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Continuous grazing of mixed native warm-season grass in the fescue belt

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Abstract

Continuous, season-long (May–August) grazing is the most commonly used grazing strategy among tall fescue [*Lolium arundinaceum* (Schreb.) Darbysh.] belt beef (*Bos taurus*) producers. However, little information is available regarding the feasibility of managing native warm-season grass (NWSG) pastures in this region with continuous, season-long grazing. We compared stand sustainability, beef cattle performance, and pasture production between continuous (CONT), season-long grazing and heavy-early (HEAVY), a modified continuous grazing strategy, on mixed-NWSG pastures. Heavy-early was designed to match the growth curve of NWSG, with an initial stocking target of 1.25 times the CONT density until 25 June, at which time stocking was reduced to 0.75 times the CONT density. Pastures were mixed big bluestem (*Andropogon gerardii* Vitman), indiangrass [*Sorghastrum nutans* (L.) Nash], and little bluestem [*Schizachyrium scoparium* (Michx.)]. The plant population (plants m^{-2}) was similar between treatments, but years differed ($P < .001$), with a 35% reduction from 2017, the third and final year of grazing, to 2018. Despite the decline in plant density, overall tiller density (tillers m^{-2}) increased 14%, indicating that the grazing strategies were likely sustainable. The grazing strategies had similar ($P > .05$) average daily gain (ADG; kg d^{-1}), animal-days ha^{-1}, and total gain (kg ha^{-1}). Weaned steer ADG was 0.98 kg d^{-1} for CONT and 0.89 kg d^{-1} for HEAVY. Total gain was 379 kg ha^{-1} for CONT and 334 kg ha^{-1} for HEAVY. Continuous grazing appears to be an appropriate strategy for managing NWSG pastures in the Fescue Belt.

1 | INTRODUCTION

Native warm-season grass (NWSG) has been used as livestock forage in North America since European settlement. However, it has had limited use in the eastern United States in recent decades. Tall fescue is the primary forage grass grown across a region of the eastern United States known as the Fescue Belt, which lies east of the Great Plains and extends from the southern edge of glaciation to

Abbreviations: AD, animal-days ha^{-1}; ADF, acid detergent fiber; ADG, average daily gain; BB, big bluestem; BBIG, big bluestem/indiangrass; CONT, continuous, season-long stocking; CP, crude protein; IG, indiangrass; GAIN, total gain ha^{-1}; HEAVY, heavy-early stocking; IVTDMD48H, in vitro true dry matter digestibility 48 h; LB, little bluestem; NDF, neutral detergent fiber; NIRS, near-infrared spectroscopy; NWSG, native warm-season grass.

the Atlantic and Gulf Coastal Plains. In the Fescue Belt, tall fescue is grown on approximately 14 million ha (Buckner, Powell, & Frakes, 1979; Stuedemann & Hoveland, 1988), with most of that planted to the endophyte-infected KY-31 cultivar (Schmidt & Osborn, 1993; Stuedemann & Hoveland, 1988). Tall fescue (hereafter "fescue"), a perennial cool-season grass, has many positive attributes as a forage species. However, fescue presents grazing managers with a number of challenges. One such challenge, referred to as the "summer slump" (Burns & Fisher, 2013; Burns, Mochrie, & Timothy, 1984), is the slowdown in growth of cool-season grass caused by warm summer temperatures and compounded by fescue toxicosis (Kallenbach, 2015; Schmidt & Osborn, 1993; Stuedemann & Hoveland, 1988). Fescue toxicosis, caused by an endophytic fungus (*Epichloe coenophiala*), has been estimated to cost the beef (*Bos taurus*) cattle industry up to US$2 billion annually (Hoveland, 1993; Kallenbach, 2015; Schmidt & Osborn, 1993), adjusted to 2019 dollars. The effects of fescue toxicosis are most apparent during spring and summer (Kallenbach, 2015; Roberts & Andrae, 2004).

One way to mitigate problems associated with the summer slump and fescue toxicosis is to integrate perennial warm-season grasses into fescue-based grazing systems (Anderson, 2000; Burns & Fisher, 2013; Keyser et al., 2016; Moore, White, Hintz, Patrick, & Brummer, 2004) and rotate cattle onto warm-season grass when growth rates of fescue decline in late spring and summer. Perennial warm-season grass forage options in the Fescue Belt include bermudagrass (*Cynodon dactylon* L.) and NWSG such as switchgrass (*Panicum virgatum* L.), big bluestem (*Andropogon gerardii* Vitman; BB), indiangrass [*Sorghastrum nutans* (L.) Nash; IG], little bluestem [*Schizachyrium scoparium* (Michx.); LB], and eastern gamagrass [*Tripsacum dactyloides* (L.) L.]. Native warm-season grasses are low input, endophyte free, persistent, productive during summer, and drought tolerant (Anderson, 2000; Boyer, Zechiel, Keyser, Rhinehart, & Bates, 2020; Keyser, Bates, Waller, Harper, & Doxon, 2012; Keyser, Harper, Bates, Waller, & Doxon, 2011; Lowe et al., 2015).

Producer acceptance and utilization of NWSG in the Fescue Belt has been slow. One reason may be that continuous grazing, which is the most common grazing strategy of Fescue Belt beef producers, is considered incompatible with NWSG forages in the eastern United States (Henning, 1993; Lacefield, Henning, & Smith, 1997; Smith, Lacefield, & Keene, 2009). Continuous grazing is simpler and requires less labor and infrastructure than rotational grazing. However, recommendations for Fescue Belt producers state that NWSG must be rotationally grazed to be productive and sustainable (Henning, 1993; Lacefield et al., 1997; Smith et al., 2009). The increased labor and infrastructure associated with rotational grazing may serve as an impediment to adoption of NWSG for typical producers. However, data on production-scale continuous, season-long (May–August) grazing of NWSG in the eastern United States are very limited. Working in Mississippi, Monroe, Burger, Boland, and Martin (2017) reported that continuous, season-long, grazing of NWSG with steers resulted in increased average daily gain (ADG) compared with mixed fescue and bermudagrass pastures.

The primary objective of our research was to assess the feasibility of continuous, season-long (May–August) grazing of mixed stands of BB, IG, and LB (hereafter, "mixed NWSG") in the Fescue Belt. In addition, we compared forage mass and nutritive value, stand sustainability, beef cattle performance, and pasture production of mixed NWSG pastures using either continuous, season-long grazing or heavy-early (HEAVY), a modified continuous grazing strategy.

Core Ideas

- Native warm-season grass (NWSG) pastures were continuously grazed for 3 yr.
- Continuous grazing strategies had similar animal performance and pasture production.
- Continuous grazing strategies were economical and sustainable throughout the study.
- Continuous grazing appears appropriate for managing NWSG pastures in Fescue Belt.

2 | MATERIALS AND METHODS

The study was conducted at the East Tennessee Research and Education Center, Holston Unit (HOLSTON) near Knoxville, TN (35°58′ N, 83°51′ W, 253 m asl), in Knox County, and a private agricultural operation (LOUDON) in Loudon County, TN (35°45′ N, 84°18′ W, 259 m asl). Experimental NWSG pastures ranged from 8.0 to 10.5 ha (mean, 9.1 ha), which is typical of pastures used for beef production in the region. Soils at HOLSTON were primarily Shady–Whitwell complex (fine-loamy, mixed, subactive, thermic Typic Hapludults; fine-loamy, siliceous, semiactive, thermic Aquic Hapludults; respectively). LOUDON soils were primarily Alcoa loam (fine, parasesquic, thermic Rhodic Paleudults), Cumberland silty clay loam (fine, mixed, semiactive, thermic Rhodic Paleudalfs), and Emory silt loam (fine-silty, siliceous, active, thermic Fluventic Humic Dystrudepts) (Soil Survey Staff, 2019).

2.1 | Establishment

Pastures were planted to mixed NWSG in May 2012. The seed mix consisted of 60% BB, 30% IG, and 10% LB based on seed mass, all 'KY Ecotype' (Roundstone Native Seed, LLC). The seed mix was developed to create a more diverse forage base and to better distribute forage availability over space, grazing season, and years. Pastures were soil tested prior to planting using a 1:1 soil/solution test for pH and Mehlich 1 extractants for P and K. All pastures had soil pH >5.2 and P and K at or above medium levels (Savoy, 2009), so no amendments were applied. A no-till drill was used to plant each pasture with 11.2 kg pure live seed ha^{-1}. All pastures were predominantly fescue before conversion and were treated with glyphosate [N-(phosphonomethyl) glycine] at 2.24 kg a.i. ha^{-1} in fall 2011 and again in spring 2012 to control grass and broad-leaf weed competition prior to planting. Immediately after planting, all pastures were treated with imazapic {2-[[(RS)-4-isopropyl-4-methyl-5-oxo-2-imidazolin-2-yl]]-5-methylnicotinic acid} at 70 g a.i. ha^{-1} for pre-emergent control of grass and broadleaf weed competitors. Drought conditions in 2012 resulted in unsatisfactory plant populations in LOUDON pastures, so pastures were successfully replanted in 2013 following the same protocols.

2.2 | Treatments

Native warm-season grasses grow rapidly from mid-April through late June; growth rates are slower in the remainder of the growing season. The difference in productivity between early and late season presents a dilemma for producers who use continuous grazing systems. If they stock heavily enough to keep up with rapid early-season grass growth they may overutilize the slower-growing forage later in the summer or, conversely, if they stock more lightly to accommodate the late season, early-season growth will lead to overmature swards (Backus et al., 2017). The HEAVY continuous grazing strategy was developed to address this issue by more closely matching grazing pressure to the growth curve of NWSG by incorporating a single stocking density adjustment during the grazing season. The initial target stocking density for HEAVY was set at 1.25 times the continuous, season-long density to provide increased grazing pressure to match rapid early-season grass growth. On 25 June, stocking was reduced to 0.75 times the continuous density to reduce grazing pressure to match slowing grass growth. The HEAVY strategy is one step up in management effort relative to continuous, season-long grazing but is less management intensive than rotational grazing. Heavy-early grazing may benefit producers by increasing total beef production without sacrificing sustainability (i.e., long-term, >10 yr, vigor and productivity) of the grass sward. Sustainability may be improved by reducing grazing pressure later in the grazing season when grass growth has slowed and plants are building carbohydrate reserves leading into winter dormancy.

Two grazing treatments were used in the 3-yr study: season-long (May–August) continuous stocking (CONT) and HEAVY. All initial stocking was on a 272-kg steer basis. Initial stocking was adjusted depending on assessment of carrying capacity (e.g., initial stocking density of CONT ranged from 861 to 1,141 kg ha^{-1}, depending on pasture and year), but the target ratio of HEAVY/CONT stocking densities was held constant. Cattle at HOLSTON were Angus or Angus cross, and cattle at LOUDON were Angus cross. Weaned steers were the model animal, although heifers and cow-calf pairs (grazers only) were used as necessary to achieve stocking targets after adjusting for metabolic weight (272-kg steer basis). Testers (i.e., animals from which data were collected and remained on experimental pastures throughout the grazing season; Mott & Lucas, 1952), were all weaned steers except for 2016 and 2017, when weaned heifers were also used but analyzed separately from the steers. Pastures assigned to HEAVY were reduced to 0.75 times the initial CONT stocking density on 25 June each year, based on actual weights.

2.3 | Experimental design

The experiment was a randomized complete block design with three pastures per block, and all pastures were measured for 3 yr (2015–2017). Sites (HOLSTON and LOUDON) were blocks and pastures were experimental units. Treatments (CONT or HEAVY) were maintained throughout the study (i.e., not re-randomized each year) to allow sustainability of the grazing strategies to be assessed.

2.4 | Grazing management

Initial stocking occurred once grass canopy height reached approximately 40 cm, which occurred between 28 April and 10 May, depending on the year. Stocking densities were intended to maintain mean canopy height between 30 and 46 cm over the majority of a pasture (Backus et al., 2017). No adjustments were made to animal numbers during the grazing season. For HEAVY, grazers removed from pastures on 25 June were randomly selected. Animals were removed as necessary to reduce stocking to 75% of the CONT stocking density. Animals removed were representative of animals on the pasture. Grazing was terminated each year when average grass canopy height fell below

30 cm in a pasture, regardless of treatment. All animal care was in accordance with UT-IACUC Protocol No. 2258 approved on 14 Apr. 2014 and 5 Apr. 2017 by the Institutional Animal Care and Use Committee. Free access to shade, water, and mineral supplement were provided in all pastures.

2.5 | Pasture management

Prior to onset of grazing in Year 1 of the experiment, basic soil tests (as described in Establishment) were conducted for all pastures. No N was applied during the study. Pastures required occasional weed control, and where needed, metsulfuron methyl [Methyl 2-[[[[(4-methoxy-6-methyl-1,3,5-triazin-2yl)amino]carbonyl]amino]sulfonyl]benzoate] and chlorsulfuron [2-Chloro-N-[(4-methoxy-6-methyl-1,3,5-triazin-2-yl)aminocarbonyl]benzenesulfonamide], and aminopyralid (2-pyridine carboxylic acid, 4-amino-3,6-dichloro-) or 2,4-D [(2,4-dichlorophenoxy) acetic acid] were applied. Pastures at LOUDON were burned annually in mid-to-late March. HOLSTON pastures were not burned.

2.6 | Sampling methods

Forage samples were taken corresponding to each weigh day (see below) throughout the grazing season. Fifteen plant tissue samples (0.25 m^2 each) were clipped and weighed per pasture. For each sample, two cuts were made. First, forage within the grazing horizon was clipped, and then all remaining vegetation below the grazing horizon was clipped to 5 cm to allow for estimation of total forage mass. Grazing horizon was determined based on the position within grass plants above which grazing was concentrated. The grazing horizon was separated from lower forage strata to more accurately represent what animals were eating and to avoid biasing forage nutritive values low by including material from lower strata that is not typically consumed (Backus et al., 2017; Keyser et al., 2016).

Both samples (grazing horizon and below grazing horizon) were dried in a forced-air drying oven (Model EWN-68-7G2, Wisconsin Oven Corporation) at 55 °C for 72 h and weighed to determine dry weight portion of the forage mass (including both samples). The dried grazing horizon samples were ground using a Wiley Mill (Thomas Scientific) to 2-mm and then ground using a UDY Mill to pass through a 1-mm screen (UDY Corporation). Near-infrared spectroscopy (NIRS) technology (FOSS 5000, FOSS NIRSystems, Inc.) was used to determine forage nutritive vales. Equations for the forage nutritive analysis and biomass quality were standardized and checked for accuracy using the grass hay equation developed by the NIRS Forage and Feed Consortium (McIntosh et al., 2016). WinISI II (Infrasoft International LLC) software was used for NIRS analysis. The Global H statistical test compared the samples against the model and other samples within the database for accurate results; all forage samples fit the equation with H <3.0 and are reported accordingly (Murray & Cowe, 2004). Forage nutritive analyses included crude protein (CP), in vitro true dry matter digestibility 48 h (IVTDMD48H), acid detergent fiber (ADF), and neutral detergent fiber (NDF). All reported nutritive values were on a dry matter basis and are presented accordingly.

Plant and tiller counts were conducted annually (2015–2018) in the spring at grazing initiation at 25 randomly selected points distributed throughout each pasture. During 2018, a nongrazing year, counts were conducted in early May, which corresponded to grazing initiation for the 2015–2017 grazing seasons. At each point, the total number of plants of all mixed NWSG combined (BB, IG, and LB) within a 0.25-m^2 quadrat was recorded in 2015 and 2016. In addition to the combined (all species) plant count, plant counts were conducted by species in 2017 and 2018. For each species, tillers of the plant closest to the right rear corner of the sampling frame were counted and recorded. For 2017 and 2018, plant population (plants m^{-2}) was multiplied by tiller count (tillers plant^{-1}) to calculate tillers m^{-2} for individual species and all species combined. Grass canopy height (not extended leaf length) was taken biweekly throughout the grazing season beginning immediately prior to grazing initiation. Heights were recorded per species to the nearest centimeter at 25 randomly selected points per pasture.

Cattle were weighed at grazing initiation, at 28-d intervals throughout the grazing season, and at termination of grazing, for a total of 4 to 5 weigh days, depending on the length of the grazing season. Weights at initiation and termination of grazing were taken on two consecutive days, and the mean was used as "on" and "off" weight, respectively. Scales were calibrated annually. Average daily gain (kg d^{-1}) was calculated per pasture and year and based only on tester animals. The ADG of individual tester animals was the difference between initial and final weight divided by the total number of days on test. Pasture productivity was measured by animal use days (AD; d ha^{-1}) and total gain (GAIN; kg ha^{-1}) per pasture. Animal-days were the total number of grazing days ha^{-1} for tester animals and grazers based on metabolic weight (272-kg steer basis). Total gain was calculated by multiplying ADG by AD. For HEAVY pastures, GAIN was calculated as the weighted mean (number of days) of gains for the period from initiation of grazing to partial destocking on 25 June (early-season) and from 25 June to termination of grazing (late-season).

2.7 | Pasture budgets

Enterprise budgets were developed to estimate establishment and operational costs for grazing mixed NWSG. The University of Tennessee Switchgrass Budget (University of Tennessee Department of Agricultural and Resource Economics, 2009) was used to calculate establishment and production costs, based on a 10-yr useful production life. Establishment costs were annualized across the 10-yr pasture life using an equivalent annual annuity formula and a 6% annual interest rate. The annualized establishment cost was added to the annual operational costs to determine total annual production cost. Establishment costs included seed, herbicide, custom application of herbicide, custom no-till planting, custom mowing, and annual land rent. Finally, a 10% cost of re-establishment was included in the establishment budget to account for the risk of initial establishment failure and replanting. In addition to prorated establishment cost, operational costs included herbicide, fertilizer, custom application of herbicide and fertilizer, prescribed burning, and annual land rent. All costs were based on observed prices in Tennessee in 2018. Seed cost was US\$28.49 kg^{-1} for BB, US\$24.20 kg^{-1} for IG, and US\$35.20 kg^{-1} for LB. Cost of P was US\$1.19 kg^{-1}; no N, K, or lime were budgeted. We assumed 91 kg ha^{-1} P in the form of diammonium phosphate would be applied once every 3 yr over the course of a 10-yr stand life. Total annual pasture production cost (US\$ ha^{-1}) was divided by GAIN (kg ha^{-1}) to calculate cost of GAIN (US\$ kg^{-1}) for mixed NWSG.

2.8 | Statistical analyses

Forage mass was analyzed using a repeated-measures, mixed-effects ANOVA with split-plot arrangement of treatments with replication in the whole plot in SAS 9.4 (SAS Institute). Autoregressive repeated measures analysis was used because pastures received the same treatment each year of the study. Fixed effects were treatment (whole-plot factor), year (sub-plot factor), and sampling period (repeated measures factor) and all interactions among these factors. Random effects were block and appropriate interactions to form split-plot error terms. Forage nutritive values (CP, IVTDMD48H, NDF, and ADF) were analyzed using a mixed model ANOVA with repeated measures in SAS 9.4 (SAS Institute). Whereas for forage mass we were interested in difference among both years and sampling periods, for forage nutritive values we were only interested in differences among sampling periods, so years were pooled, and the repeated measures factor was sampling period. Fixed effects were treatment and sampling period, and random effects were block and interactions with block. Plant population and tiller counts were analyzed similarly to forage nutritive values, but the repeated measures factor was year because these metrics were measured annually. Fixed effects were treatment and year, and random effects were the same as for forage nutritive values. Grass heights were analyzed with indicator-variable regression to determine if cattle preferentially grazed any grass species. Grass species (BB, IG, and LB) were converted to indicator variables, which were tested for different intercepts and for linear and quadratic slopes. If slopes of the indicator variables were different, contrasts were run to determine where the differences occurred. Cattle performance (ADG) and pasture productivity (AD and GAIN) were analyzed with a similar mixed-model ANOVA as for-age nutritive values except that sampling periods within years were pooled.

Testing for fixed effects was done at the $\alpha = .05$ level of significance. If tests for fixed effects were significant, least squares means were compared using LSD. Dependent variables were checked for equal variance and normality by inspecting residual plots and Levene's and Shapiro–Wilk test statistics. All models were run with and without repeated measures, and the −2 Residual Log Likelihoods compared. If the more complex repeated measures models did not improve the −2 Residual Log Likelihood by at least five, repeated measures was dropped in favor of the simpler split-split-plot model for forage mass and split-plot models for all other variables.

2.9 | Rainfall and temperature

Weather data were recorded at the East Tennessee Research and Education Center Plant Science Unit near Knoxville, TN (35°54′7.39″ N, 83°57′26.81″ W), in Knox County, which was the closest weather station to both study sites. Weather data for the study period (2015–2018) were compared with long-term (30-yr) means at the same location.

3 | RESULTS & DISCUSSION

Temperature for all 3 yr was near or slightly above 30-yr means for almost all spring and summer months. Rainfall was above the 30-yr mean for all months in 2015 except May, which was drier than normal. Spring and summer rainfall in 2016 was below the mean for all months except June, with March and August being very dry (−53 and

TABLE 1 Stocking density at initiation of grazing seasons, 2015–2017, for evaluation of continuous grazing strategies for mixed native warm-season grass pastures at two sites, HOLSTON and LOUDON, in Knox and Loudon Counties, TN, respectively

Year	Site	Treatment[a] CONT	HEAVY	Stocking ratio[b]
		kg ha^{-1}		
2015	HOLSTON	920	1,092	1.19
	LOUDON	861	1,025	1.19
2016	HOLSTON	933	1,026	1.10
	LOUDON	994	1,231	1.24
2017	HOLSTON	964	1,130	1.17
	LOUDON	1,141	1,296	1.14

Note. All stocking was on a 272-kg steer basis.
[a] CONT, continuous, season-long, stocking of pastures; HEAVY, heavy-early continuous, season-long, stocking of pastures.
[b] Ratio of initial stocking density of HEAVY compared with CONT. Target stocking ratio was 1.25.

−82% of the mean, respectively). March and April 2017 were wet (82 and 102% above the mean, respectively), and August was dry (−82%; National Weather Service, 2019).

Due to logistical constraints (e.g., animal health and animal availability), actual stocking ratios differed from targets (1.25 ratio of HEAVY/CONT initial stocking densities). The 3-yr mean initial stocking densities for HOLSTON and LOUDON were 939 and 999 kg ha^{-1}, respectively, for CONT and 1,083 and 1,184 kg ha^{-1}, respectively, for HEAVY (Table 1). Actual 3-yr mean HEAVY/CONT initial stocking density ratios were 1.15 at HOLSTON and 1.19 at LOUDON. Despite not meeting the target, initial stocking density approached the target ratio in several instances (Table 1).

3.1 | Pasture characteristics

Despite the different stocking strategies, CONT and HEAVY had similar forage mass (Tables 2 and 3). Forage mass was greater in the first year (2015) of the study than in the two subsequent years (2016 and 2017), which were similar (Tables 2 and 3). Pastures at LOUDON were burned annually in mid-to-late March and as a result greened up approximately 10–14 d earlier than pastures at HOLSTON, which were not burned. In 2015, grazing initiation date was not adjusted to account for this early grass growth. As a result, much of the sward became overly mature, but animal performance and pasture production did not suffer, suggesting sufficient palatable forage was still available. In subsequent years, cattle were stocked earlier to compensate for earlier grass growth on burned pastures. Keyser et al. (2016) documented mean forage mass of 2.79 Mg DM ha^{-1} for a 3-yr big bluestem/indiangrass (BBIG) grazing experiment, which is within the range observed during this experiment (Table 3).

Seasonal forage mass reflected the growth curve of NWSG. Mass differed by 28-d sampling period (Tables 2 and 3), with less at grazing initiation (early May) and grazing termination (late August). Using a put-and-take grazing strategy, Backus et al. (2017) also found that forage mass of BBIG pastures generally increased after early spring. Forage mass was similar (range, 2–4 Mg DM ha^{-1}) at their north-central Tennessee study site and generally higher (range, 2–6 Mg DM ha^{-1}) at their southwest Tennessee study site compared with that observed in our study. In our study, without the flexibility to reduce stocking later in the summer, forage mass declined in both treatments. The overall similarity in forage mass between treatments for the full summer grazing season is not surprising because our treatments only served to shift grazing intensity within the season and did not alter it overall. Furthermore, HEAVY may have responded with enough compensatory growth (Belsky, Carson, Jensen, & Fox, 1993; Noy-Meir, 1993) following the more intensive grazing during the early part of the grazing season to have obscured any difference by mid-summer, when such differences should have been most pronounced. The lighter-than-intended initial HEAVY stocking also likely contributed to the lack of a mid-summer difference in forage mass. Regardless of patterns within or among years, ample forage mass was available in both treatments, which is crucial during hot summer months in the Fescue Belt because fescue is largely unproductive during this time of year (Roberts, Lacefield, Ball, & Bates, 2009), and NWSG can be used to fill this forage gap.

There was an interaction between treatment and sampling period for ADF (P = .019), but that was the only significant model for forage nutritive value that included treatment (Table 2). Although ADF increased throughout the grazing season for both treatments, with the greatest increase between Periods 1 and 2, HEAVY had greater ADF than CONT for Period 3 (early July) (Table 3; Figure 1) but was similar for Periods 4 (late July) and 5 (late August). There were no differences in forage nutritive

TABLE 2 Mixed model ANOVA results for forage mass and forage nutritive values of mixed native warm-season grass (NWSG) forage, 2015–2017, during mixed NWSG continuous grazing experiment in Knox and Loudon Counties, TN

Variable[a]	Effect	Numerator df	Denominator df	*F*-value	*P* > *F*
Forage mass	treatment[b]	1	5.94	0.57	.479
	year	2	12.33	12.32	.001***
	treatment × year	2	12.33	0.08	.922
	period[c]	4	25.85	5.92	.002**
	treatment × period	4	25.85	0.47	.761
	year × period	8	25.85	2.17	.065
	treat × year × period	8	25.85	0.46	.874
CP	treatment	1	3.45	0.13	.741
	period	4	14.70	101.13	<.001***
	treatment × period	4	14.70	2.34	.103
NDF	treatment	1	3.59	0.06	.827
	period	4	14.70	127.16	<.001***
	treatment ×period	4	14.70	1.78	.187
ADF	treatment	1	4.82	2.60	.171
	period	4	15.50	103.30	<.001***
	treatment × period	4	15.50	4.08	.019*
IVTDMD	treatment	1	4.39	0.01	.916
	period	4	15.30	55.05	<.001***
	treatment ×period	4	15.30	2.26	.111

Note. Forage mass was the combined dry weight of grazing horizon and below grazing horizon cuts of forage samples. Forage nutritive values were based only on the grazing horizon.

[a] ADF, acid detergent fiber; CP, crude protein; IVTDMD, in vitro true dry matter digestibility; NDF, neutral detergent fiber.

[b] Treatments represent continuous, season-long (May–August), and heavy-early continuous stocking of pastures.

[c] Forage mass was collected at grazing initiation, every 28-d sampling period thereafter, and at termination of grazing.

*Significant at the .05 probability level. **Significant at the .01 probability level. ***Significant at the .001 probability level.

values between CONT and HEAVY for CP, IVTDMD48H, or NDF (Tables 2 and 3). However, CP, IVTDMD48H, and NDF differed among 28-d sampling periods (Tables 2 and 3). Crude protein and IVTDMD48H were greatest during early May (Table 3). Crude protein declined from Period 1 (early May) to Period 2 (early June) and remained generally level for the remainder of the grazing season. The IVTDMD48H declined from Period 1 to Period 2, remained level for Periods 2 and 3, and declined at the end of the grazing season. Neutral detergent fiber (Table 3) increased from Period 1 to Period 2, remained level during Periods 2 and 3, and again increased slightly at the end of the grazing season. The greatest change in all forage nutritive variables was between Periods 1 and 2. High CP and IVTDMD48H and low fiber levels early in the grazing season make mixed NWSG appropriate forage for growing animals such as steers and heifers. By stocking more heavily in the beginning of the grazing season, the HEAVY strategy maximizes grazing days during the early-season periods of rapid, high-quality forage production and decreases grazing pressure as grass growth slows and decreases in quality later in the summer. However, that we did not observe such differences may have been a result of both stocking strategies having maintained swards in a similar physiological state. It is also possible that the adaptability of these forages allows for more similar nutritive values across a broader range of growth conditions than what we initially expected. The patterns of change in mixed NWSG forage nutritive values across sample periods in this study were similar to those observed by Backus et al. (2017) in mixed BB and IG, with highest quality early in the grazing season. However, Backus et al. (2017) documented declining CP throughout the grazing season (reaching levels as low as 50 g kg^{-1} by late August), perhaps partly because they included material from below the grazing horizon in their sample, whereas we sampled within the grazing horizon only. Compared with our study, Burns and Fisher (2013) also found similar mean values (g kg^{-1}) for CP (90), IVTDMD48H (660), NDF (743), and ADF (418) for BB despite applying at least 312 kg N ha^{-1} during their study.

Plant population densities of CONT (11.8 plant m^{-2}) and HEAVY (10.8 plants m^{-2}) were similar ($P = .221$), but there

TABLE 3 Mean forage mass and nutritive values of mixed native warm-season grass forage for treatments and summer sampling periods (2015–2017; years pooled) in Knox and Loudon Counties, TN

Variable	Forage mass	CP[a]	NDF[b]	ADF[c]	IVTDMD[d]
	Mg ha^{-1}	g kg^{-1}			
Treatment[e]					
CONT	3.205	98	644	414	702
HEAVY	2.955	96	647	425	703
Year					
2015	4.020a				
2016	2.635b				
2017	2.586b				
Period[f]					
7 May	2.340b	147a	557c	347c	805a
4 June	3.413a	85bc	655b	423b	689bc
1 July	3.909a	92b	653b	423b	689b
28 July	3.376a	81c	681a	450a	669cd
23 Aug.	2.362b	82c	683a	454a	661d

Note. Forage mass was the combined dry weight of the grazing horizon and below grazing horizon cuts of forage samples. Forage nutritive values were based only on the grazing horizon and reported on a dry matter basis. Means within columns and model factor without common letters differ ($P < .05$).

[a] Crude protein.

[b] Neutral detergent fiber.

[c] Acid detergent fiber.

[d] In vitro true dry matter digestibility.

[e] Treatments represent continuous (CONT), season-long (May–Aug.), and heavy-early (HEAVY) continuous, season-long, stocking of pastures.

[f] Forage was sampled concurrent with cattle weigh days, approximately every 28 d beginning in early May.

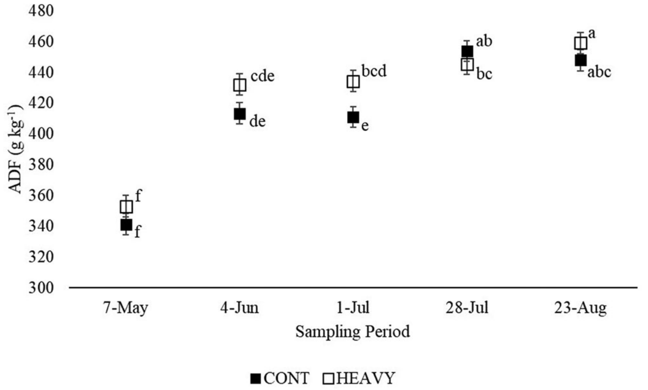

FIGURE 1 Treatment × sampling period interaction ($P = .019$) for acid detergent fiber (ADF) of mixed big bluestem, indiangrass, and little bluestem (mixed native warm-season grass [NWSG]) forage, sampled every 28 d, 2015–2017 (years pooled), during a mixed NWSG grazing experiment in Knox and Loudon Counties, TN. The ADF values were based only on the grazing horizon of forage samples. Treatments were continuous (CONT) season-long (May–August) and heavy-early (HEAVY) continuous stocking. Period dates are average sampling dates across years. Error bars are ±1 SE. Treatment means without a letter in common differ

was a difference among years ($P < .001$; Table 4). Populations were similar for the first 3 yr (2015–2017; $\bar{x}$ = 12.5 plants m^{-2}) but declined by 35% from 2017 to 2018 (Table 5). The majority of the decline in plant density from 2017 to 2018 was due to a reduction of IG plants (−65%), with a lesser reduction of BB (−25%) and LB (−14%; no data available per grass species prior to 2017). Reductions of IG occurred at both sites, with HOLSTON and LOUDON declining 63 and 67%, respectively. LOUDON had a reduction of 36 and 46% for BB and LB plants, respectively, as opposed to HOLSTON, which had a 10% reduction of BB, but gained 59% for LB plants.

Tiller density is a quantifiable method that can be used to gauge sward persistence and vigor as influenced by defoliation (Matthew, Garay, & Hodgson, 1996). Tillers plant^{-1} of all three grass species varied by year but not by treatment (Table 4). Big bluestem (BB) tillers decreased by 39% from 2015 to 2016 and increased by 78% from 2017 to 2018 (Table 5). Despite the decline in the BB plant population, the increase in BB tillers plant^{-1} resulted in a net increase in BB tillers m^{-2} of 38% from 2017 (448 tillers m^{-2}) to 2018 (618 tillers m^{-2}). Indiangrass tillers per plant decreased 52% from 2015 to 2016 and remained stable for the duration of the study (Table 5), and IG tiller density decreased by 64% from 2017 (145 tillers m^{-2}) to 2018 (52 tillers m^{-2}). Similar to BB, and despite the decline in the LB plant population, LB tiller density increased 21% from 2017 (100 tillers m^{-2}) to 2018 (121 tillers m^{-2}) because of an increase in tillers plant^{-1} (Table 5). Overall tiller density, inclusive of all three

TABLE 4 Mixed model ANOVA results for plant population (all species combined) and big bluestem (BB), indiangrass (IG), and little bluestem (LB) tillers plant^{-1}, 2015–2017, during mixed native warm-season grass (NWSG) grazing experiment in Knox and Loudon Counties, TN

Variable	Effect	Numerator df	Denominator df	*F*-value	*P* > *F*
Plant population	treatment[a]	1	16.00	1.62	.221
	year	3	16.00	10.25	<.001***
	treatment × year	3	16.00	2.32	.114
BB tillers	treatment	1	16.00	2.20	.157
	year	3	16.00	4.75	.015*
	treatment × year	3	16.00	2.26	.121
IG tillers	treatment	1	16.00	0.22	.647
	year	3	16.00	17.84	<.001***
	treatment × year	3	16.00	0.52	.674
LB tillers	treatment	1	3.11	0.43	.557
	year	2	8.00	6.88	.018*
	treatment × year	2	8.00	3.29	.091

[a]Treatments represent continuous, season-long (May–Aug.), and heavy-early continuous stocking of pastures.
*Significant at the .05 probability level. **Significant at the .01 probability level. ***Significant at the .001 probability level.

TABLE 5 Overall plant population and tillers plant^{-1}, 2015–2017, during mixed big bluestem (BB), indiangrass (IG), and little bluestem (LB) forage grazing experiment in Knox and Loudon Counties, TN

		Tillers plant^{-1}		
Variable	Plants m^{-2}	BB	IG	LB
Treatment[b]				
CONT	11.8	103	67	84
HEAVY	10.8	84	63	78
Year				
2015	12.4a	113a	116a	79ab
2016	13.1a	69b	56b	–[a]
2017	11.9a	69b	44b	65b
2018	7.7b	123a	44b	97a

Note. Means within columns without a common letter differ ($P < .05$).
[a]LB tillers plant−1 were not counted in 2016.
[b]Treatments represent continuous (CONT), season-long (May–Aug.), and heavy-early (HEAVY) continuous stocking of pastures.

species, increased 14% from 2017 (693 tillers m^{-2}) to 2018 (791 tillers m^{-2}).

The decline in plant population observed in 2018 (Table 5) was largely driven by loss of IG plants between 2017 and 2018. Indiangrass plant populations decreased despite apparently receiving less grazing pressure than either BB or LB (see Selective Grazing below). The IG decline may have resulted from competition with larger BB plants that increased in tiller numbers or, to a lesser extent, weed pressure at HOLSTON. Another possibility is that weather and the late-maturing phenology of IG relative to BB (Ball, Hoveland, & Lacefield, 2007; Keyser et al., 2012) may have contributed to poor detection of IG plants, rather than an actual population decline. East Tennessee experienced a cool spring in 2018, which may have further delayed the growth of already later-maturing IG plants. Plant counts were conducted in early May 2018, possibly before sufficient IG growth had occurred, making detection of IG plants more difficult than in previous years. The decline in BB plants was likely because large BB plants outcompeted smaller BB plants due to an increase in tiller numbers. Another possibility is that, in some cases, observers may have mistakenly counted multiple small BB plants that were growing close to one another as single plants.

Grass canopy heights of the two experimental grazing strategies were similar at the beginning of the grazing season (Figure 2). The heavier early-season stocking of

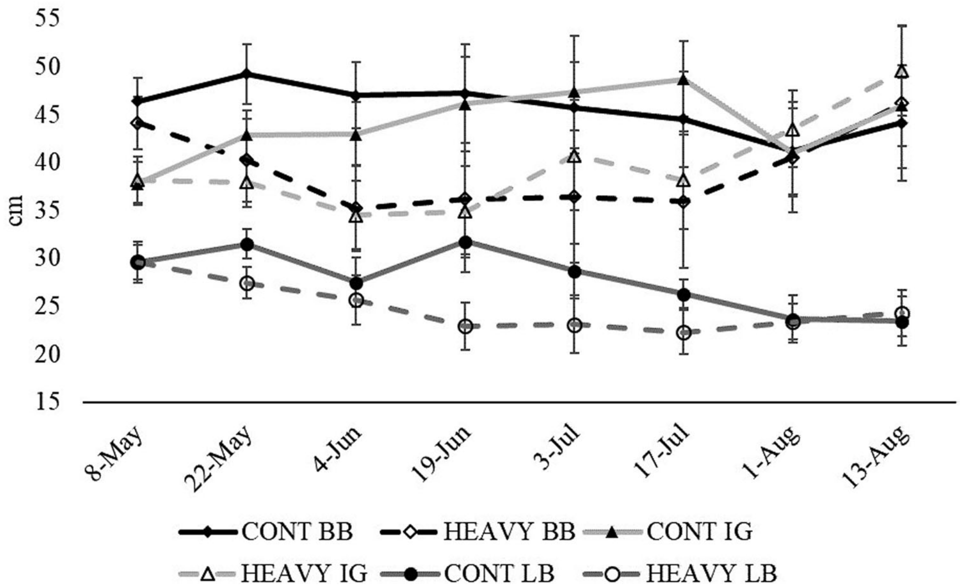

FIGURE 2 Grass heights of big bluestem (BB), indiangrass (IG), and little bluestem (LB), taken every 2 wk, for continuous (CONT), season-long (May–August), and heavy-early (HEAVY) continuous stocking of mixed native warm-season grass pastures (2015–2017; years pooled) in Knox and Loudon Counties, TN. Dates are average sampling dates across years. Error bars are ±1 SE. Data are descriptive and are meant to illustrate trends in grass height between treatments and among species

HEAVY resulted in canopy heights of all three grass species decreasing until partial destocking on 25 June. For several weeks following partial destocking, HEAVY grass canopy heights stabilized, and then, late in the growing season, BB and IG canopies increased in height. The lighter early-season stocking of CONT allowed for selective grazing of the grass species; BB in CONT decreased in height through August, whereas IG increased during this period. Cattle in CONT appeared to increase grazing pressure on IG later in the growing season, causing IG canopy heights to decline during that period (Figure 2). This pattern likely reflects the later maturing nature of IG relative to the bluestems and perhaps that availability of palatable bluestem forage was limited later in the grazing season. Despite the difference in stocking, grass heights of CONT and HEAVY were similar at the end of the grazing season.

The grass height regression model explained 97.7% ($P < .001$) of the variation in grass height and provided empirical evidence of selective grazing of both bluestems over IG. The model indicated grass species had different intercepts ($P < .001$), the mean slope for all species differed from zero ($P = .018$), the linear slopes of the species differed ($P < .001$), the quadratic slopes did not differ ($P > .05$) among species, but the common quadratic slope differed from zero ($P = .017$). Mean canopy heights (y-intercepts) of BB and LB were 46.3 and 33.0 cm, respectively, at the beginning of the grazing season and had comparable rates of linear slope decline ($P = .058$; −1.79 and −2.42 cm per 2-wk period, respectively; Figure 3). The rate of linear slope decline of both species differed from IG (BB vs. IG, $P < .001$; LB vs. IG, $P < .001$), which began the grazing season at 39.3 cm and declined 0.37 cm per 2-wk period throughout the grazing season. However, the quadratic slope for all species was 0.17 cm per 2-wk period, resulting in a grass height increase over time for IG but in height decreases for both bluestems. Preferential grazing of LB and BB by cattle over other NWSG has been documented on native range in the Great Plains (Fahnestock & Knapp, 1993; Hartnett, Hickman, & Walter, 1996; Tomanek, Martin, & Albertson, 1958), but this may be the first time it has been documented in planted mixed NWSG pasture.

3.2 | Animal performance

Average daily gain of steers was similar between treatments, with no year effect or treatment × year interaction (Table 6). Steers gained 0.98 kg d^{-1} on CONT and 0.89 kg d^{-1} on HEAVY, which is within the range of ADG reported in other studies. Steer ADG ranged from 0.70 kg d^{-1} on BB in South Dakota (Krueger & Curtis, 1979) to 1.08 kg d^{-1} in North Carolina under heavy N fertilization (234–360 kg N ha^{-1}) (Burns & Fisher, 2013). Average daily gains in our study approached those of Burns and Fisher (2013) but without N fertilization. Reported steer ADG on IG monocultures include 1.08 kg d^{-1} (Krueger & Curtis, 1979) and 0.57 kg d^{-1} (Monroe et al., 2017). In Tennessee, Backus et al. (2017) documented steer ADG at two different sites of 0.82 and 0.96 kg d^{-1} on BBIG. Steer ADG in a similar continuous, season-long mixed NWSG grazing experiment

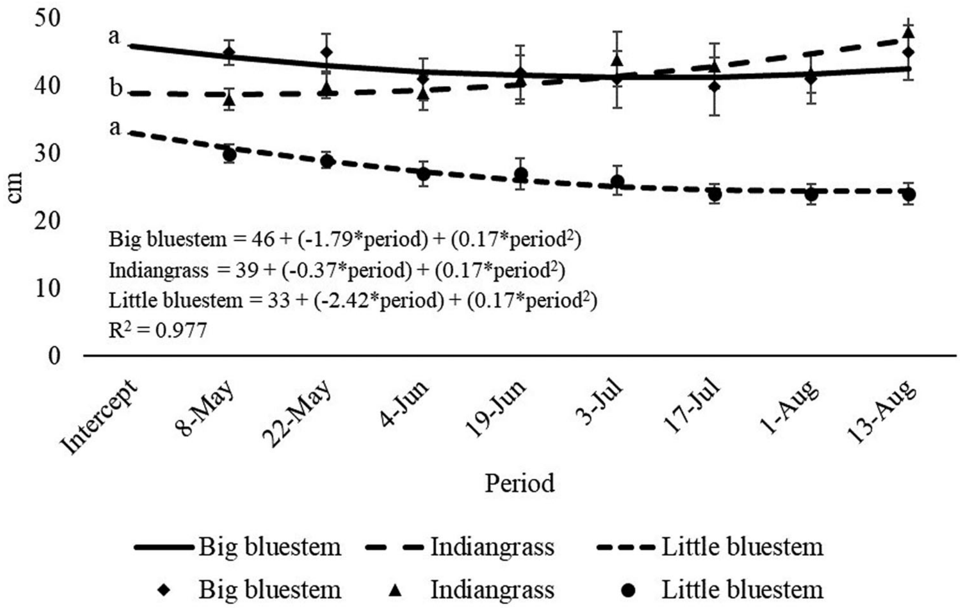

FIGURE 3 Regression lines for big bluestem, indiangrass, and little bluestem grass heights, taken every 2 wk, 2015–2017, during mixed big bluestem, indiangrass, and little bluestem forage grazing experiment in Knox and Loudon Counties, TN. Linear slopes of regression lines without a letter in common differ. Period dates are average sampling dates across years. Error bars for grass height period means are ±1 SE

TABLE 6 Mixed model ANOVA results for average daily gain (ADG), animal-days, and total gain of steers and ADG of heifers, 2015–2017, during mixed native warm-season grass forage grazing experiment in Knox and Loudon Counties, TN

		Steers				Heifers			
Variable	Effect	Numerator df	Denominator df	*F*-value	*P* > *F*	Numerator df	Denominator df	*F*-value	*P* > *F*
ADG	treatment[a]	1	3.82	3.24	.150	1	3.65	1.15	.350
	year	2	7.29	0.89	.452	1	4.00	0.79	.426
	treatment × year	2	7.29	3.30	.096	1	4.00	3.84	.122
Animal days	treatment	1	2.92	0.86	.425				
	year	2	6.58	7.37	.021*				
	treatment × year	2	6.58	1.77	.243				
Total gain	treatment	1	10.20	3.45	.092				
	year	2	10.01	1.41	.288				
	treatment × year	2	10.01	2.33	.147				

[a] Treatments represent continuous, season-long (May–August), and heavy-early continuous stocking of pastures.
*Significant at the .05 probability level.

conducted in Mississippi was lower (0.55 kg d^{-1}) (Monroe et al., 2017) than ADG in this or other studies. The lower ADG of steers documented in Monroe et al. (2017) may have been because of the higher proportion of lower-yielding LB in their mixed NWSG sward coupled with the incomplete eradication of bermudagrass, which approximately doubled in coverage from Year 1 to Year 2 of their experiment (Monroe, Hill, & Martin, 2017). Heifer calves on CONT and HEAVY had similar ADG (0.89 and 0.81 kg d^{-1}, respectively), and there was no year effect or year × treatment interaction (Table 6). Average daily gains in this range are appropriate for heifer development (Bagley, 1993; Hoffman, 1997) or adding additional weight to growing animals before marketing (Burns & Fisher, 2013). The lack of difference among ADG in this and other studies is likely because neither continuous grazing strategy negatively affected forage mass or nutritive quality.

3.3 | Pasture productivity

Mean length of all grazing seasons across treatments, years, and sites was 105 d and ranged from 99 (HOLSTON, 2017) to 112 d (HOLSTON, 2015). LOUDON was more consistent, with grazing days ranging from 105 (2015 and 2017) to 106 (2016). Monroe et al. (2017) reported mean grazing season length of 112 d on continuously grazed mixed NWSG in Mississippi, and Burns and Fisher (2013) reported mean grazing season length of 137 d on BB in North Carolina. Animal-use days were similar between treatments (CONT, 382 d ha^{-1}; HEAVY, 368 d ha^{-1}) but differed among years (P = .021). Animal-days for 2015 (393 d ha^{-1}) and 2016 (382 d ha^{-1}) were similar, with both differing from 2017 (350 d ha^{-1}). Initiation of grass growth in spring 2017 was later, and growth remained slightly slower compared with previous years. One explanation for this growth pattern, and subsequently the shorter 2017 grazing season, is that a severe fall (August–November) drought in 2016 resulted in pre-dormancy stress that may have, along with the unusually cool spring in 2017, reduced early-season growth. Furthermore, both sites were more heavily stocked in 2017 than in previous years. In North Carolina, Burns and Fisher (2013) reported 698 steer-days ha^{-1} on small (0.3 ha) BB paddocks using put-and-take stocking and N fertilization rates up to 360 kg ha^{-1}. In Tennessee, Backus et al. (2017) reported full season (May–August) grazing equivalent to 343 and 440 steer-days at two locations using put-and-take stocking and fertilized with 67 kg ha^{-1} N annually.

Total GAIN did not differ between treatments (CONT, 379 kg ha^{-1}; HEAVY, 334 kg ha^{-1}) or among years, and there was no treatment × year interaction (Table 6). Relative to our results, Backus et al. (2017) reported lower GAIN (257 kg ha^{-1}) at their West Tennessee study area and somewhat greater GAIN (415 kg ha^{-1}) at their Middle Tennessee study site while grazing steers on BBIG. Total gain on BB monocultures has been reported from 138 (Krueger & Curtis, 1979) to 732 kg ha^{-1} (Burns & Fisher, 2013) with heavy (312–360 kg ha^{-1}) N fertilization. If the initial stocking ratio target of 1.25 (HEAVY/CONT) had been met each year, the GAIN between treatments would have likely been more numerically similar. Within sites, the difference in annual GAIN between CONT and HEAVY decreased from 41 to 0% as the initial stocking ratio increased from 1.10 (HOLSTON 2016) to 1.24 (LOUDON 2016; Table 1), respectively. Stocking HEAVY too lightly early in the grazing season, when forage mass and nutritive quality are greatest, numerically reduced its overall grazing days relative to CONT.

Despite the different stocking strategies, CONT and HEAVY had similar ADG, AD, and GAIN. The major difference between the two continuous grazing strategies was the distribution of grazing pressure. Lower early-season stocking densities for CONT allowed selective grazing of the most palatable and nutritious plant material. This resulted in greater early-season ADG for CONT (1.22 kg d^{-1}) than HEAVY (0.92 kg d^{-1}). Animals on HEAVY had greater competition for forage, which led to less selective grazing, resulting in lower early-season ADG. The opposite was true for late-season (i.e., 25 June to late August) ADG when forage was lower in quality and grass growth was slower; animals on HEAVY (0.84 kg d^{-1}) had less competition for forage than those on CONT (0.64 kg d^{-1}). The reduced grazing pressure on HEAVY also allowed the sward to begin to recover and provided more fresh leaves for grazing. Animal-use days were similar between treatments by design. A greater percentage of AD occurred in the early season on HEAVY (62%) than CONT (54%). Greater early-season ADG but fewer early-season AD on CONT and lower early-season ADG but greater early-season AD for HEAVY resulted in a similar percentage of season-long GAIN being accounted for in the early-season for each treatment (CONT, 67%; HEAVY, 64%). Lower grazing pressure resulted in a slightly numerically greater percentage of season-long GAIN occurring during late-season for HEAVY (36%) than CONT (33%), which maintained the same stocking density throughout the grazing season.

Total establishment cost in 2018 dollars for mixed NWSG was US$652.36 ha^{-1}. Seed cost was the largest component

TABLE 7 Establishment and annual operational costs for mixed big bluestem, indiangrass, and little bluestem pastures for mixed native warm-season grass grazing experiment in Knox and Loudon Counties, TN

Pasture costs	US$ ha^{-1}
Establishment costs	
Seed[a]	313.08
Establishment[b]	279.97
Risk of re-establishment	59.31
Total	652.36
Annualized establishment[c]	88.64
Annual operational costs[d]	
Fertilizer	41.96
Herbicide	13.71
Prescribed burning	46.33
Land rent	49.42
Total annual pasture cost[e]	240.06

Note. Costs are based on the University of Tennessee Switchgrass Budget (University of Tennessee Department of Agricultural and Resource Economics, 2009)

[a] All seed was 'KY Ecotype' (Roundstone Native Seed, LLC).

[b] Other establishment costs included herbicide, fertilizer, custom applications of herbicide and fertilizer, custom no-till planting, and land rent for establishment year.

[c] Includes 6% annual interest.

[d] Includes cost of custom application.

[e] Sum of annualized establishment and annual operational costs.

of establishment cost for mixed NWSG, accounting for over 50% of cost before addition of the 10% re-establishment risk cost (Table 7). Total annual pasture cost was US$240.06 ha^{-1}, which included annualized establishment cost, fertilizer (P only), custom fertilizer application, herbicide, custom herbicide application, custom prescribed burning, and annual land rent (Table 7). Cost of steer GAIN on mixed NWSG was US$0.63 kg^{-1} for CONT and US$0.72 kg^{-1} for HEAVY. The difference in cost of GAIN between treatments was because CONT and HEAVY produced numerically different amounts of GAIN (CONT, 379 kg ha^{-1}; HEAVY, 334 kg ha^{-1}). This is considerably less than cost of GAIN for mixed BB and IG (US$0.87 kg^{-1}) and similar to the cost for switchgrass (US$0.69 kg^{-1}) reported by Keyser et al. (2016). The difference in cost of GAIN between this study and Keyser et al. (2016) is likely due to the lower BB and IG seed cost and the faster-gaining weaned steers used in this study, as opposed to pregnant heifers. Seed cost accounted for 34% of total annual mixed BB and IG pasture cost in Keyser et al. (2016) (US$36.72 kg^{-1} for BB, US$50.05 kg^{-1} for IG; US$417.17 ha^{-1}) but for only 15% in this study (US$28.49 kg^{-1} for BB, US$24.20 kg^{-1} for IG, and US$35.20 kg^{-1} for LB) (Table 7).

4 | CONCLUSIONS

Animal performance and pasture production of both CONT and HEAVY mixed NWSG grazing strategies were at levels acceptable for backgrounding weaned calves or heifer development. They are also greater than that reported on fescue/clover pastures during late spring and summer and offer relief from infected tall fescue during this time of year (Kallenbach, Crawford, Massie, Kerley, & Bailey, 2012; Keyser et al., 2016; Thompson et al., 1993). Furthermore, these continuous grazing strategies appear to be economical and sustainable, although sustainability should continue to be monitored over a longer period. Differences between CONT and HEAVY may have been greater if the target stocking density ratio had been met. Producers who wish to graze NWSG but are not willing or able to rotationally graze may use a continuous grazing strategy. Although both continuous season-long grazing strategies compared in the study produced similar animal performance and pasture production, CONT may be more feasible due to reduced management requirements, less animal handling time, lower transportation costs, and familiarity to producers.

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CONFLICTS OF INTEREST

The authors declare no conflicts of interest.

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