ABSTRACT

The introduced perennial, warm-season grass, Caucasian bluestem \textit{(Bothriochloa caucasia} (Trin.) C.E. Hubbard \textquote{Caucasian}), appears to be adapted to the mid-Atlantic region. This 4-yr experiment compared animal and pasture productivity of Caucasian bluestem over three canopy heights, or forage masses (FM), designated as Short (14.6 cm), Medium (32.2 cm), and Tall (39.8 cm). The relationship of canopy height to diet and canopy characteristics was also evaluated. The soil was a Cecil clay loam (fine, kaolinitic, thermic Typic Kanhapludult). Pastures were continuously stocked using variable stocking from mid-May through mid-September. Forage mass (harvested to a 2.5-cm stubble), increased linearly \((P = 0.04) \) averaging 1.42, 2.31 and 2.75 Mg ha\(^{-1}\) for Short, Medium, and Tall canopy heights. Steer average daily gain (ADG) was similar among FM treatments \((0.76 \text{ kg d}^{-1})\) but weight gain decreased linearly \((P < 0.01)\) from Short to Tall \((\text{from 817 to 518 kg ha}^{-1})\). Increasing FM resulted in a quadratic decrease \((P \leq 0.04)\) in stocking rate \((\text{from 9.7 to 7.8 steers ha}^{-1})\) and animal days \((\text{from 1019 to 700 d ha}^{-1})\) and a linear decrease \((P = 0.02)\) in effective feed units \((\text{from 4025 to 2806 kg ha}^{-1})\). Stand counts of Caucasian bluestem increased linearly \((P = 0.05)\) from Tall to Short FM \((\text{from 22.8–70.0%})\) with the Tall providing openings for potential weed invasion. Caucasian bluestem can be heavily stocked and may provide acceptable quality forage for summer grazing in the mid-Atlantic region.

WARM-SEASON GRASSES SERVE AS a critical forage resource during the summer stress period in year-round grazing systems in the North-South transition zone (Burns et al., 2004). Bermudagrass \textit{(Cynodon dactylon} (L.) Pers.), especially \textquote{Coastal}, and more recently several improved bermudagrass cultivars, have generally served as reliable pasture and hay sources in the mid-Atlantic Region (Burns et al., 1984, 2009; Burns and Fisher, 2007). Daily animal performance of the grazing animal in this region, however, has been moderate in mid-to-late summer (Utley et al., 1978, 1981; Burns et al., 1984; Greene et al., 1990; Burns and Fisher, 2008). A need exists for a productive perennial warm-season grass with greater nutritive value. Caucasian bluestem is a perennial, warm-season grass with attributes that may make it a valuable component of pasture systems in the southeastern United States and boost production during summer (Coleman et al., 2004). Caucasian bluestem, an old world bluestem, was introduced into the United States from Georgia, Russia in 1929 (Harlan and Chheda, 1963). It was selected for evaluation in the Southern Great Plains, that is, Woodward OK, from among other old-world bluestems because of its greater water use efficiency and greater photosynthetic and CO\(_2\) exchange rates (Coyne et al., 1982; Coyne and Bradford, 1984; Svejcar and Christiansen, 1987a; Philipp et al., 2007). Furthermore, Caucasian bluestem has been successfully evaluated farther east into portions of Oklahoma (Taliferro et al., 1984) and into Missouri (Anderson and Matches, 1983) as a harvested forage and from Oklahoma (Christiansen and Svejcar, 1987; Forbes and Coleman, 1993) to Virginia (Allen et al., 2000) when grazed as pasture or evaluated in small-plot studies in West Virginia (Belesky and Fedders, 1995). These studies have shown that Caucasian bluestem has production characteristics that may have merit in animal production systems for the mid-Atlantic Region. Information, however, on the relationship between forage mass and animal response, stand persistence and pasture productivity under grazing is not available. The objectives of this experiment were to estimate (i) the forage quality of Caucasian bluestem for summer grazing, (ii) the optimum forage mass for grazing Caucasian bluestem in the mid-Atlantic Region of the United States, and (iii) the relationship of plant canopy characteristics and animal ingestive mastication to steer daily performance.

MATERIALS AND METHODS

This experiment was conducted during a 5-yr period at the North Carolina Agricultural Research Service Lake Wheeler Road Field laboratory located south of Raleigh, NC. Soil at the experimental site is a fine, kaolinitic, thermic Typic Kanhaplundult (Cecil clay loam) typical of much of the Piedmont Region.

Abbreviations: ADF, acid detergent fiber; ADG, average daily gain; CELL, cellulose; CP, crude protein; DM, dry matter; EFU, effective feed unit; FM, forage mass; HEMI, hemicellulose; IVTOD, in vitro true organic matter disappearance; LOF, lack of fit; NDF, neutral detergent fiber; OM, organic matter.
A 9.5-ha area, previously used for general cropping, was limed according to soil test the fall before seeding (mean pH = 6.5), deep disked in the spring, and a firm seedbed prepared. The area was blocked according to slope and surveyed to establish three 0.39-ha plots, in each of two land replicates (total = 2.3 ha). The land area was seeded with debeaked Caucasian bluestem with a modified (coulters placed on 15-cm centers) Truax drill (Truax Company, 4300 Quebec Avenue North, New Hope, MN 55428) at 11 kg ha⁻¹ of pure live seed. Fields were initially irrigated as needed and excellent stands were obtained. The year after establishment and before initiation of the experiment, the area was harvested for hay. Consequently, stands were well established when the grazing trial was initiated in April 2000.

Pastures

Pasture Management

Treatments consisted of Caucasian bluestem managed to maintain three canopy heights and subsequently three levels of FM throughout the grazing season (three treatments). Canopy height target values were <14 cm for Short, 25 to 35 cm for Medium, and >38 cm for Tall. Stocking rate was varied to generate canopy characteristics and to maintain each FM treatment. Mowing was not used to either create or maintain the canopies. For example, the Short treatment was stocked first followed by the Medium and the Tall treatments based on the target canopy height. Initial stocking was dependent on environmental conditions and occurred 13 May for the Short and 18 May for the Medium and Tall in the first year. Stocking was initiated 25 May in the second year for the first replicate. Grassy weeds in the second replicate were sprayed with ‘Plateau’ (ammonium salt of imazapic (±)-2-[(4,5-dihydro-4-methyl-(1-methyl)pyridinecarboxylic acid) and the replication was not used experimentally that summer. For example, the Short treatment was stocked first followed by the Medium and the Tall treatments based on the target canopy height. Initial stocking was dependent on environmental conditions and occurred 13 May for the Short and 18 May for the Medium and Tall in the first year. Stocking was initiated 25 May in the second year for the first replicate. Grassy weeds in the second replicate were sprayed with ‘Plateau’ (ammonium salt of imazapic (±)-2-[(4,5-dihydro-4-methyl-(1-methyl)pyridinecarboxylic acid) and the replication was not used experimentally that summer. Spring growth during the third year was delayed because of below normal rainfall (179 mm below the 30-yr average) during 5 of the 6 mo before March and dry conditions were further exacerbated by below normal rainfall in April (~41.8 mm), May (~66.5 mm) and June (~16.8 mm). Although canopy heights were developed and maintained by grazing animals no animal performance data are reported due to the short season. Stocking was initiated 19 May for the Short and Medium and 27 May for the Tall in the fourth year and 1 June for the Short and Medium and 4 June for the Tall in the fifth year. The end of each grazing season was based on reduced pasture growth rates in late summer. Caucasian bluestem growth declined rapidly in September as minimum temperatures fell below 16°C and moisture became limiting. Consequently, grazing was terminated based on management of the Short FM and the range in experimental grazing heights was maintained. Grazing was terminated on 12 September in the first year, 13 September in the second year, 9 September in the fourth year, and 13 September in the fifth year. Because no data were obtained in the third year, years are reported as year one, year two, year four, and year five.

All residual growth from the previous fall was removed by burning in late February or early March. All paddocks during the trial were evaluated for nutrient maintenance needs based on bermedagrass requirements using annual soil test. Only in the fourth fall after establishment were maintenance nutrients required with each paddock receiving 20 kg ha⁻¹ of P, 75 kg ha⁻¹ of K and 2.2 Mg ha⁻¹ of lime. Nitrogen, as NH₄NO₃, was applied annually to all paddocks at 78.4 kg ha⁻¹ the first week in April, the second week in June, and again in the third week of July, totaling 235 kg ha⁻¹ of N for the season. Soil pH was maintained between 6.2 and 6.5.

Pasture Measurements

Forage Mass and Canopy Characteristics

Canopy height was used as an index to maintain variation in FM. For grazing management, pasture height was estimated three times each week by walking through the pastures and measuring the average height of the natural canopy (not extended) with a meter stick. Detailed canopy characterization was conducted in concert with FM determinations in both years four and five. Pastures were sampled 19 June, 15 July, and 26 August in year four and 15 July and 2 September in year five. Three stratified but randomly located strips of 21.5 m were taken (one from each third of each pasture being sampled) from all treatments. Before harvesting, 15 canopy-height estimates were obtained from each strip (a total of 45 for the pasture). Forage from the Short was harvested with a conventional 50-cm wide rotary lawn mower set to leave a 2.5-cm stubble. Forage on the Medium and Tall paddocks was first harvested with a 50-cm sickle-bar mower set to leave a 10-cm stubble. The cut forage was collected and the residual removed with the 50-cm wide rotary mower set to leave a 2.5-cm stubble. Harvested forage was weighed, bagged, and the fresh weight recorded, subsampled, and the subsample dried at 75°C for dry matter (DM) determination. Fresh weight was multiplied by the DM concentration to determine FM (kg DM ha⁻¹).

Hand cut samples (2.5-cm stubble) were taken along the mower strip for canopy characterization. Intact canopy samples were cut and bagged in the field to retain the canopy structure and composited by strip. Samples were immediately transported to the field laboratory for processing. Subsamples from each strip within pasture were composited for the pasture. Half of the sample was quick frozen in liquid nitrogen (~195°C) and placed in a freezer (~16°C) until lyophilized. After lyophilization, samples were stored in the freezer until ground and returned to the freezer until analyzed. The other half of the sample was placed on a large paper cutter then cut into 50-mm strata from the base to the extended height. Each strata was bagged and placed in a refrigerator until separated into leaf blade (hereafter referred to as leaf), stem plus sheath (hereafter referred to as stem), head, and dead material (plant fragment that was ≥50% dead tissue). After separation the stratified samples were placed in a freezer (~16°C), lyophilized, ground, and returned to a freezer. All FM samples and canopy fractions were ground in a cyclone mill (Udy Corp., Fort Collins, CO) to pass a 1-mm screen and stored in a freezer (~16°C) for laboratory analyses.

Stand Counts

Basal stand counts were taken in the spring following the last year of grazing (5 May, after 5 yr of grazing and 7 yr after seeding). Stand counts were obtained by three stratified (each third of the pasture), but randomly located, 18.5-m line transects. Centimeters of ground along the line transect not occupied by Caucasian bluestem were recorded. Readings from the three line transects were totaled and divided by the total length to estimate the proportion of ground not occupied by Caucasian bluestem. Caucasian bluestem presence was estimated as 100 minus the proportion not occupied by Caucasian bluestem.
This provided a conservative estimate of Caucasian bluestem groundcover since only basal stems (crowns) were recorded.

Animal

Management

Angus steers (Bos taurus), obtained through North Carolina graded spring feeder-calf sales, served as the experimental animals and managed under the approval of the North Carolina State Univ. Animal Care and Use Committee (IACUC no. 00–038-A). Steers were treated prophylactically for internal parasites before grazing and the treatment was repeated in July. Each year, at the beginning of grazing, a uniform set of steers were ranked by weight and grouped into two sets with a lighter and heavier steer paired and designated as tester one and tester two and then a pair of testers was randomly assigned to each pasture. This minimized the variation in animal weight per pasture 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 and fresh water, but shade was not provided.

Weight and Body Condition

Initial unshrunk weights of the tester steers averaged 245 kg (± 17 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, mid-summer, 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 effective feed units (Petersen and Lucas, 1968; Petersen, 1994) as an estimate of pasture productivity.

Masticate Collection and Characterization

Seven Angus steers (average body weight > 450 kg) fitted with esophageal cannulas (Ellis et al., 1984) were maintained on Coastal bermudagrass and used to collect masticated samples representing the diet. This sampling occurred in years four and five and in concert with FM determination and canopy characterization. Masticate collections were conducted by field replicate with all pasture treatments within a replicate sampled concurrently. Masticate collection consisted of two sequential sampling days for three sampling events in year four (June, July, and August) and two sampling events in year five (July and September). For each event, six steers from a seven steer pool were randomly assigned to treatments on Day 1 and Day 2. We constrained the randomization so 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. Masticate was collected by first removing the cannula, discarding the first six to eight bolus, then walking beside the animal with a plastic lined net and catching the subsequent extrusa. After collecting an adequate quantity of extrusa, along with the saliva (about 20 min), 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). Samples were subsequently stored in a freezer (–16°C) until lyophilized. After lyophilization, samples were ground in a cyclone mill to pass a 1-mm screen and stored in a freezer (–16°C) before laboratory analyses. After laboratory analyses were completed, the data from the two consecutive days were averaged before statistical analyses.

Laboratory Analysis

All canopy and masticate samples were scanned in a model 5000 near-infrared reflectance spectrophotometer (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. 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 (Burns and Cope, 1974). Samples from the IVTOD procedure were subsequently extracted with a neutral detergent solution in a batch processor (Ankom Technology Corp., Fairport, NY). The calculations of IVTOD 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 autoanalyzer (AOAC, 1990), and crude protein (CP) was calculated 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 using a batch processor (Ankom Technology Corp., Fairport, NY) and reagents prepared according to Van Soest and Robertson (1980). Hemicellulose (HEMI) was determined by difference (NDF – ADF). The results of the laboratory analyses of the selected samples were added to existing libraries and used to develop NIRS prediction equations for all samples (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. A trend analysis (three FM treatments) was conducted within the analysis of variance using orthogonal contrasts to partition the sum of squares. 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 we will refer to as lack of fit (LOF), since there were only 2 degrees of freedom available. A significant LOF indicates a deviation from a simple linear fit with the three canopy heights. Regression analysis was used to examine the response of cumulative steer gain by treatment over the grazing season. Simple correlation analysis was used to examine the relationship between canopy height and FM. All differences were considered significant if the statistical test resulted in a $P \leq 0.05$.

**Rainfall and Temperature**

This study was conducted over a 5-yr period that included the typical variation in rainfall and temperature. Year one had below normal rainfall in February, March, May, and June, but above normal rainfall and below normal temperatures during much of the grazing period, followed by below normal rainfall during the fall (Table 2). Below normal rainfall carried over into year two with only March, June, July, and August having normal, or above, rainfall with generally greater than normal temperature. Below normal rainfall in the fall of year two, and hence drought conditions, were not relieved during the spring of year three but were continued with below normal rainfall in April, May, and June. This delayed and reduced initial growth of Caucasian bluestem. Although pastures were grazed in July and August, steer performance data were not obtained during this short period. Year four had above normal rainfall from February through September with generally below normal temperature. Year five had below normal rainfall through May but above normal rainfall during the remainder of the grazing season. Weather during these 5 yr was below normal in rainfall but the rainfall pattern provided contained periods of drought stress that are typical of the region.

**RESULTS AND DISCUSSION**

**Steer and Pasture Performance**

The grazing season for Caucasian bluestem in this study was from mid-to-late May through mid-September and similar to locations in Virginia (Allen et al., 2000) and farther west in Oklahoma (Svejcar and Christiansen, 1987b; Phillips and Coleman, 1995). As designed, the canopy heights increased linearly from the Short to the Tall treatment (Table 3). As expected, FM increased with canopy height and the two measures were highly correlated ($r = 0.99; P = 0.02$; see also Coleman and Forbes, 1998, $r = 0.95$). In contrast, steer ADG was not altered by FM and averaged 0.76 kg d$^{-1}$. This was similar to 0.73 kg d$^{-1}$ reported for dairy heifers (Forwood et al., 1988) and from 0.68 to 0.81 kg d$^{-1}$ noted for steers (Phillips and Coleman, 1995; Coleman and Forbes, 1998). Steers grazing the Short were stocked at 9.7 head ha$^{-1}$ and stocking declined linearly from the Short to the Tall. Significant LOF for this variable

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**Table 2. Climatological data presenting departures from 30-yr mean.†**

<table>
<thead>
<tr>
<th>Month</th>
<th>30 yr Mean</th>
<th>Year 1</th>
<th>Year 2</th>
<th>Year 3</th>
<th>Year 4</th>
<th>Year 5</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Rainfall</td>
<td>Temp</td>
<td>Rainfall</td>
<td>Temp</td>
<td>Rainfall</td>
<td>Temp</td>
</tr>
<tr>
<td></td>
<td>mm</td>
<td>ºC</td>
<td>mm</td>
<td>ºC</td>
<td>mm</td>
<td>ºC</td>
</tr>
<tr>
<td>January</td>
<td>87.0</td>
<td>3.8</td>
<td>69.7</td>
<td>–0.2</td>
<td>–54.5</td>
<td>1.5</td>
</tr>
<tr>
<td>February</td>
<td>92.3</td>
<td>5.6</td>
<td>–37.3</td>
<td>2.1</td>
<td>–33.8</td>
<td>2.8</td>
</tr>
<tr>
<td>March</td>
<td>94.3</td>
<td>10.2</td>
<td>–50.3</td>
<td>1.6</td>
<td>83.5</td>
<td>–0.7</td>
</tr>
<tr>
<td>April</td>
<td>64.8</td>
<td>15.0</td>
<td>52.2</td>
<td>–0.8</td>
<td>–21.8</td>
<td>1.0</td>
</tr>
<tr>
<td>May</td>
<td>98.0</td>
<td>19.4</td>
<td>–42.2</td>
<td>1.7</td>
<td>–9.8</td>
<td>0.6</td>
</tr>
<tr>
<td>June</td>
<td>92.0</td>
<td>23.5</td>
<td>–29.5</td>
<td>1.6</td>
<td>21.5</td>
<td>1.4</td>
</tr>
<tr>
<td>July</td>
<td>100.3</td>
<td>25.6</td>
<td>54.4</td>
<td>–0.7</td>
<td>3.0</td>
<td>–1.0</td>
</tr>
<tr>
<td>August</td>
<td>100.5</td>
<td>25.1</td>
<td>65.5</td>
<td>–0.6</td>
<td>21.5</td>
<td>1.3</td>
</tr>
<tr>
<td>September</td>
<td>79.8</td>
<td>21.7</td>
<td>15.7</td>
<td>–1.0</td>
<td>–58.3</td>
<td>–1.1</td>
</tr>
<tr>
<td>October</td>
<td>71.5</td>
<td>15.6</td>
<td>–71.5</td>
<td>0.0</td>
<td>–25.0</td>
<td>–0.4</td>
</tr>
<tr>
<td>November</td>
<td>74.5</td>
<td>10.7</td>
<td>–10.5</td>
<td>–1.8</td>
<td>–62.0</td>
<td>2.5</td>
</tr>
<tr>
<td>December</td>
<td>81.0</td>
<td>5.9</td>
<td>–43.3</td>
<td>–4.0</td>
<td>–30.8</td>
<td>2.8</td>
</tr>
</tbody>
</table>

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

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**Table 3. Mean canopy height (Ht) and forage mass (FM), and associated per-animal and per-hectare performance from steers grazing Caucasian bluestem at three levels.**

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Canopy</th>
<th>Animal and pasture response</th>
<th>ADG‡</th>
<th>SR‡</th>
<th>Animal day</th>
<th>Weight gain</th>
<th>EFU‡</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Ht</td>
<td>FM</td>
<td>kg</td>
<td>steer ha$^{-1}$</td>
<td>ha$^{-1}$</td>
<td>kg ha$^{-1}$</td>
<td></td>
</tr>
<tr>
<td>Short</td>
<td>14.6‡</td>
<td>1.42‡</td>
<td>0.77‡</td>
<td>9.7§</td>
<td>1019§</td>
<td>817§</td>
<td>4025§</td>
</tr>
<tr>
<td>Medium</td>
<td>32.2</td>
<td>2.31</td>
<td>0.80</td>
<td>7.8</td>
<td>813</td>
<td>657</td>
<td>3430</td>
</tr>
<tr>
<td>Tall</td>
<td>39.8</td>
<td>2.75</td>
<td>0.71</td>
<td>7.0</td>
<td>700</td>
<td>518</td>
<td>2806</td>
</tr>
</tbody>
</table>

Significance ($P$):

- Treatment: 0.01<br>
- Linear: <0.01<br>
- LOF¶: 0.11

† ADG = average daily gain; SR = stocking rate; EFU = effective feed unit.
‡ Each value is the mean of multiple measurements within years for two pasture replicates in 2 yr ($n = 4$).
§ Each value is the mean of two pasture replicates in 3 yr and one pasture replicate in 1 yr ($n = 7$).
¶ LOF = lack of fit.
was attributed to the disproportionate decline from the Short to the Medium treatments compared with the decline between the Medium and Tall treatments (Table 3). An important point to note in this environment was that the mean (30 yr) August rainfall was 100 mm (Table 2) and animal gains before mid-July were generally maintained into September (Fig. 1). A small decrease in the rate of gain, however, was apparent by early August (quadratic fit; \( P = 0.02 \)). Further testing revealed that the intercepts of the three treatments were similar \(( P = 0.15 \)) and that the significant quadratic component, although small, resulted from the response in the Tall treatment (Fig. 1). The Tall had greater gains initially but then rates of gain declined later in the season. These responses, including the decline in cumulative gain for Tall, were in contrast to Oklahoma results that suggested grazing should be terminated by late July to avoid reduced animal performance (Coleman and Forbes, 1998).

Steer gain per hectare, as an estimate of pasture productivity, averaged 817 kg from the Short and declined linearly to 518 kg with increasing FM. This difference was attributed to animal d ha\(^{-1}\) which declined linearly from 1019 d ha\(^{-1}\) for the Short to 700 d ha\(^{-1}\) for the Tall (Table 3) with no significant variation in ADG. Effective feed units, another estimate of pasture productivity, was greatest for the Short averaging 4025 kg ha\(^{-1}\) and declined linearly to 2806 kg ha\(^{-1}\) for the Tall.

Both animal and pasture productivity indicated that (when continuously stocked) Caucasian bluestem was best used if stocked heavily with the canopy maintained at about 15-cm in height. This observation could be related to increased tillering and a dense cover of leafy growth in the Short treatment in contrast to the more open canopies under the Medium and Tall treatments. This would be consistent with the observations of Belesky and Fedders (1995) who reported increased tiller populations and a dense ground cover with increased defoliation frequency. Forwood et al. (1988) noted continuous tiller formation during grazing and Christiansen and Svejcar (1988) and Svejcar and Christiansen (1987b) reported greater tiller density m\(^{-2}\) under heavy vs. light stocking of this species. Stand survival was of interest in this trial and will be addressed later in the manuscript.

### Canopy Characteristics

#### Whole Canopy

Averaged over the three FM treatments, the pasture sward was 98.0% Caucasian bluestem and 2.0% other weedy grasses \((\text{crabgrass} (\text{Digitaria} \text{spp.}))\) with weeds contributing little to the FM (Table 4). Mass of Caucasian bluestem increased linearly from Short to Tall, as noted for the total FM (Table 3). Canopies differed among treatments in IVTOD, CP, and NDF and its constituent fiber fractions (Table 4). Concentrations decreased linearly in IVTOD (from 652 to 618 g kg\(^{-1}\)) and CP (from 98 to 66 g kg\(^{-1}\)), whereas NDF increased (from 644 to 749 g kg\(^{-1}\)) from the Short to Tall treatments. Constituent fiber fractions showed the same response as NDF, with the exception of lignin which was not altered \(( P = 0.07)\). These data indicate that the Short FM is of greater nutritive value than the Medium and Tall FM. This relationship is also consistent with the often observed relationship of reduced nutritive value with increasing plant morphological development (Anderson and Matches, 1983; Dabo et al., 1987, 1988; Harmoney and Hickman, 2004). This difference, however, is not reflected in steer ADG, which was similar among pasture treatments (Table 3).

### Table 4. Forage mass (FM), botanical composition and in vitro true organic matter disappearance (IVTOD), crude protein (CP), neutral detergent fiber (NDF), and fiber fractions (dry matter basis).

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Pasture FM (\text{kg ha}^{-1})</th>
<th>Other FM</th>
<th>IVTOD (\text{g kg}^{-1})</th>
<th>CP (\text{g kg}^{-1})</th>
<th>NDF (\text{g kg}^{-1})</th>
<th>ADF</th>
<th>HEMI</th>
<th>CELL</th>
<th>Lignin (\text{g kg}^{-1})</th>
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<tbody>
<tr>
<td>Short</td>
<td>1381‡</td>
<td>39</td>
<td>652</td>
<td>98</td>
<td>644</td>
<td>388</td>
<td>256</td>
<td>320</td>
<td>65</td>
</tr>
<tr>
<td>Medium</td>
<td>2220</td>
<td>90</td>
<td>645</td>
<td>76</td>
<td>718</td>
<td>420</td>
<td>299</td>
<td>360</td>
<td>56</td>
</tr>
<tr>
<td>Tall</td>
<td>2724</td>
<td>30</td>
<td>618</td>
<td>66</td>
<td>749</td>
<td>441</td>
<td>308</td>
<td>380</td>
<td>59</td>
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<table>
<thead>
<tr>
<th>Treatment</th>
<th>Linear</th>
<th>LOF$\S$</th>
<th>ADF</th>
<th>HEMI</th>
<th>CELL</th>
<th>Lignin</th>
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<tbody>
<tr>
<td>0.06</td>
<td>0.03</td>
<td>0.52</td>
<td>0.05</td>
<td>0.04</td>
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<td>0.07</td>
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<td>0.20</td>
<td>0.13</td>
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</table>

† ADF = acid detergent fiber; HEMI = hemicellulose; CELL = cellulose.
‡ Each value is the mean of multiple harvest within year for two pasture replicates and 2 yr \((n = 4)\).
§ LOF = lack of fit.

![Fig. 1. Cumulative steer gain from Caucasian bluestem during the grazing season (22 May through 14 September) for Short \((y = 8.99 + 22.81X - 0.37X^2)\), Medium \((y = 8.99 + 21.70X - 0.22X^2)\) and Tall \((y = 8.99 + 26.25X - 0.84X^2)\) forage mass treatments [mean of 4 yr and two land replicates (1 yr had one land replicate)].](image-url)
Canopy Fractions

Morphology of Caucasian bluestem was altered by the experimental treatments and as canopy height increased, the proportion of the stem in the canopy increased linearly from Short to Tall (Table 5). Leaf proportions did not differ \( (P = 0.13) \). The need to maintain a leafy Caucasian bluestem pasture to provide adequate nutritive value for growing animals was noted by Dabo et al. (1987, 1988) and Svejcar and Christiansen (1987b). Importance of an adequate quantity of leaf mass to support animal performance was also emphasized by Forbes and Coleman (1993). Reducing the proportion of stems may aid in diet selection of leafy material by grazing ruminants. The proportion of the dry matter that consisted of heads was <2.8% and probably of little importance.

Experimental treatments did not alter the IVTOD of the leaf tissue (mean = 832 g kg\(^{-1}\), stem tissue \( (P = 0.07\); mean = 595 g kg\(^{-1}\) ) or the dead tissue (mean = 527 g kg\(^{-1}\) ) (Table 5). These mean values are consistent with values reported in the literature (Dabo et al., 1988; Forbes and Coleman, 1993).

Crude protein was greater in the Short treatment for all three plant fractions (leaf, stem, and dead) and declined linearly from the Short to the Tall. Only the CP concentrations observed in the leaf tissue would be adequate to support steer daily gain (0.76 kg d\(^{-1}\); NRC, 1996). The NDF concentrations of leaf tissue were not altered by the canopy height treatments (mean = 637 g kg\(^{-1}\) ) but linear increases in NDF occurred in both the stem (from 778 to 796 g kg\(^{-1}\) ) and dead (from 765 to 789 g kg\(^{-1}\) ) fractions (Table 5). The head fraction was a small part of the Caucasian bluestem canopy and was not altered by canopy height treatments (Table 5). The IVTOD, CP, and NDF of the head fraction averaged 583, 66, and 724 g kg\(^{-1}\), respectively (data not shown).

![Fig. 2. Strata distribution and associated overall SE for Caucasian bluestem continuously stocked Short, Medium, and Tall for forage mass (shaded area, FM, kg ha\(^{-1}\)), proportion (open rectangle, Prop, %), in vitro true organic matter disappearance (closed triangle, IVTOD, g kg\(^{-1}\)), crude protein, (closed circle, CP g kg\(^{-1}\)), and neutral detergent fiber (closed rectangle, NDF, g kg\(^{-1}\)) for: (a) leaf (Mass = 15.7, Prop = 4.6, IVTOD = 5.2, CP = 1.4, and NDF = 13.7), (b) stem (Mass = 94.8, Prop = 1.4, IVTOD = 18.5, CP = 2.3, and NDF = 5.0), (c) head (Mass = 7.9, Prop = 0.2, IVTOD = 77.6, CP = 11.1, and NDF = 54.6), and (d) dead (Mass = 190.8, Prop = 4.4, IVTOD = 9.7, CP = 0.8, and NDF = 3.4) fractions.]

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Proportion</th>
<th>IVTOD</th>
<th>CP</th>
<th>NDF</th>
</tr>
</thead>
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<tr>
<td></td>
<td>Leaf</td>
<td>Stem</td>
<td>Head</td>
<td>Dead</td>
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<tr>
<td>Short</td>
<td>27.2†</td>
<td>41.8</td>
<td>2.4</td>
<td>28.6</td>
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<tr>
<td>Medium</td>
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</tr>
<tr>
<td>Tall</td>
<td>19.6</td>
<td>51.5</td>
<td>2.6</td>
<td>26.3</td>
</tr>
</tbody>
</table>

Significance (P):
- Treatment: 0.24 0.05 0.78 0.41 0.29 0.14 0.27 0.02 0.04 0.03 0.30 0.08 0.06
- Linear: 0.13 0.03 0.65 0.33 0.17 0.07 0.27 0.01 0.02 0.02 0.72 0.04 0.03
- LOF‡: 0.85 0.27 0.65 0.38 0.72 0.54 0.23 0.08 0.20 0.06 0.17 0.60 0.65

† Each value is the mean of multiple harvest within year for two pasture replicates and 2 yr \((n = 4)\).
‡ LOF = lack of fit.
little evidence of a gradient caused by maturity. This consistency is also evident for both CP and NDF with treatment being the head fraction of the Short which is more variable. An exception is the head fraction of the masticate and difference (Diff) between masticate and the FM sample being positive for CP concentration of the FM (Table 4) and of the stem fraction. Very little DM was found in the head fraction. Leaf mass and distribution of leaf within the canopy did not vary as much as might be expected from Short to Tall treatments. Mass in the stem fractions increased from the Short to the Tall treatments.

Examining the proportion (%) of total mass contributed by each fraction, by stratum, showed that leaf increased up to about 15 cm for the Short and 30 cm for Medium and Tall treatments, then declined (Fig. 2). Proportion of the FM in stems was similar (45–55%) until approximately 45 cm and then declined at the higher strata. The head fraction was only a small proportion at the lower strata then increased at the higher strata and is consistent with the decline in proportion of leaf and stem tissue. The dead fraction was generally greater at the lower strata (0–15 cm) then declined at the higher strata.

The IVTOD of the four tissue fractions is surprisingly consistent across the strata regardless of FM treatment. An exception is the head fraction of the Short which is more variable. This consistency is also evident for both CP and NDF with little evidence of a gradient caused by maturity.

### Dry Matter and Nutritive Value Distribution

Plotting the distribution of FM and its nutritive value, by 5-cm strata for each canopy fraction (including associated overall SE’s), provides a means of representing canopy structure of each plant fraction among the three FM treatments (Fig. 2). In each treatment, mass (kg ha⁻¹) is greatest for the stem fraction. Very little DM was found in the head fraction. Leaf mass and distribution of leaf within the canopy did not vary as much as might be expected from Short to Tall treatments. Mass in the stem fractions increased from the Short to the Tall treatments.

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The IVTOD of the four tissue fractions is surprisingly consistent across the strata regardless of FM treatment. An exception is the head fraction of the Short which is more variable. This consistency is also evident for both CP and NDF with little evidence of a gradient caused by maturity.

### Digestive Mass

Total leaf and stem mass, as well as the digestible leaf and stem mass, increased linearly with increasing FM (Table 6). Total mass of dead and head material, as well as their digestible masses, were not altered by FM. The proportion of the digestible leaf mass was similar among FM treatments, whereas the proportion of digestible stem mass increased linearly. Reduction in digestible proportion of the pasture that is stem in the Short, along with similar quantities of digestible dead material, indicates that steers grazing the Short would have had a greater opportunity to select a diet consisting of more leaf. Further, because quantities of digestible leaf and stem were greater for Medium and Tall, the production of digestible leaf and stem had apparently declined, relative to Short, and growth was not adequate at their FM to support a stocking rate comparable to the Short.

### Grazing Behavior

Masticate samples, representing the diets selected from the FM, were greater in nutritive value than canopy average and this is reflected in the ‘Diff’ values (difference between the masticate sample and the FM sample) being positive for IVTOD and CP and negative for NDF from the Medium and Tall (Table 7). This response is attributed to selective consumption of green leaf and is consistent with other literature (Burns and Sollenberger, 2002). Diets selected, however, were similar among the FM treatments in IVTOD (mean = 761 g kg⁻¹), CP (110 g kg⁻¹) and NDF (667 g kg⁻¹) (Table 7). This is consistent with the observation of similar steer ADG among the three FM treatments (Table 3) in this study and also as reported by Forbes and Coleman (1993). The selected diet (masticate) has adequate CP concentrations to support the ADG (0.76 kg) of steers in this study (NRC, 1996). This is in contrast to the CP concentration of the FM (Table 4) and of the stem and dead fractions composing the canopy (Table 5). Difference (Diff) between the IVTOD, CP, and NDF concentrations of the selected diet and the canopy offered was altered by the FM treatments (Table 7). The Diff in IVTOD and CP increased linearly and the NDF concentrations decreased linearly with increasing FM. This indicates that steers increased their selectivity (fed from a smaller portion of the canopy) as FM increased from Short to Tall. Further, the organic matter intake of Caucasian bluestem pasture was reported by Forbes and Coleman (1993) to be best explained by green leaf mass with maximum intake occurring at 1.07 Mg ha⁻¹ of green leaf mass.
mass. In our study, green leaf mass averaged 0.38 Mg ha\(^{-1}\) for the short and increased to 0.51 Mg ha\(^{-1}\) for the tall (Table 6). Based on the results of Forbes and Coleman (1993), daily dry matter intake, especially of green leaf mass, would be greatest on the Tall vs. the Short, and provides indirect evidence that FM of the Short treatment in our study was probably inadequate for maximum daily DM intake and may have limited ADG. This is further supported by results from Ackerman et al. (2001) who noted that grazing time of steers increased from light to heavy stocking when grazing Plains Old World bluestem (\textit{Bothriochloa ischaemum} L. Keng).

### Plant Persistence

After the year of establishment, and at the initiation of this trial, excellent stands of Caucasian bluestem were present. Stand counts (by line transect), made in May after termination of 5 yr of grazing (7 yr from establishment), differed among the FM treatments (\(P = 0.05\)). During the experiment Caucasian bluestem stands declined linearly with increased FM resulting in 70.0\% cover for the Short, 40.2\% for the Medium, and 22.8\% for the Tall (SE = 9.1\%). Under continuous defoliation at \(\leq 14\) cm, Caucasian bluestem pillowed profusely with few areas of bare ground. This was in contrast to the more erect growth habit expressed when grazed \(>14\) cm and accompanied with areas of bare ground noted for the Medium and Tall treatments. These results are consistent with the literature regarding importance of maintaining Caucasian bluestem in a young and actively growing state (Dabo et al., 1988).

Improved stand density under heavy stocking (Svejcar and Christiansen, 1987b; Christiansen and Svejcar, 1988) has been attributed to both crown architecture (sites for tiller initiation and protection) and plant physiology (water use efficiency) ensuring a nongrazeable basal-stem mass for nonstructural carbohydrate storage and reduced water stress to maintain plant survival under frequent close defoliation (Christiansen and Svejcar, 1987, 1988; Svejcar and Christiansen, 1987a, 1987b; Coyne et al., 1982; Philipp et al., 2007).

### SUMMARY AND CONCLUSIONS

Caucasian bluestem stands were readily established and pastures effectively used by steers. Canopy heights of about 14, 32, and 40 cm resulted in FM levels of 1.42, 2.31 and 2.75 Mg ha\(^{-1}\) and resulted in similar steer ADG (mean = 0.76 kg) when continuously stocked. Pasture at the Short canopy height, however, produced greatest weight gains ha\(^{-1}\) averaging 817 kg ha\(^{-1}\) when stocked at 9.7 steer ha\(^{-1}\). Pastures grazed at the 32 and 40 cm mean canopy heights were stocked with fewer cattle (7.8 and 7.0 head ha\(^{-1}\) respectively) to maintain the FM and produced less gain ha\(^{-1}\). Pasture productivity (calculated as effective feed units) was greatest for Short FM averaging 4025 kg ha\(^{-1}\) and declined linearly to 2806 kg ha\(^{-1}\) for the Tall FM. Masticate data indicated that steers were effectively used by steers. Canopy heights of about 14, 32, and 40 cm resulted in FM levels of 1.42, 2.31 and 2.75 Mg ha\(^{-1}\) and declined linearly to 2806 kg ha\(^{-1}\) for the Tall FM. Consequently, close continuous defoliation was beneficial and would be an objective in production systems.

Caucasian bluestem has potential as a warm-season pasture for the mid-Atlantic Region. Its productivity, however, is limited mainly to mid-May through mid-September. Although this period interfaces well with the general growth curve for adapted cool-season perennial grasses, the land devoted to Caucasian bluestem will be nonproductive for much of the year. Interseeding of Caucasian bluestem in the fall with a cool-season annual for either a harvested forage (removed in late March) or grazing in late winter warrants evaluation and may have merit in a production system.

### REFERENCES


