were averaged before statistical analyses.

Laboratory Analysis

All canopy and masticate samples were scanned in a near-infrared reflectance spectrophotometer (NIRS), and the H statistic (0.6) used to identify samples by spectra for laboratory analyses to develop NIRS prediction equations for all samples. In vitro true organic matter disappearance (IVTOD) 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) and subsequently extracted with NDF solution in a batch processor (Ankom Technology Corp., Fairpoint, NY). The calculation included adjustment for ash. Ruminal inoculum was obtained from a mature Hereford steer fed a mixed alfalfa (*Medicago sativa* L.) and orchardgrass (*Dactylis glomerata* L.) hay. Total N was determined by auto-analyzer (AOAC, 1990), and crude protein (CP) was estimated as 6.25 times total N.

Fiber fractions, consisting of neutral detergent fiber (NDF), acid detergent fiber (ADF), cellulose (CELL), and sulfuric acid lignin were estimated in a batch processor (Ankom Technology Corp., Fairport, NY) using reagents according to Van Soest and Robertson (1980). Hemicellulose (HEMI) was determined by difference (NDF − ADF). Laboratory values were used to develop NIRS calibration equations to predict values for each sample from the reflectance spectrum (Table 1).

Statistical Analysis

Variables were analyzed using PROC MIXED of SAS (SAS Institute, 2004) with replications and years as random effects and with years as a repeated measure. An exception was made for the interrelated variables of ADG, animal grazing days ha^{-1}, weight gain ha^{-1}, stocking rate, and EFU by using MANOVA within GLM to test these variables as a group with years as a repeated variable (SAS Institute, 2004). A trend analyses (three canopy height treatments) was conducted within the analysis of variance in which the canopy height sum of squares were partitioned between two contrasts. One contrast accounted for the proportion of the sum of squares explained by a linear response. The second contrast is the remainder of the sum of squares, or the quadratic component, which is more appropriately termed lack of fit (LOF), since there are only 2 df available. A significant LOF indicates a deviation from a simple linear fit with the M canopy height either greater or lesser than expected from a linear interpolation of the S and T canopy heights. Differences were considered significant with statistical test at $P \leq 0.10$.

RESULTS AND DISCUSSION

This study was conducted 5 yr; however, while climatic conditions during the spring of the initial year were favorable a drought developed and resulted in the termination of the formal grazing trail by 28 June (Table 2). Consequently, pastures were only grazed periodically as they reached their target heights and no animal response data are reported. This year was considered as a preliminary year to permit establishment of HM differentials and allow their influence on the canopy structure to develop. In Years 1 and 2 of the subsequent 4-yr trial, intensive measurements were obtained relative to both HM characterization and animal responses as detailed in the materials and methods. In Years 3 and 4, animal performance data were obtained as well as associated HM estimates to characterize the treatments. During the first 2 yr of the study, when intensive measurements were taken, the moisture status was variable but generally favorable through March in both years. In Year 1, however, below normal rainfall occurred in April, May, and June with normal or above rainfall in July and August. On the other hand, Year 2 rainfall was below normal in April, July, and August, with near normal rainfall in May followed by a very wet June. Rainfall was adequate in both years to maintain pastures in a growing state. Years 3 and 4 were generally favorable during the grazing season, although Year 3 started out with below normal rainfall through March. Mean air temperatures were generally near normal or above in all 4 yr of the trial, although several exceptions are noted in Years 1 and 3 (Table 2).

Herbage mass levels were controlled during this experiment in an attempt to maintain them similarly between Coastal and T44 and this was accomplished ($P = 0.19$), but overall the HM effect was strong ($P < 0.01$) with HM differing, as expected, among grazing HM levels (Table 3). Herbage mass increased linearly from the SHM to THM treatments and no cultivar × HM interaction occurred. The significant ($P = 0.08$) LOF is attributed to the lesser difference in the HM between the M and T treatments for T44 vs. Coastal (0.99 vs. 1.34 Mg ha^{-1}, respectively).

Steer Performance

Average daily gain was greater from T44 than from Coastal (0.58 vs. 0.51, respectively) (Table 3). Utley et al. (1978) also reported greater ADG from T44 (0.80 kg d^{-1}) compared with Coastal (0.67 kg d^{-1}). On the other hand, Utley et al. (1981) in a later study, and Greene et al. (1990) reported similar steer ADG between these cultivars. In the former case, steer season mean ADG was 0.70 kg, and in the latter case, 0.65 kg.

Increasing HM increased ADG from 0.39 kg d^{-1}, for the SHM to 0.65 kg d^{-1} for the MHM but declining for the THM level (0.59 kg), resulted in a significant LOF to linear (Table 3). Both cultivars were stocked, on average, similarly at 13.1 steers

Table 1. The number of samples and range for each forage and masticate constituent used for near-infrared reflectance spectrophotometry calibration, its standard error of calibration (SEC), and its standard error of cross validation (SECV).

				Calibration		Validation	
Item†	*n*	Range	Mean	SEC	R^2	SECV	R^2
		g kg^{-1}				g kg^{-1}	
Canopy							
OM	90	842–959	926	3.5	0.966	4.8	0.941
IVTOD	105	396–903	667	19.6	0.977	24.1	0.965
CP	102	71–268	142	3.0	0.997	5.2	0.989
NDF	100	561–794	681	13.0	0.938	19.2	0.863
ADF	103	208–430	323	10.5	0.959	13.0	0.937
CELL	101	190–360	275	7.4	0.963	9.3	0.940
Lignin	101	17–100	48	3.0	0.977	4.8	0.941
Masticate							
OM	111	698–959	887	4.9	0.987	6.0	0.981
IVTOD	114	608–921	789	15.4	0.945	20.7	0.901
CP	116	99–234	171	2.6	0.994	3.8	0.986
NDF	116	459–783	637	13.1	0.948	16.5	0.918

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

Table 2. Climatological data recorded approximately 5 km from the experimental site.†

	30 yr-mean		Departure from 30-yr mean									
			Preliminary		Year 1		Year 2		Year 3		Year 4	
Month	Rainfall	Temp.	Rainfall	Temp.	Rainfall	Temp.	Rainfall	Temp.	Rainfall	Temp.	Rainfall	Temp.
	mm	°C	mm	°C	mm	°C	mm	°C	mm	°C	mm	°C
January	87	3.8	26	2.5	2	–1.1	26	2.3	–9	1.4	100	3.3
February	93	5.6	–37	–0.7	–18	1.2	21	–0.6	–22	2.6	53	2.2
March	94	10.2	59	–1.4	54	1.0	–32	1.3	–9	2.4	90	–0.1
April	65	15.0	56	–1.2	–43	2.6	–32	1.1	54	–2.1	13	–0.1
May	98	19.4	–15	1.2	–27	–1.5	–1	1.1	–43	–1.7	–3	1.3
June	92	23.5	–84	1.0	–37	1.5	102	–0.3	4	–1.6	–6	1.7
July	101	25.6	–48	2.5	17	0.8	–18	1.3	63	0.8	21	0.8
August	100	25.1	–56	0.6	5	–0.7	–33	1.9	–75	–0.3	16	0.3
September	80	21.7	8	1.5	–30	–1.1	18	–0.3	–3	–0.1	9	2.0
October	72	15.6	2	–0.3	44	–0.4	156	1.8	10	–0.3	–2	0.6
November	75	10.7	–8	0.3	–42	1.5	42	–2.3	27	–2.2	–15	0.4
December	81	5.9	12	1.3	–49	2.9	34	–1.7	–12	–0.9	5	2.2

† Data recorded at the Raleigh–Durham International Airport and reported by the National Oceanic and Atmospheric Administration.

Table 3. Mean herbage mass and animal^{-1} and ha^{-1} performance from steers grazing Coastal and Tifton 44 bermudagrasses at three levels of herbage mass.†

Treatment	Herbage mass	ADG	Animal day	Weight gain	SR	EFU
	Mg ha^{-1}	kg	ha^{-1}	kg ha^{-1}	Steer ha^{-1}	kg ha^{-1}
Coastal (C)						
Short	2.43‡	0.42§	1750§	1110§	15.7§	6380§
Medium	4.11	0.56	1250	840	12.0	4840
Tall	5.45	0.54	1090	730	11.7	4350
Mean	4.00	0.51	1360	890	13.1	5190
Tifton 44 (T44)						
Short	2.29	0.36	1870	1010	16.6	6400
Medium	4.06	0.74	1270	1100	11.7	5500
Tall	5.05	0.64	1070	840	10.7	4550
Mean	3.80	0.58	1400	980	13.0	5480
Significance (*P*)						
Treatments	<0.01	<0.01	<0.01	0.04	<0.01	<0.01
C vs.T44	0.19	0.09	0.67	0.26	0.74	0.35
Herbage mass (HM)						
Linear	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
LOF	0.08	0.01	0.05	0.57	<0.01	0.45
Cultivar × HM						
Linear	0.48	0.14	0.54	0.30	0.18	0.82
LOF	0.48	0.10	0.87	0.14	0.84	0.40

† ADG = average daily gain; SR = stocking rate; EFU = effective feed unit.

‡ Each value is the mean of multiple harvest within years for two pasture replicates and 4 yr (n = 8).

§ Each value is the mean of two replicates and 4 yr (n = 8).

ha^{-1} (Table 3). As anticipated, a greater stocking rate was associated with the SHM level producing the least ADG but with greater numbers of animal days ha^{-1} and weight gain ha^{-1}. These results are consistent with the well-established general relationship between ADG and stocking rate as HM becomes limiting (Mott, 1960). Stocking rate was greatest at 16.2 steers ha^{-1} for the SHM but decreased appreciably to 11.9 steers ha^{-1} for the MHM with much less change at 11.2 steers ha^{-1} for the THM resulting in a significant LOF to linear (Table 3).

Once the targeted MHM and THM canopy heights were obtained, grazing resulted in similar areas that were taller or shorter than the target canopy height. In general, animals grazed both extremes in a manner described by Burns and Sollenberger (2002) as random grazing (see Fig. 4D, their paper), but especially in the THM, animals avoided much penetration below the surface 5 cm and into the mature, lower canopy. This boundary probably contributes appreciably to the similar ADG noted for steers between the MHM and the THM, since forage was never limiting.

Pasture Production

As determined by the treatments imposed, HM increased from the SHM to the THM (Table 3). Consequently, treatments differed in animal days ha^{-1}, weight gain ha^{-1}, stocking rate, and in EFU (kg ha^{-1}) (Table 3). These differences were not associated with cultivar as Coastal and T44 had similar animal day ha^{-1} (mean = 1380), weight gain (mean = 935 kg ha^{-1}), stocking rate (mean = 13.1 steers ha^{-1}), and EFU (mean = 5335 kg ha^{-1}), but differed among HM levels. The SHM produced greatest animal days ha^{-1}, which declined from the SHM to the THM (Table 3). However, the decline from SHM to MHM (550 d ha^{-1}) was greater compared with the decline from MHM to THM (180 d ha^{-1}), resulting in a significant LOF. This is reflected in, and consistent with, the change in stocking rate needed to maintain HM levels (Table 3). Greatest EFU production also occurred on the most intensively grazed treatment. This treatment required the greatest stocking rate to maintain the SHM canopy and subsequently had greatest utilization. As stocking rate was relaxed to permit greater HM, EFU declined linearly as utilization efficiency was reduced. Because calculation of EFU involves both pasture productivity and the quality of the animal's diet, the greatest EFU from the SHM indicate that although ADG declined on the shorter treatment the increased stocking rate compensated on a per-hectare basis to increase the EFU. Although pasture dry matter production was not determined as such, greater production from the SHM is consistent with Clapp et al. (1965), who reported 18.4% greater dry matter yield from season-long defoliation of Coastal bermudagrass from 5 to 1.9 cm vs. 15 to 7.6 cm. Further, they reported least dry matter yield when Coastal was defoliated from 10 to 7.6 cm.

In general, the SHM, regardless of cultivar, resulted in greatest forage utilization, and hence, greatest pasture production in terms of EFU. Animal daily gain, however, was reduced and attributed, in part, to reduced daily DM intake. On the other hand, the MHM supported maximum ADG but pasture productivity, as measured by EFU, was sacrificed due to lower forage utilization and probably reduced forage growth (Clapp et al., 1965). The weight gain obtained in this study averaged 935 kg ha^{-1} and was surprisingly similar to the 969 kg ha^{-1} reported by Greene et al. (1990), and both studies obtained greater gains than the 742 kg ha^{-1} reported by Utley et al. (1981).

Weight gain ha^{-1} declined linearly from SHM to the THM. Although ADG was increased with HM, the declining stocking rate reduced weight gain ha^{-1}. The S canopy height for T44 reduced ADG sufficiently to result in a reduction in weight gain ha^{-1} and provides an optimum HM for weight gain ha^{-1}. Grazing to an even shorter HM would be required for Coastal to further decrease ADG and depress weight gain ha^{-1} to estimate its optimum HM for weight gain ha^{-1}.

Canopy Characteristics

Whole Canopy

Examination of the offered canopy provides additional insight into the animal response obtained. Comparison of the compressed or extended heights of each pasture treatment showed that Coastal was slightly taller than T44 but there was no cultivar × HM treatment interaction for heights (Table 4). The 0.5 cm for compressed height and 2 cm for extended height in favor of Coastal, however, is probably of little biological importance. The significant LOF for both compressed and extended heights is attributed to the greater difference between SHM and MHM than between MHM and THM.

Because ruminants preferentially select leafy tissue when provided with an opportunity (Chacon et al., 1978; Fisher et al., 1991), the leafy area, as measured by LAI, was determined. No difference was noted between Coastal and T44 (mean = 2.29, SE = 0.41), but increasing HM from SHM to THM increased LAI linearly (SHM = 1.49, MHM = 2.57, and THM = 2.82) (Table 4). These shifts are consistent with the LAI reported for Coastal by Clapp et al. (1965), averaging 1.6 for a comparable S (5–8 cm canopy), 2.0 for M (10-cm canopy) and 2.2 for T (15-cm canopy). The greater LAI obtained in this

study for the M and T canopies, relative to those reported by Clapp et al. (1965), is attributed to grazing defoliation in our study compared with mechanical harvest by Clapp et al. (1965).

The IVTOD, CP, NDF, and constituent fiber fractions of Coastal and T44 canopies were generally similar with the exception of HEMI, which was greater for T44 and consistent with the literature (Burns and Fisher, 2007). There was a significant LOF for HEMI as a result of elevated HEMI for the MHM compared with SHM to THM. The effect was significant but not linear. Also, a significant ($P = 0.10$) cultivar × HM interaction occurred for CP and attributed to the greater CP concentration noted for the MHM T44 vs. the MHM Coastal treatment. However, this provides little explanation for the greater ADG obtained from the MHM, compared with the SHM (Table 3). The general lack of change in LAI and nutritive value among HM treatments indicates that quantity (greater daily dry matter intake) may have been more important than nutritive value in determining ADG in this experiment.

Table 4. Mean compressed and extended canopy heights, and leaf area index (LAI) of short, medium, and tall Coastal and Tifton 44 bermudagrasses, and associated nutritive value (freeze-dry basis).

	Canopy†			Nutritive value§						
Treatment†	Compressed	Extended	LAI‡	IVTOD	CP	NDF	ADF	HEMI	CELL	Lignin
	cm			g kg^{-1}						
Coastal (C)										
Short	5.8	16.2	1.61	582	118	713	363	348	304	62
Medium	10.1	28.2	3.07	562	110	726	355	362	291	65
Tall	13.6	38.4	2.71	570	133	695	361	334	289	72
Mean	9.8	27.6	2.46	571	120	711	360	348	295	66
Tifton 44 (T44)										
Short	5.4	14.3	1.38	613	146	708	354	357	291	60
Medium	10.0	27.5	2.07	600	155	712	345	363	280	63
Tall	12.6	35.0	2.93	567	111	734	374	363	308	61
Mean	9.3	25.6	2.13	593	137	718	358	361	293	61
Significance (*P*)										
Treatments	<0.01	<0.01	0.09	0.75	0.21	0.43	0.75	0.06	0.54	0.32
C vs. T44	0.02	0.02	0.34	0.37	0.16	0.54	0.85	0.03	0.84	0.14
Herbage mass (HM)										
Linear	<0.01	<0.01	0.02	0.34	0.48	0.79	0.53	0.48	0.96	0.19
LOF	0.03	0.03	0.28	0.93	0.64	0.61	0.31	0.05	0.23	0.95
Cultivar × HM										
Linear	0.39	0.39	0.58	0.56	0.10	0.14	0.44	0.15	0.20	0.24
LOF	0.21	0.21	0.21	0.63	0.11	0.24	0.61	0.13	0.50	0.54

† Each value is the mean of multiple readings within years for two pasture replicates and 4 yr ($n = 8$).

‡ Each value is the mean of two pasture replicates and 2 yr ($n = 4$).

§ IVTOD = in vitro true organic matter disappearance; CP = crude protein; NDF = neutral detergent fiber; ADF = acid detergent fiber; HEMI = hemicellulose; CELL = cellulose. Each value is the mean of two pasture replicates and 2 yr ($n = 4$).

Table 5. The proportion of leaf, stem and dead tissue, and associated in vitro true organic matter disappearance (IVTOD), crude protein (CP), and neutral detergent fiber (NDF) of Coastal and Tifton 44 bermudagrasses (oven-dry basis).

	Proportion			IVTOD			CP			NDF		
Treatment	Leaf	Stem	Dead	Leaf	Stem	Dead	Leaf	Stem	Dead	Leaf	Stem	Dead
	%			g kg^{-1}								
Coastal (C)												
Short	17.8†	51.9	30.3	806	580	461	226	95	100	629	740	711
Medium	21.0	47.4	31.6	782	572	405	209	88	83	659	748	740
Tall	14.7	48.3	37.0	817	593	446	250	110	119	605	723	693
Mean	17.8	49.2	33.0	802	582	437	228	98	101	631	737	715
Tifton 44 (T44)												
Short	17.7	43.1	39.2	805	639	499	246	125	125	641	738	705
Medium	15.8	41.1	42.8	803	633	505	238	133	143	680	749	688
Tall	18.0	44.7	37.2	765	595	440	191	95	93	686	754	738
Mean	17.2	43.0	39.7	791	622	481	225	118	120	669	747	710
Significance (*P*)												
Treatments	0.89	0.39	0.32	0.04	0.31	0.17	0.41	0.16	0.10	0.06	0.73	0.16
C vs. T44	0.84	0.07	0.08	0.20	0.07	0.07	0.82	0.08	0.10	0.02	0.46	0.73
Herbage mass (HM)												
Linear	0.72	0.78	0.52	0.13	0.48	0.16	0.44	0.54	0.63	0.48	0.98	0.62
LOF	0.69	0.40	0.69	0.47	0.97	0.75	0.78	0.66	0.74	0.08	0.51	0.87
Cultivar × HM												
Linear	0.67	0.46	0.27	0.03	0.24	0.37	0.20	0.09	0.10	0.06	0.30	0.13
LOF	0.33	0.99	0.34	0.03	0.47	0.10	0.27	0.11	0.03	0.38	0.68	0.02

† Each value is the mean of two pasture replicates and 2 yr ($n = 4$).

Leaf, Stem, Dead Fractions

The morphology of the canopies offered showed the leaf fraction to compose only 17.5% of the dry matter compared with the greater proportions present as stem (46.1%) and dead (36.4%) (Table 5). Both cultivars had similar proportions of leaf, but Coastal had a greater proportion of stem and least dead and none of the three fractions were altered by HM. The specific leaf weight (data not shown) was greater for Coastal than T44 (31.9 vs. 28.9 g m^{-2}, SE = 2.5) and was also not altered by increasing HM.

The IVTOD and CP concentrations within the leaf fraction were similar between Coastal and T44, whereas the NDF concentration of the leaf was greater for T44 than Coastal (669 vs. 631 g kg^{-1}) (Table 5). The IVTOD and CP concentrations in the stem and dead fractions were greater for T44 than Coastal, whereas the NDF concentrations were similar. Increasing HM did not alter IVTOD, CP, or NDF, although leaf NDF showed a LOF from linear and associated with greater concentration in the MHM of T44 compared with Coastal and the relative change between MHM and THM. Additionally, some interactions occurred between cultivar and HM. Both the leaf IVTOD linear and LOF from linear contrasts were significant. This was the result of the relatively lesser IVTOD for Coastal for the MHM and the relatively lesser IVTOD for T44 for the THM. The IVTOD, CP and NDF of the dead material from the canopy also had a significant LOF to linear. For the IVTOD and CP of the dead material this was the result of least CP for Coastal MHM and the greatest CP for the T44 MHM. For the NDF of the dead material the LOF to linear was the result of the relatively greatest NDF for the MHM and least NDF for the

THM of Coastal in contrast to the relatively least NDF for the MHM and greatest NDF for the THM of T44. Because animals generally prefer green leaves, the significant contrasts in the CP and NDF of the dead material would likely be of little biological significance. In the case of bermudagrass, however, the morphology of its canopy does not facilitate the grazing of only green leaf, resulting in a diet of reduced nutritive value (Fisher et al., 1991). That, along with the variation in the leaf IVTOD, although small, could affect intake and in particular the intake of the MHM and THM between the cultivars.

Table 6. Organic matter (OM), median particle size (MPS), in vitro true organic matter disappearance (IVTOD), crude protein (CP), and neutral detergent fiber (NDF) of whole masticate of Coastal and Tifton 44 bermudagrasses.

Treatment	MPS	OM	IVTOD	CP	NDF
	mm	g kg^{-1}			
Coastal (C)					
Short	1.04†	844	801	182	587
Medium	1.12	897	813	174	647
Tall	1.19	906	813	185	641
Mean	1.11	882	809	180	625
Tifton 44 (T44)					
Short	0.96	873	827	190	621
Medium	1.21	915	800	167	672
Tall	1.19	908	820	173	666
Mean	1.12	898	816	177	653
Significance (P)					
Treatments	0.03	0.16	0.71	0.69	0.14
C vs. T44	0.86	0.25	0.57	0.70	0.11
Herbage mass (HM)					
Linear	0.01	0.04	0.88	0.53	0.06
LOF‡	0.11	0.16	0.48	0.25	0.10
Cultivar × HM					
Linear	0.43	0.41	0.53	0.41	0.74
LOF	0.12	0.93	0.27	0.80	0.82

† Each value is the yearly mean of two sequential samplings days on each of two sampling dates for two pasture replicates and 2 yr (n = 4).

‡ LOF = lack of fit.

The constituent fiber fractions of ADF, HEMI, CELL, and lignin in leaf, stem, and dead tissue was determined (data not shown) and all but HEMI had similar concentrations (g kg^{-1}) between Coastal and T44 and not altered by HM (Leaf: ADF = 270, SE = 11.5; CELL = 235, SE = 11.3; lignin = 31, SE = 1.9; Stem: ADF = 379, SE = 14.3; CELL = 322, SE = 12.7; lignin = 61, SE = 4.6; Dead: ADF = 376, SE = 12.2; CELL = 287, SE = 11.4; lignin = 83, SE = 4.2). Hemicellulose responded differently with T44 having greater concentrations than Coastal in leaf (391 vs. 371 g kg^{-1}, SE = 9.5), stem (369 vs. 353 g kg^{-1}, SE = 6.2), and in the dead tissue (343 vs. 329, SE = 10.6).

Because of the large difference in IVTOD, CP, and ADF among the leaf, stem, and dead fractions, it is of interest to examine the composition of the diet selected by the grazing animal relative to the proportion of leaf, stem, and dead present in the canopy.

Grazing Behavior

Diet Selected

The diet selected by steers in this study, as represented by masticate collected from the HM offered, did not differ between cultivars in particle size, OM, IVTOD, CP, or NDF, although NDF concentrations approached significance (P = 0.11) (Table 6). Increasing HM offered, however, resulted in a linear increase in masticate particle size and OM from the SHM to the THM. The SHM apparently contained more soil contamination (least OM) and is consistent with the proximity of its canopy to the soil surface. Further, the canopy of the SHM appeared to be masticated differently with decreased particle size compared with MHM and THM after initial mastication.

The masticate IVTOD (>800 g kg^{-1}), CP (>165 g kg^{-1}), and NDF (<672 g kg^{-1}) concentrations indicate that the steers would have had to consume predominately leaf because of the reduced IVTOD (<639 g kg^{-1}) and CP (<143 g kg^{-1}) and greater NDF (>693 g kg^{-1}) in the stem and dead fractions (Table 5).

Characterization of the whole masticate by separating it into particle-size classes showed that large particles made up 20 to 31% of the dry matter, medium particles 50 to 56% of the total diet dry matter, followed by small particles, which contributed 16 to 24% (Table 7). Within the large particle-size class, only NDF concentrations differed between cultivars with T44 greater than Coastal and consistent with the literature (Burns and Fisher, 2007). The proportion of large particles increased linearly as HM increased, but a significant cultivar × HM LOF from linear resulted because the proportion of particles was greater for T44 and lesser for Coastal from the MHM. The IVTOD also increased linearly from the SHM to the THM. There was no significant cultivar effect or interaction and the means ranged from 754 g kg^{-1} for the SHM to

Table 7. The proportion (Prop) of diet dry matter consisting of large, medium, and small particle sizes and associated organic matter (OM), in vitro true organic matter disappearance (IVTOD), crude protein (CP), and neutral detergent fiber (NDF) of Coastal and Tifton 44 bermudagrasses.

	Large (>1.7 mm)				Medium (<1.7 and ≥0.5 mm)				Small (<0.5 mm)			
Treatment	Prop	IVTOD	CP	NDF	Prop	IVTOD	CP	NDF	Prop	IVTOD	CP	NDF
	%	g kg^{-1}			%	g kg^{-1}			%	g kg^{-1}		
Coastal (C)												
Short	27.3†	722	144	622	50.6	835	188	589	22.1	848	214	542
Medium	26.7	782	155	664	53.9	817	173	655	19.5	837	198	611
Tall	31.2	794	170	654	51.2	812	188	641	17.5	833	201	618
Mean	28.4	766	156	647	51.9	818	183	628	19.7	839	204	590
Tifton 44 (T44)												
Short	20.1	785	156	650	56.1	847	191	627	23.9	845	212	585
Medium	31.3	786	155	683	52.8	800	169	673	16.0	817	184	650
Tall	30.7	810	165	676	52.5	802	173	669	16.8	836	188	641
Mean	27.3	794	158	670	53.8	819	178	656	18.9	833	195	625
Significance (P)												
Treatments	0.05	0.12	0.69	0.06	0.04	0.63	0.61	0.15	0.08	0.24	0.18	0.12
C vs. T44	0.52	0.11	0.84	0.04	0.04	0.78	0.60	0.11	0.57	0.34	0.21	0.09
Herbage mass (HM)												
Linear	0.01	0.04	0.18	0.04	0.14	0.31	0.44	0.07	0.02	0.18	0.06	0.04
LOF‡	0.37	0.68	0.71	0.05	0.35	0.50	0.20	0.10	0.15	0.11	0.12	0.11
Cultivar × HM												
Linear	0.14	0.22	0.50	0.82	0.05	0.65	0.47	0.67	0.47	0.73	0.53	0.57
LOF‡	0.05	0.29	0.88	0.73	0.03	0.67	0.95	0.53	0.20	0.20	0.67	0.81

† Each value is the yearly mean of two sequential samplings days on each of two sampling dates for two pasture replicates and 2 yr (n = 4).

‡ LOF = lack of fit.

802 g kg^{-1} for the THM. The NDF concentration was greatest in T44 and was also influenced by HM showing a linear increase from SHM to THM, as well as a significant LOF from linear. The latter is attributed to the decline in NDF between the MHM and THM treatments. Note also that the increases in NDF were concurrent with increases rather than decreases in IVTOD, indicating an increasing fraction of digestible fiber from the taller treatments.

The proportion of medium particles, although greatest for T44, varied with HM increasing from SHM to THM for Coastal, but declining for T44. Both cultivars showed a decline from MHM to THM, but of different magnitude (significant cultivar × HM LOF from linear). Concentrations of IVTOD and CP in the medium particles were similar between cultivars and not altered by increasing HM. The significant LOF from linear for the NDF concentrations is attributed to the greater NDF concentration in the MHM of both cultivars.

Small particles showed no difference in either dry matter proportion, or in concentration of IVTOD, CP, or NDF between cultivars. Increased HM, however, altered the proportions of small particles, which decreased from SHM to the THM. It is unclear whether this effect is based on smaller particles generated from possible shorter segments gathered from the canopy in the SHM, increased mastication, or both. Associated with the increased HM was decreased CP and increased NDF as herbage mass increased from SHM to THM. Once again, neither was associated with a decrease in IVTOD and would indicate an increased proportion of digestible fiber.

Grazing Time

Degree of selective grazing can alter grazing time with preferred canopies generally providing an animal's daily allowance within 5 to 6 h, whereas more complex canopies or canopies with limited herbage mass may extend grazing time upward of 12 h to satisfy animal needs (Allden and Whittaker, 1970; Arnold, 1981). Results from this study were unexpected as daily grazing time (data not shown) averaged 11.8 h (SE = 0.60) with no difference found between cultivars or among HM treatments. Examination of grazing times outside of the normal grazing periods to determine if herbage allowance altered grazing behavior showed animals grazed 0.9 h (SE = 0.23) during the early morning from 2400 to 0400 h and 2.6 h (SE = 0.47) during the heat of the day (1300–1600 h) with no difference noted during these grazing periods between cultivars or among HM treatments.

SUMMARY AND CONCLUSIONS

Coastal and T44 pastures differed in quality supporting similar stocking rates (13.1 steers ha^{-1}) that resulted in different ADG (0.51 vs. 0.58 kg), but similar weight gain ha^{-1} (938 kg) and EFU ha^{-1} (5338 kg). Examining the canopy of each cultivar showed them to be generally similar in nutritive value (IVTOD = 582 g kg^{-1}; CP = 129 g kg^{-1}; NDF = 715 g kg^{-1}) and in leaf area (LAI = 2.30). Further, both cultivars were similar in the proportion of the canopy dry matter consisting of leaf (17.5%), whereas T44 had the least proportion of stem (43.0 vs. 49.2) and greatest dead (39.7 vs. 33.0%). Although leaf was present in least proportion its IVTOD averaged 797 g kg^{-1} compared with 602 g kg^{-1} for stem and 459 g kg^{-1} for dead. It is noted that the concentration of NDF in the leaf of T44 was greater compared with Coastal (669 vs. 631 g kg^{-1}), whereas the NDF of the stem and dead fractions were greater, but similar.

The diets selected from canopies of increasing height were generally similar in IVTOD (813 g kg^{-1}) and CP (17.9 g kg^{-1}) but with NDF increasing and consistent with the IVTOD, CP, and NDF of the leaf fraction, which was appreciable greater compared with stem and dead tissue. Similarity in diet IVTOD between cultivars, despite T44 having greater NDF concentration, is consistent with greater NDF digestibility of T44 compared with Coastal as reported by Burns and Fisher (2007). Although grazing time (11.8 h d^{-1}) was not altered by increasing HM, ingestive mastication showed a change in particle size with increasing canopy height with large particles positively correlated ($r = 0.76$; $P = 0.08$) and small particles negatively correlated ($r = -0.85$; $P = 0.03$) with ADG. The relationship between particle size and ADG has been previously noted and reported by Burns and Sollenberger (2002). The IVTOD also increased in the large particles with increasing canopy height and herbage mass, and although NDF increased in large and small particles with canopy height, this increase was not associated with a decline in digestibility. These data indicate that steers apparently prefer the leaf portion of the canopies and the increase in canopy height and subsequent increase in steer ADG likely resulted from greater dry matter intake of the leaf tissue. This is further supported by a linear ($P = 0.05$) increase in leaf mass [kg ha^{-1}; i.e., HM (kg ha^{-1}) × percent leaf] with increasing HM averaging 501, 894, and 941 kg ha^{-1} (SE = 175 kg ha^{-1}) of leaf for the S, M, and T canopies, respectively. The increase in leaf mass between the SHM and MHM was large, averaging 78% and consistent with the 60% increase in steer ADG (0.40 vs. 0.64 kg). The increase in leaf mass between the MHM and THM was minor (averaging 5%), and with no apparent shift in grazing time, had little influence on subsequent steer ADG (0.64 vs. 0.59 kg). The reduction in stocking rate associated with increased canopy height reduced weight gain ha^{-1} and EFU through reduced pasture growth and utilization efficiency with no benefit in animal performance. Tifton 44 is a viable pasture cultivar for the upper South with greater quality, as reflected in ADG, than Coastal, and most productive when HM is maintained at about 4 Mg ha^{-1} (soil surface) producing about 1100 kg ha^{-1} of gain.

REFERENCES

Allden, W.G., and I.A.M.D. Whittaker. 1970. The determinants of herbage intake by grazing sheep: The interrelationship of factors influencing herbage intake and availability. Aust. J. Agric. Res. 21:755–766.

AOAC. 1990. Official methods of analysis. 15th ed. Association of Official Analytical Chemists, Arlington, VA.

Arnold, G.W. 1981. Grazing behavior. p. 79–104. *In* F.H.W. Morley (ed.) Grazing animals. World Animal Science B. Elsevier Sci. Publ. Co., New York.

Blaser, R.E., J.T. Johnson, F. McClaugherty, J.P. Fontenot, R.C. Hammes, Jr., H.T. Bryant, D.D. Wolf, and D.A. Mays. 1981. Animal production with controlled and fixed stocking and managed stocking rates. p. 612–615. *In* J.A. Smith and V.W. Hays (ed.) Proc 14th Int. Grassl. Congr., Lexington, KY. 15–24 June 1981. Westview Press, Boulder, CO.

Burns, J.C., and W.A. Cope. 1974. Nutritive value of crownvetch forage as influenced by structural constituents and phenolic and tannin compounds. Agron. J. 66:195–200.

Burns, J.C., and D.S. Fisher. 2007. Dry matter intake and digestibility of 'Coastal', 'Tifton 44', and 'Tifton 85' bermudagrass hays grown in the U.S. upper south. Crop Sci. 47:795–810.

Burns, J.C., R.D. Mochrie, and D.H. Timothy. 1984. Steer performance from two perennial Pennisetum species, switchgrass and a fescue–Coastal bermudagrass system. Agron. J. 76:795–800.

Burns, J.C., R.D. Mochrie, and D.H. Timothy. 1985. Intake and digestibility of dry matter and fiber of flaccidgrass and switchgrass. Agron. J. 77:933–936.

Burns, J.C., and J.G. McIvor, L. Villalobos M., R.R. Vera, and D.I. Bransby. 2004. Grazing systems for C_4 grasslands: A global perspective. p. 309–354. *In* L.E. Moser et al. (ed.) Warm-season (C_4) grasses. Agron. Monogr. 45. ASA, CSSA, and SSSA, Madison, WI.

Burns, J.C., and L.E. Sollenberger. 2002. Grazing behavior of ruminants and daily performance from warm-season grasses. Crop Sci. 42:873–881.

Burton, G.W., and W.G. Monson. 1978. Registration of Tifton 44 bermudagrass. Crop Sci. 8:911.

Chacon, E.A., T.H. Stobbs, and M.B. Dale. 1978. Influence of sward characteristics on grazing behavior and growth of Hereford steers grazing tropical grass pastures. Aust. J. Agric. Res. 29:89–102.

Clapp, J., Jr., D.S. Chamblee, and H.D. Gross. 1965. Interrelationships between defoliation systems, morphological characteristics and growth of 'Coastal' bermudagrass. Crop Sci. 5:468–471.

Ellis, W.C., E.M. Bailey, and C.A. Taylor. 1984. A silicone esophageal cannula: Its surgical installation and use in research with grazing cattle, sheep, or goats. J. Anim. Sci. 59:204–209.

Faix, J.J., C.J. Kaiser, and F.C. Hinds. 1981. Bermudagrass for forage in the Central U.S. transitional climatic zone. Agron. J. 73:313–316.

Fisher, D.S., J.C. Burns, and K.R. Pond. 1988. Estimation of mean and median particle size of ruminants diets. J. Dairy Sci. 71:518–524.

Fisher, D.S., J.C. Burns, K.R. Pond, R.D. Mochrie, and D.H. Timothy. 1991. Effects of grass species on grazing steers: I. Diet composition and ingestive mastication. J. Anim. Sci. 69:1188–1198.

Greene, B.B., M.M. Eickhorn, W.M. Oliver, B.D. Nelson, and W.A. Young. 1990. Comparison of four hybrid bermudagrass cultivars for stocker steer production. J. Prod. Agric. 3:253–255.

Gross, H.D., L. Goode, W.B. Gilbert, and G.L. Ellis. 1966. Beef grazing systems in Piedmont North Carolina. Agron. J. 58:307–310.

Mandebvu, P., J.W. West, G.M. Hill, R.N. Gates, R.D. Hatfield, B.G. Mullinix, A.H. Parks, and A.B. Caudle. 1999. Comparison of Tifton 85 and Coastal bermudagrasses for yield, nutrient traits, and digestion by growing steers. J. Anim. Sci. 77:1572–1586.

Mott, G.O. 1960. Grazing pressure and the measurement of pasture production. p. 606–611. *In* C.L. Skidmore (ed.) Proc. Int. Grassl. Congr., 8th, Univ. of Reading, UK. 11–21 July 1960. Alden Press, UK.

Mott, G.O., and H.L. Lucas, Jr. 1952. The design, conduct, and interpretation of grazing trials on cultivated and improved pastures. p. 1380–1385. *In* R.E. Wagner et al. (ed.) Proc. Int Grassl. Congr., 6th, Penn State College. 17–23 Aug. 1952. State College Press, PA.

Petersen, R.G. 1994. Pasture trials. p. 291–317. *In* Agricultural field experiments, design and analysis. Marcel Dekker, New York.

Petersen, R.G., and H.L. Lucas, Jr. 1968. Computing methods for the evaluation of pastures by means of animal response. Agron. J. 60:682–687.

Rakes, A.H., J.C. Burns, and L.W. Whitlow. 1988. Evaluation of cattle-feeding strategies for Piedmont dairy farms. Bull. 477. North Carolina Agric. Res. Service, North Carolina State Univ., Raleigh.

Riewe, M.E., J.C. Smith, J.H. Jones, and E.C. Holt. 1963. Grazing production curves: I. Comparison of steer gains on gulf ryegrass and tall fescue. Agron. J. 55:367–369.

SAS Institute. 2004. SAS/STAT 9.1 User's guide. SAS Inst., Cary, NC.

Stobbs, T.H. 1970. Automatic measurement of grazing time by dairy cows on tropical grass and legume pastures. Tropic. Grassl. 4:237–244.

Thom, W.O., H.B. Rice, M. Collins, and R.M. Morrison. 1990. Effect of applied fertilizer on Tifton 44 bermudagrass. J. Prod. Agric. 3:498–501.

Utley, P.R., W.G. Monson, G.W. Burton, R.E. Hellwig, and W.C. McCormick. 1978. Comparison of Tifton 44 and Coastal bermudagrass as pasture and as harvested forages. J. Anim. Sci. 47:800–804.

Utley, P.R., W.G. Monson, G.W. Burton, and W.C. McCormick. 1981. Evaluation of Tifton 44, Coastal and Callie bermudagrasses as pasture for growing beef steers. J. Anim. Sci. 52:725–728.

Van Soest, P.J., and J.B. Robertson. 1980. Systems of analysis for evaluating fibrous feeds. p. 49–60. *In* W.J. Pigden et al. (ed.) Standardization of analytical methodology for feeds. Int. Development Res. Center, Ottawa, ON, Canada.