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# Evaluation of eastern gamagrass and a sorghum × sudangrass for summer pasture

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**Abstract**

Improved summer forage production is important in forage systems dominated by cool-season perennial grasses. Improved forage may be especially important for heifer [*Bos taurus* (L)] development. Therefore, we compared two summer forage options, a perennial, eastern gamagrass [*Tripsacum dactyloides* (L.) L.], and a widely used summer annual, sorghum [*Sorghum bicolor* (L.) Moench] × sudangrass [*Sorghum bicolor* (L.) Moench ssp. *drummondii* (Nees ex Steud.) de Wet & Harlan] hybrid, as options for providing summer pasture for bred heifers (418 ± 31 kg initial body mass). We used put-and-take grazing (i.e., routine adjustment of stocking to maintain target canopy conditions) to evaluate pasture characteristics, animal performance, and pasture productivity, 2013–2015. Crude protein of eastern gamagrass (EG) exceeded ($P = 0.01$) that of the sorghum × sudangrass hybrid (SXS), but FM, ADF, and NDF were all similar between the two forage types. Although SXS provided greater ADG ($P = 0.03$) in two of three years, EG provided twice as many AD ha$^{-1}$ ($P = 0.03$) and consequently, greater ($P < .001$) GAIN in two of three years. Calving rates (89%) did not differ between the two forages. Increased N rates (67 vs.137 kg ha$^{-1}$ N) did not alter EG pasture characteristics but appeared to improve GAIN (279 and 355 kg ha$^{-1}$, respectively). Cost of gain was greater for SXS in 2014 and 2015 ($1.71 and $1.64 kg$^{-1}$) than for EG ($0.62 and $0.62 kg$^{-1}$). Both EG and SXS could be useful for providing summer forage for bred heifers.

## 1 | INTRODUCTION

Perennial native warm-season grasses (NWSG), including eastern gamagrass (EG), have been evaluated as prospective forage crops for summer pasture (Aiken, 1997; Tracy, Maughan, Post, & Faulkner, 2010; Burns & Fisher, 2013; Backus et al., 2017). Improved warm-season forage options such as EG may be especially important for forage systems within the transition zone that are dominated by cool-season perennial grasses. One example is the tall fescue [TF; *Schedonorus arundinaceus* (Schreb.) Dumort.] Belt, a region within the USA that lies east of the Great Plains and extends from the southern edge of glaciation to the Atlantic and Gulf Coastal Plains, which has a forage system dominated by approximately 14 million ha of the cool-season perennial, TF (Kallenbach, 2015). As a warm-season grass, EG could be

**Abbreviations:** AD, animal days per hectare; ADF, acid detergent fiber; ADG, average daily gain; CP, crude protein; DM, dry matter; EG, eastern gamagrass; FM, forage mass; GAIN, total gain per hectare; NDF, neutral detergent fiber; NWSG, native warm-season grass; PLS, pure live seed; SXS, sorghum × sudangrass hybrid; TF, tall fescue.

particularly useful for filling in the summer forage gap within the TF Belt. Net returns from grazing weaned beef [*Bos taurus* (L.)] steers on EG over the summer were positive (Lowe et al., 2015) thus making this perennial attractive from an economic perspective. In another economic analysis, EG outperformed a summer annual [crabgrass, *Digitaria ciliaris* (Retz.) Koeler] in terms of net returns for grazing weaned beef heifers (Boyer, Zechiel, Keyser, Rhinehart, & Bates, 2019).

Annuals, such as sorghum × sudangrass (SXS), offer producers more flexibility and can produce forages with increased nutritive values compared with warm-season perennials (Tracy et al., 2010). In the case of SXS, high forage yields, 7–10 Mg ha$^{-1}$, can be produced at a time of year when TF has become semi-dormant and is not productive (Fontaneli, Sollenberger, & Staples, 2001; Machicek, Blaser, Darapuneni, & Rhoades, 2019). However, these summer annuals are less cost-effective (Boyer et al., 2019; Keyser, Bates, Waller, Harper, & Holcomb, 2015; Tracy et al., 2010), may not be available in early summer (Tracy et al., 2010; Zechiel, 2017) and thus provide fewer grazing days (Zechiel, 2017) than perennials.

Another challenge within the TF Belt, particularly for reproductive animals such as first-calf heifers, is fescue toxicosis caused by a symbiotic fungal endophyte (*Neotyphodium coenophialum*) which produces ergot alkaloids. It has been estimated that greater than 90% of TF pastures are infected with this endophyte (Kallenbach, 2015) leading to reductions in reproductive performance (Caldwell et al., 2013; Campbell, Backus, Dixon, Carlisle, & Waller, 2013; Porter & Thompson, 1992). In addition, heifers may be particularly sensitive to fescue toxicosis (Burns, 2012; Drewnoski, Oliphant, Poore, Green, & Hockett, 2009; Paterson, Forcherio, Larson, Samford, & Kerley, 1995) making non-toxic summer forage especially important for heifer development (Keyser et al., 2016).

Nitrogen inputs can improve yield (Brejda, Brown, Lorenz, Henry, & Lowry, 1997; Moyer & Sweeney, 2008) and forage nutritive parameters (Moyer & Sweeney, 2016; Waramit, Moore, & Fales, 2012) of EG, but perennial NWSGs have relatively low fertilization requirements (Lemus et al., 2008; Rushing, Lemus, White, Lyles, & Thornton, 2019) that when exceeded, can negatively affect net returns (Boyer, Tyler, Roberts, English, & Larson, 2012; Holman, Obour, & Mengel, 2019). However, EG has demonstrated strong positive yield responses to increased N amendments suggesting that for this species, additional N inputs may be warranted (Brejda et al., 1997). With SXS, N application can increase nitrate toxicity risk and must be carefully managed (Holman et al., 2019). Furthermore, use of low-input production models are also of increasing interest from a perspective of enhancing agricultural sustainability (Matson, Parton, Power, & Swift, 1997; Pimentel et al., 2008).

Therefore, we implemented an experiment to compare EG to SXS using bred beef heifers in a low input environment. Specifically, we compared sward characteristics, animal performance, pasture productivity, and cost of gain for these two forages when managed with and without N amendments. We hypothesized that both forages would provide adequate grazing to offset the summer slump and acceptable levels of gain for bred heifers. We also hypothesized that EG would be more cost-effective than the annual SXS and that EG pasture productivity would increase with N amendments and at a cost-effective level.

**Core Ideas**

- Improved summer forage is needed, especially for breeding animals
- Eastern gamagrass and sorghum × sudangrass are prospective warm-season forage options
- Forage nutritive quality and forage mass were generally similar for the two species
- Eastern gamagrass had lower ADG but provided more grazing days and gain per hectare
- Eastern gamagrass produced gain at a lower cost

## 2 | MATERIALS AND METHODS

We conducted research at the East Tennessee Research and Education Center (ETREC) in Knoxville, TN (35°50′23″ N, 83°57′47″ W; elevation 288 m). Climate for this location is classified as humid subtropical (Cfa) with hot summers and consistent precipitation throughout the year (NOAA, 2020). Soils at the site were dominated by Decatur silty clay loam (Fine, kaolinitic, thermic Rhodic Paleudults) with inclusions of Emory silt loam (Fine-silty, siliceous, active, thermic Fluventic Humic Dystrudepts). These well-drained soils were formed over weathered limestone under warm humid conditions and have depths to bedrock of approximately 1.5 m. Soils were sampled to a depth of 15 cm in 2013 and pH was 6.0 with 42 kg ha$^{-1}$ P and 282 kg ha$^{-1}$ K (Mehlich 1). In 2015, pH was 5.7 and P 42 kg ha$^{-1}$ and K 144 kg ha$^{-1}$.

Weather data was collected at a weather station located on ETREC and compared to the 30-yr means for that location (NOAA, 2019). Above normal precipitation occurred in April 2013, June 2015, in July every year except 2016, and in August 2014 (Figure 1a). Conversely, precipitation was below normal in five months: April 2016, May 2014 and 2015, June 2015, and August 2016. Temperatures remained near the 30-year mean for most of the study period with 2016 being the warmest year experiencing above normal temperatures during June–August (Figure 1b).

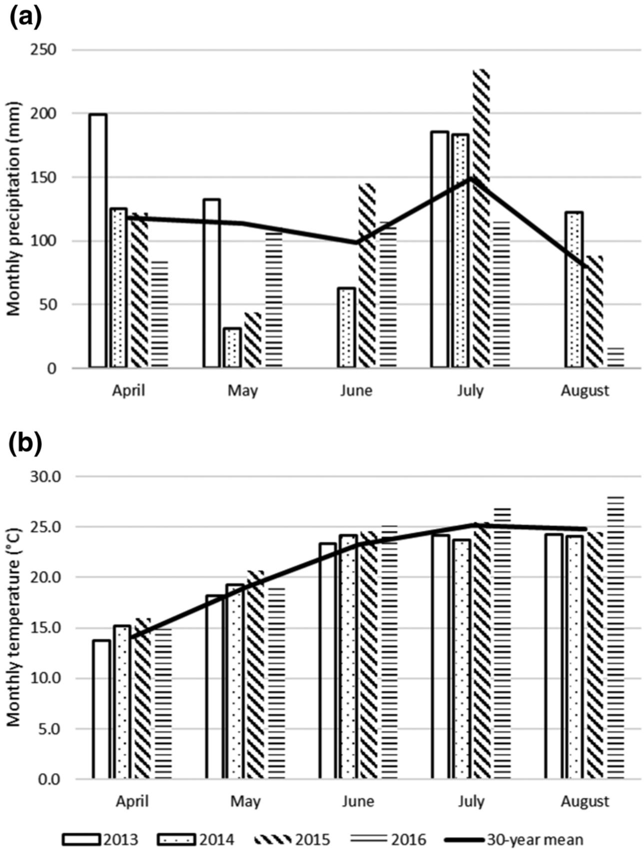


**FIGURE 1** Monthly mean precipitation (a) and temperature (b) and 30-year means for summer grazing period (April–September), 2013–2016, East Tennessee Research and Education Center, located near Knoxville, TN

## 2.1 | Experiments

The first experiment was conducted 2013–2015 and included three replicates of two forage treatments (Forage Type) assigned in a completely randomized design. Forage Types were EG, cultivar 'Highlander' (Grabowski, Douglas, Lang, & Edwards, 2005) and SXS, 'FSG 208′ (Allied Seed, LLC, Nampa, ID), a cultivar that included the brown midrib trait. Experimental units for EG were three, 2.43-ha pastures subdivided into three, 0.81-ha paddocks. For SXS, experimental units were three, 3.64-ha pastures divided into three, 1.21-ha paddocks. The larger size for the SXS pastures was chosen because of the lower carrying capacity of this forage relative to EG, thus allowing a comparable number of testers to be used in both treatments. For the second experiment, conducted in 2016 only, we used two pastures (2.43 ha) each (four pastures total) of the EG cultivars Highlander and 'Pete' (Fine, Barnett, Anderson, Lippert, & Jacobson, 1990) and randomly assigned each cultivar to one of two N treatments, 67 or 134 kg ha$^{-1}$ N applied in late April in the form of urea (46–0–0). We did not include a control N level because of logistical constraints (availability of pastures and cattle) and because the three preceding years of grazing provided a reference condition without N amendments. Pastures for the N experiment were subdivided into two, 1.22-ha paddocks.

## 2.2 | Pasture establishment and management

Establishment of EG cultivar Highlander occurred in April 2010 (two experimental units) and February 2012 (third experimental unit) using a no-till corn planter (John Deere, model 1740, Moline, IL) on 76-cm row spacing at a depth of 3 cm and a rate of 13.5 PLS kg ha$^{-1}$. Following the same protocols, two additional EG pastures (also 2.43 ha each) were established in February 2011 using cultivar Pete for use in the second experiment. Pastures had been in TF prior to establishment of EG. The fall preceding seeding with EG, pastures were sprayed with glyphosate (*N*-(phosphonomethyl)glycine) at the rate of 2.24 kg ha$^{-1}$ a.i. to eradicate all vegetation. A second glyphosate treatment (2.24 kg ha$^{-1}$ a.i.) was applied in April 2010 in preparation for no-till planting. Pastures planted in February (2011 and 2012) did not receive a second application of herbicide. The SXS was established annually in late April to early May, 2013–2015 using a Haybuster (model 107, DuraTech Industries International, Inc., Jamestown, ND) no-till drill at a depth of 1 cm and a seeding rate of 33.75 kg ha$^{-1}$. Prior to planting SXS each spring, pastures were sprayed with glyphosate (*N*-(phosphonomethyl)glycine) (2.24 kg ha$^{-1}$ a.i.) to eradicate all vegetation.

Two Highlander EG pastures were sprayed with [(2,4-Dichlorophenoxy)acetic acid] at the rate of 1.33 kg ha$^{-1}$ a.i. in April 2015 for broadleaf weed control; no other weed control measures were implemented during either experiment. No N, P, K or lime was applied during the first experiment. For the second experiment, one pasture (Highlander) received 33 kg ha$^{-1}$ K in the form of muriate of potash and 67 kg ha$^{-1}$ of P in the form of DAP in April 2016. Application of N to this pasture was adjusted to account for the N applied with the DAP.

## 2.3 | Pasture measurements

Pasture canopy height was taken at 16 random locations before animals entered a given paddock and upon rotation off a given paddock (i.e., starting and ending heights) for all rotations and Forage Types. Monthly forage samples were taken at initial stocking, corresponding to each weigh period, and at conclusion of grazing in late summer. The forage sample was taken from 10 randomly located 0.25-m$^2$ plots within the actively grazed paddock. Samples were clipped at 25 and 36 cm residual heights for the SXS and EG, respectively, to reflect the grazing horizons of each forage. Wet weights were taken and a grab sample retained for determining moisture content and use in calculating forage nutritive values. In addition, the material remaining below the forage horizon (25 and 36 cm, respectively) in each forage 0.25-$m^2$ sample plot was harvested to a 5-cm residual height for herbage mass calculations. Plant population (plants $m^{-2}$) was determined for EG at 5 randomly located 0.25-$m^2$ plots per experimental unit during the dormant season 2013. In 2016 we sampled at 15 randomly located 0.25 $m^2$ per experimental unit.

Forage samples were dried for 52 h in a forced-air oven at 55 °C and then weighed to calculate DM, and ground in a Wiley mill (Thomas Scientific, Swedesboro, NJ) using a 2-mm screen. To analyze samples with a near-infrared (NIR) spectrometer, they were ground further with a UDY cyclone mill (UDY Corporation, Fort Collins, CO) through a 1-mm screen. Samples were analyzed with NIR for crude protein (CP), acid detergent fiber (ADF), and neutral detergent fiber (NDF) (FOSS 6500, Foss NIRsystems, Inc., Laurel, MD) utilizing Win SII II software (Infrasoft International, LLC, State College, PA). Equations for the forage nutritive analysis were standardized and checked for accuracy using the grass hay equation developed by the NIRS Forage and Feed Consortium. All forage samples fit the equation with $H < 3.0$ and are reported accordingly (Murray & Cowe, 2004).

## 2.4 | Animals and grazing management

We stocked pastures with bred yearling, straightbred Angus heifers in 2013–2015 with four assigned per experimental unit as testers (animals that would remain on the test pastures throughout each grazing season and thus, be the basis of animal performance calculations) based on body mass (i.e., achieving equivalent total mass and comparable mass ranges). Initial mean body mass of testers assigned to EG was 423 ± 31 kg (2013), 405 ± 24 kg (2014), and 430 ± 29 kg (2015). For SXS pastures, mean initial body mass was 450 ± 16 (2013), 406 ± 28 (2014), and 404 ± 30 (2015). We initiated grazing in early May each year (8, 7, 5 May, respectively, in 2013–2015) on EG pastures and in June (19, 17, and 3 June, respectively, in 2013–2015) for SXS pastures. Grazing was terminated each year based on sward condition. For EG, grazing ended on 29, 26, and 25 August in 2013–2015, respectively. However, grazing was terminated early for one EG experimental unit each in 2013 (31 July) and 2014 (24 June). For SXS, grazing was terminated 29 August and 26 August (2013 and 2014, respectively) and on 28 July in 2015. In 2016, we used similar animals (444 ± 37 kg initial mean body mass) assigned in the same manner, began grazing on 13 May and concluded on 9 September for all pastures. All other grazing management was the same in 2016 as it had been during the previous three years. Rotations were based on target canopy heights at entry of 72 cm defoliated to 36 cm for EG and 72 cm defoliated to 25 cm for SXS. Additional animals (grazers, animals used only to maintain target canopies and not used to calculate animal performance) were added to or removed from pastures as needed to sustain season-long grazing with the four testers while maintaining target canopy heights. If additional heifers were not available, we used yearling steers (2013) or cows (2015 and 2016) as grazers. Stocking adjustments were made on rotations among the paddocks within each experimental unit. Rotations were intended to occur approximately weekly based on those reported by Burns and Fisher (2010) and actually occurred approximately every 8 days. Animals had free access to mineral supplement, water, and shade in all pastures. All animals were cared for under the auspices of Institutional Animal Care and Use protocols 1823-0412 and 2258-3714.

## 2.5 | Animal measurements

Initial and final body mass measurements for testers (on- and off-test) were based on the mean of unshrunk weights taken on two consecutive days. Weights were also taken approximately every 28 d throughout the trial. Average daily gain was calculated for each tester using the difference between off weights and on weights divided by the total number of days on trial; grazers were not included in ADG calculations. For grazing days, days grazed by all animals, grazers plus testers, were used and corrected for pasture size to calculate animal grazing days per hectare (AD). Where cows were used as grazers, grazing days were corrected based on metabolic weight using the formula $\{\text{mass}^{0.75}/1000^{0.75}\}$ and a mean body mass of 600 kg for the cows. Because steer grazers were similar in size to testers, no adjustment was required for body mass. Total gain per hectare (GAIN) was calculated as the product of ADG and AD per pasture per year. Final pregnancy outcomes (Pregnancy) for all heifers were documented annually at the time of calving (January–February).

## 2.6 | Economics

Enterprise budgets were developed to estimate total pasture costs including perennial forage establishment and annual operational expenses (Table 1). Forage costs were then used to estimate cost of gain ($ $kg^{-1}$ beef) for grazing bred beef heifers on EG and SXS. A 10-year stand life was assumed for EG pasture similar to other NWSG (Lowe et al., 2015). A 10% risk of reestablishment was assumed for EG to allow for potential stand failure and subsequent reestablishment. Establishment costs included seed, herbicide, custom drilling of seed, and custom herbicide application. The cost of these inputs was based on average local costs in 2019. Eastern gamagrass seed cost was $39.07 $kg^{-1}$ while SXS seed cost was $3.42 $kg^{-1}$. The annual cost for EG pastures was calculated by adding the annualized establishment cost and land rent. SXS

**TABLE 1** Total and annualized pasture costs (US$ $ha^{-1}$) for eastern gamagrass (EG) and sorghum × sudangrass hybrid (SXS)

| Cost | EG | SXS |
|---|---|---|
| | US$ $ha^{-1}$ | |
| Establishment | 641.04 | 189.45 |
| Risk of re-establishment | 64.10 | - |
| Total establishment | 705.14 | 189.45 |
| Annualized establishment | 105.09 | 189.45 |
| Land rent | 51.89 | 51.89 |
| Total annual pasture cost | 156.98 | 241.34 |

pasture costs were the actual annual costs of establishment with land rent added.

### 2.7 | Statistical analysis

To analyze pasture characteristics [Height, forage mass (FM), CP, ADF, and NDF], pasture replicate was included as a random effect as part of a repeated measures, mixed-effects ANOVA analysis in package nlme in program R (Pinheiro, Bates, DebRoy, & Sarkar, 2019; R Core Team, 2014). Fixed effects for pasture characteristics were Julian date (Date), Forage Type (EG or SXS), and Year (2013, 2014, 2015). All two- and three-way interactions were evaluated for pasture characteristics. Similarly, heifer performance (ADG and Pregnancy) and pasture productivity (AD and GAIN) measures were analyzed using a repeated measures mixed-effects ANOVA though Date was not included in these models, and individuals not successfully bred were excluded from the Pregnancy analysis. A Two-way interaction between Forage Type and Year was included. For each independent variable q-q and residual plots were inspected; all models conformed to assumptions of normality and equality of variances.

A mixed-effects ANOVA analysis in package nlme in program R (Pinheiro et al., 2019; R Core Team, 2014) was used to evaluate differences between 2013 and 2016 plant populations. The fixed effect for plant populations was year and Pasture was included as a random effect.

Because we only had a single year of data for the N experiment, we only present means and standard errors for pasture characteristics (FM, CP, ADF, NDF) heifer performance (ADG), and pasture productivity (AD and GAIN) measures. As a point of reference, we also include means and standard errors for years when no N amendments were applied (2013–2015).

Cost of gain data were analyzed for each year using the Mixed procedure in SAS 9.2 with treatment being the fixed effect and replication as the random effect. The DIFF function of LSMEANS was used to compare treatment means at the $P \leq .05$ significance level (SAS Institute, 2008).

## 3 | RESULTS

### 3.1 | Pasture characteristics

For Height, there was a two-way interaction, Date × Forage Type ($P < .001$; Table 2), with EG increasing in height through the grazing season (57 cm on 28 April vs. 71 cm on 4 September), whereas SXS decreased in height (103 cm on 25 June vs. 80 cm on 4 September; Figure 2). However, among years, Height for SXS was consistently greater than EG in 2014 and 2015 (100 vs. 55 cm and 79 vs. 59 cm, in 2014 and 2015, respectively). Forage mass did not differ between Forage Type but declined ($P < .001$) from 7575 kg $ha^{-1}$ in 2013 to 2369 kg $ha^{-1}$ in 2014 and 1645 kg $ha^{-1}$ in 2015. Crude protein varied by Forage Type (141.4 g $kg^{-1}$ for EG and 88.9 g $kg^{-1}$ for SXS) and had an interaction, Date × Year ($P = .05$; Table 2). Pastures of both types decreased in CP throughout each season, with the greatest rate of decline occurring in 2014 (mean of 202.5 g $kg^{-1}$ on 22 May vs. 82.9 g $kg^{-1}$ on 28 August; Figure 3a). Both measures of fiber increased through the course of each grazing season with ADF increasing from a mean of 277.0 g $kg^{-1}$ on 28 April to 402.5 g $kg^{-1}$ by 28 August (Figure 3b) and NDF increasing from a mean of 553.4 to 709.4 g $kg^{-1}$ during the same interval (Figure 3c). Plant population within experimental pastures (DNS) was greater ($P < .001$) in 2013 (6.4 plants $m^{-2}$) than in 2016 (4.2 plants $m^{-2}$).

### 3.2 | Heifer performance and pasture productivity

For ADG, the interaction Forage Type × Year ($P = 0.03$; Table 3) indicated that ADG on EG was less than on SXS in 2013, was similar in 2014 and again was less for EG in 2015, albeit by a smaller margin (Figure 4a). Although Forage Type interacted with Year for AD ($P = 0.03$; Table 3), EG had greater carrying capacity than SXS in all three years (Figure 4b). Similarly, there was a Forage Type × Year interaction for GAIN ($P < .001$; Table 3) with SXS remaining consistent through the three years of the study but EG increasing markedly in 2014 and 2015 relative to 2013 (Figure 4c). Pregnancy rates differed among years (2013 = 100%, 2014 = 92%, 2015 = 79%) but not by Forage Type (89% across all three years and both forages).

### 3.3 | Nitrogen rate

In 2016, CP for the 67 kg $ha^{-1}$ rate for both cultivars was numerically lower (by 18.6 and 7.6 g $kg^{-1}$ for Highlander and Pete, respectively) than those for the 134 kg $ha^{-1}$ rate (Table 4). Although ADF appeared to be similar for the two

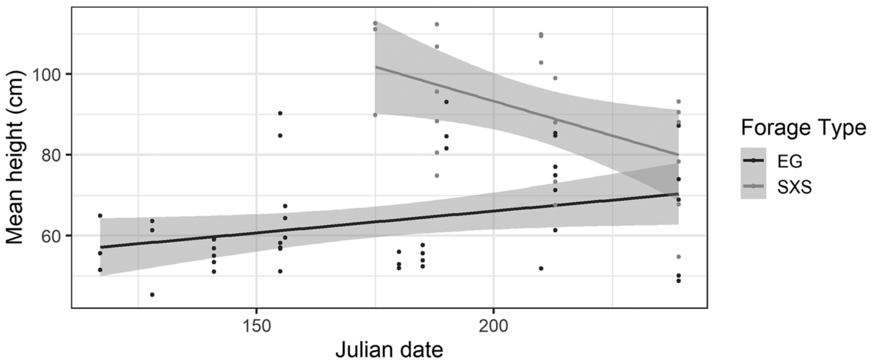


**FIGURE 2** Relationship between mean canopy height (unextended leaf blades) with 95% confidence intervals and Julian date for eastern gamagrass (EG) or sorghum × sudangrass hybrid (SXS) during grazing experiment at East Tennessee Research and Education Center, near Knoxville, TN, 2013–2015. Dots represent individual per replicate per date sample values ($n = 66$)

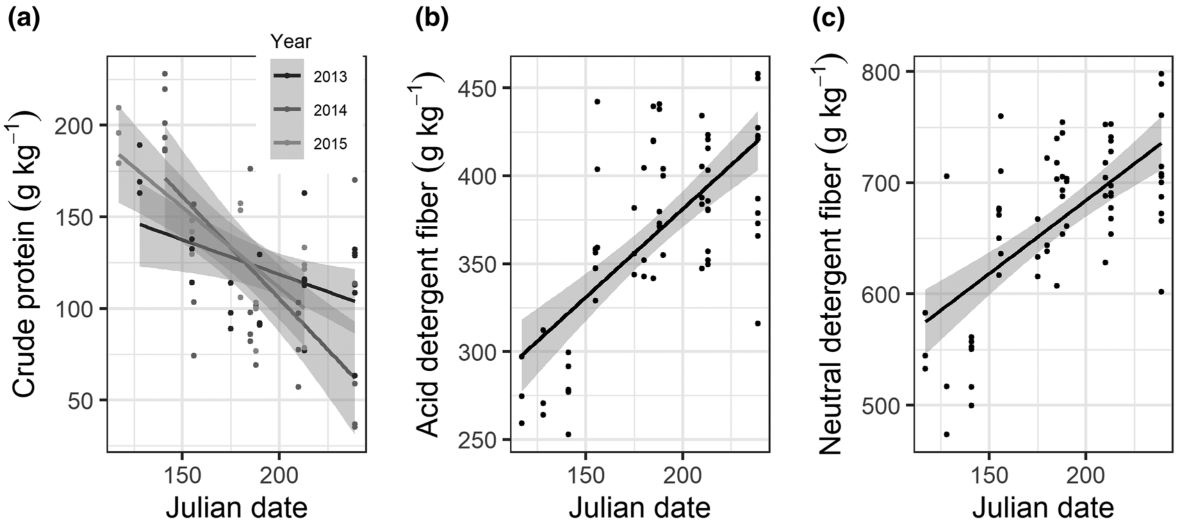


**FIGURE 3** Relationship between forage nutritive values (with 95% confidence intervals) and Julian date for (a) crude protein (CP), (b) acid detergent fiber, and (c) neutral detergent fiber, 2013–2015, during eastern gamagrass (EG) and sorghum × sudangrass hybrid (SXS) grazing experiment at East Tennessee Research and Education Center, near Knoxville, TN. Relationships are for both forages pooled because they did not differ ($P > .05$). For CP, a Year × Date interaction was significant ($P = .05$). Dots represent individual per replicate per date sample values ($n = 66$)

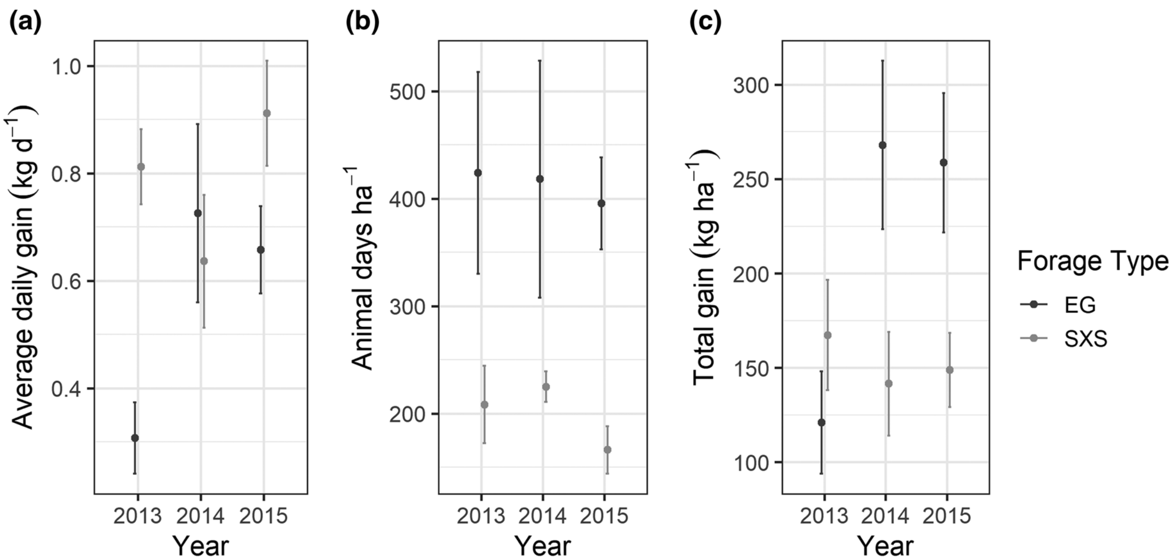


**FIGURE 4** Means and 95% confidence intervals for eastern gamagrass (EG) and sorghum × sudangrass hybrid (SXS) for (a) average daily gain, (b) animal days per hectare, and (c) total gain, 2013–2015, during bred beef heifer grazing experiment at East Tennessee Research and Education Center, near Knoxville, TN

**TABLE 2** Mixed-effects ANOVA model results for grass height (Height), forage mass (FM), crude protein (CP), acid detergent fiber (ADF), and neutral detergent fiber (NDF), 2013–2015, during eastern gamagrass and sorghum × sudangrass hybrid grazing experiment at East Tennessee Research and Education Center, near Knoxville, TN

| | Height | | FM | | CP | | ADF | | NDF | |
|---|---|---|---|---|---|---|---|---|---|---|
| **Effect** | ***F* value** | ***P* > *F*** | ***F* value** | ***P* > *F*** | ***F* value** | ***P* > *F*** | ***F* value** | ***P* > *F*** | ***F* value** | ***P* > *F*** |
| Intercept | 2530.5 | <.001 | 89.8 | <.001 | 1071.8 | <.001 | 5714.4 | <.001 | 9060.1 | <.001 |
| Date[a] | 19.86 | <.001 | 1.16 | 0.29 | 53.55 | <.001 | 55.88 | <.001 | 48.57 | <.001 |
| Forage Type | 59.69 | <.001 | 1.35 | 0.30 | 14.69 | 0.01 | 0.21 | 0.67 | 0 | 0.99 |
| Year | 9.83 | <.001 | 30.42 | <.001 | 0.11 | 0.75 | 0.07 | 0.80 | 0.01 | 0.93 |
| Date × Forage Type | 14.84 | <.001 | 0.09 | 0.76 | 0.70 | 0.41 | 1.64 | 0.21 | 2.29 | 0.14 |
| Date × Year | 0.11 | 0.74 | 0.17 | 0.68 | 3.97 | 0.05 | 0.32 | 0.57 | 0.78 | 0.38 |
| Forage Type × Year | 2.23 | 0.14 | 0.35 | 0.55 | 1.74 | 0.19 | 1.11 | 0.30 | 1.95 | 0.17 |
| Date × Forage Type × Year | 9.90 | <.001 | 0.12 | 0.73 | 2.66 | 0.11 | 0.15 | 0.70 | 0.21 | 0.65 |

[a]Date = Julian date; Forage Type = eastern gamagrass or sorghum × sudangrass hybrid; Year = 2013, 2014, or 2015.

**TABLE 3** Mixed-effects ANOVA model results for bred beef heifer average daily gain (kg $d^{-1}$; ADG), animal days per hectare (AD), total gain per hectare (GAIN), and successful pregnancy outcome (Pregnancy), 2013–2015, during eastern gamagrass and sorghum × sudangrass grazing experiment at East Tennessee Research and Education Center, near Knoxville, TN

| | ADG | | AD | | GAIN | | Pregnancy | |
|---|---|---|---|---|---|---|---|---|
| **Effect** | ***F* value** | ***P* > *F*** | ***F* value** | ***P* > *F*** | ***F* value** | ***P* > *F*** | ***F* value** | ***P* > *F*** |
| Intercept | 419.64 | <.001 | 419.644 | <.001 | 671.02 | <.001 | 492.85 | <.001 |
| Forage Type[a] | 11.47 | 0.03 | 11.4722 | 0.03 | 19.82 | 0.01 | 0.10 | 0.77 |
| Year | 16.50 | <.001 | 16.5042 | <.001 | 13.48 | <.001 | 4.23 | 0.04 |
| Forage Type × Year | 5.10 | 0.03 | 5.0975 | 0.03 | 23.15 | <.001 | 0.40 | 0.53 |

[a]Forage Type = eastern gamagrass or sorghum × sudangrass hybrid; Year = 2013, 2014, or 2015.

**TABLE 4** Means and standard deviations for forage mass (FM), crude protein (CP), acid detergent fiber (ADF), and neutral detergent fiber (NDF), 2013–2016, during eastern gamagrass nitrogen rate (Nrate) grazing experiment at East Tennessee Research and Education Center, near Knoxville, TN

| | | | FM | | CP | | ADF | | NDF | |
|---|---|---|---|---|---|---|---|---|---|---|
| **Year** | **Cultivar** | **Nrate** | **Mean** | **SD** | **Mean** | **SD** | **Mean** | **SD** | **Mean** | **SD** |
| | | kg $ha^{-1}$ | kg $ha^{-1}$ | | g $kg^{-1}$ | | | | | |
| 2013 | Highlander | 0 | 8448 | 6075 | 129.3 | 27.3 | 370.2 | 58.1 | 679.4 | 87.6 |
| 2014 | Highlander | 0 | 2244 | 1025 | 146.0 | 52.4 | 352.3 | 64.6 | 636.7 | 85.8 |
| 2015 | Highlander | 0 | 1918 | 585 | 149.9 | 31.2 | 340.2 | 42.3 | 639.3 | 57.5 |
| 2016 | Highlander | 67 | 2420 | 504 | 118.6 | 41.0 | 441.5 | 67.4 | 685.2 | 49.3 |
| 2016 | Pete | 67 | 2872 | 1407 | 126.3 | 38.5 | 421.0 | 61.4 | 660.2 | 50.4 |
| 2016 | Highlander | 134 | 1868 | 398 | 137.2 | 35.5 | 422.3 | 66.1 | 649.9 | 17.7 |
| 2016 | Pete | 134 | 2861 | 802 | 133.9 | 44.5 | 418.3 | 65.2 | 654.5 | 60.7 |

N rates, NDF was numerically lower (by 35.3 and 5.7 g $kg^{-1}$ for Highlander and Pete, respectively) at the higher N rate for both cultivars (Table 4).

For ADG, Highlander appeared to benefit more from the higher N rate than Pete, as well as having a numerically greater overall ADG regardless of rate (Table 5). Compared to the 67 kg $ha^{-1}$ rate, there were approximately 100 more AD with the highest N rate for either cultivar (Table 5). For GAIN, both cultivars showed what appeared to be substantial increases between the 67 and 134 kg rates, 105 kg $ha^{-1}$ for Highlander and 63 kg $ha^{-1}$ for Pete, approximately 35% and 26%, respectively (Table 5). Based on the 0 N rate reference, both AD and GAIN appeared to benefit from the additional fertility provided by the higher N rates.

## 3.4 | Economics

In 2013, the cost of gain for bred beef heifers did not differ ($P = 0.76$) between EG and SXS (Table 6). However, in 2014

**TABLE 5** Means and standard deviations for yearling heifer average daily gain (ADG) animal days ha$^{-1}$ (AD), and total gain (GAIN), 2013–2016, during eastern gamagrass nitrogen rate (Nrate) grazing experiment at East Tennessee Research and Education Center, near Knoxville, TN

| Year | Cultivar | Nrate | ADG Mean | ADG SD | AD Mean | AD SD | GAIN Mean | GAIN SD |
|---|---|---|---|---|---|---|---|---|
| | | kg ha$^{-1}$ | kg d$^{-1}$ | | d ha$^{-1}$ | | kg ha$^{-1}$ | |
| 2013 | Highlander | 0 | 0.31 | 0.10 | 424 | 173.3 | 121 | 42.6 |
| 2014 | Highlander | 0 | 0.73 | 0.26 | 418 | 203.5 | 268 | 70.4 |
| 2015 | Highlander | 0 | 0.66 | 0.13 | 395 | 78.7 | 259 | 58.2 |
| 2016 | Highlander | 67 | 0.61 | 0.10 | 499 | | 303 | 50.3 |
| 2016 | Pete | 67 | 0.49 | 0.13 | 519 | | 255 | 66.1 |
| 2016 | Highlander | 134 | 0.69 | 0.10 | 589 | | 407 | 56.6 |
| 2016 | Pete | 134 | 0.51 | 0.10 | 628 | | 319 | 62.0 |

**TABLE 6** Cost of gain ($ kg$^{-1}$ of beef) for bred beef heifers grazing eastern gamagrass (EG) and a sorghum × sudangrass hybrid (SXS) during an experiment at East Tennessee Research and Education Center, near Knoxville, TN, 2013–2015

| Year | Treatment | Cost of gain | Standard error | *P*-Value |
|---|---|---|---|---|
| | | $ kg$^{-1}$ | | |
| 2013 | EG | 1.41 | 0.274 | |
| | SXS | 1.54 | 0.274 | |
| | Difference | −0.13 | 0.380 | 0.762 |
| 2014 | EG | 0.62 | 0.084 | |
| | SXS | 1.71 | 0.084 | |
| | Difference | −1.09 | 0.119 | 0.012 |
| 2015 | EG | 0.62 | 0.100 | |
| | SXS | 1.64 | 0.100 | |
| | Difference | −1.02 | 0.109 | 0.011 |

($P = 0.012$) and 2015 ($P = 0.011$) the cost of gain for EG was lower than for SXS. Based on the nitrogen rate component of our study, the cost of gain for the EG cultivar Highlander was $0.73, $0.66, and $0.56 kg$^{-1}$ for nitrogen rates of 0, 67, and 134 kg ha$^{-1}$, respectively. The cost of gain for the EG cultivar Pete was $0.78 and $0.72 kg$^{-1}$ for nitrogen rates of 67 and 134 kg ha$^{-1}$, respectively.

## 4 | DISCUSSION

Forage nutritive values responded as expected during our study with CP decreasing through the grazing season and ADF and NDF increasing for both forages. Although there were no differences between EG and SXS for fiber, EG had greater CP levels overall. This difference may have been influenced by the stemmier growth habit of the SXS. However, CP for both forages remained above 100 g kg$^{-1}$ except during the latter part of the 2014 grazing season when they dropped to as low as 83 g kg$^{-1}$, likely a result of over-mature SXS during that year. Indeed, we had difficulty maintaining the SXS within our height target range. Despite the greater heights for SXS, animals continued to pick leaves from the elongated stalks. By comparison, we were able to generally maintain target heights for EG, although plants became coarser and approached the upper limit of the height criteria for this forage each year during late summer. Despite the differences between heights for EG and SXS, FM never differed between the two forages suggesting that our grazing management produced comparable conditions and did not materially influence our results. Another concern with the EG was the development of rust during mid- to late summer each year of the study. This development appeared to reduce acceptance of the infected material by the grazing animals. Both EG and SXS provided acceptable levels of FM throughout the three summers we conducted this study. This included the drought period of May and June 2014. Reduced FM in 2014 and 2015 compared with 2013 reflected improved management of both forages based on experience gained in 2013. Within the TF Belt, having adequate summer forage can be a challenge and EG and SXS provided large volumes of acceptable forage and proved to be able to offset the summer slump period.

Heifer performance on the two forages generally favored SXS with higher rates of gain in 2013 and 2014, despite the higher CP content of EG. Overall rates of gain for SXS were somewhat below those reported by Dillard et al. (2018); 0.99 kg d$^{-1}$), but those figures were for steers and therefore would be expected to be somewhat greater than those for yearling heifers. Additionally, the lack of any N amendments for SXS may have also reduced ADG somewhat as CP would have been reduced compared to fertilized stands (Holman et al., 2019). For EG, rate of gain was similar in 2014 and 2015 at 0.68 and 0.79 kg d$^{-1}$, a level very comparable to those reported elsewhere ranging from 0.67 kg d$^{-1}$ (Burns & Fisher, 2013) to 0.75 (Aiken, 1997) and 0.69 kg d$^{-1}$ (Burns & Fisher, 2010) with weaned steers. On the other hand, the 0.31 kg d$^{-1}$ we observed in 2013 for EG was more similar to what was reported by Backus et al. (2017) at 0.48 kg d$^{-1}$, also working with weaned steers. In their study, and in ours during 2013, management of EG resulted in over-mature plants which likely contributed to reduced animal performance. Thus, with the exception of EG in 2013, performance by heifers was at a level consistent with heifer development targets (Mulliniks et al., 2013; Patterson et al., 1992). Pregnancy rates overall (89% for all three years) were at acceptable levels and did not differ between these two forage options suggesting either is a viable tool for heifer development.

In all three years of our study, EG provided twice as many (412 vs. 200 d ha$^{-1}$) grazing days as SXS. A part of the explanation is that the mean starting date for grazing EG was 37 days sooner than that for SXS (7 May vs. 13 June) providing a 112-d grazing season vs. 65 d for SXS. Regardless, EG allowed for heavier stocking during the active grazing period (1788 ± 514 vs. 1392 ± 242 kg ha$^{-1}$). Although we did not document ADG for the heifers assigned to SXS during the 39 d prior to their stocking on that forage, Burns and Fisher (2013) found greater ADG, stocking rate, and gain when grazing EG vs. a TF-bermudagrass [*Cynodon dactylon* (L.)] system, despite a shorter (18 d fewer) grazing season for EG. In part, this was due to the relatively higher rates of gain on EG at that time of year. For instance, Backus et al. (2017) documented only 0.48 kg d$^{-1}$ for the full summer grazing season for weaned steers grazing EG, but 0.84 kg d$^{-1}$ for the first 30-d grazing period in spring for EG. That rate of gain, combined with greater stocking on EG suggests that switching to EG as early as 6 May each year is a reasonable management strategy. The mean end date for grazing was the same for both forages (27 August). Although forage was still available with EG (and without risk of nitrate toxicity), quality was low and animals would selectively graze other plants within EG pastures at this time of the season. It may be that mature cows would utilize the mature EG in September, but heifers did not accept it readily.

The greater stocking and AD for EG allowed it to produce greater GAIN than SXS in 2014 and 2015 despite having lower ADG than SXS. In 2013, the higher stocking/AD of EG were not enough to overcome the especially low ADG and thus GAIN did not differ between forage types in that year. For all three years, GAIN for SXS was fairly consistent (between 142 and 168 kg ha$^{-1}$) suggesting that despite the challenges presented by its tall growth form, its productivity was resilient to variation in management.

Burns and Fisher (2010) reported substantial stand thinning of EG in their treatment that maintained canopy heights at a mean of 27 cm. Although heights in our study remained, on average, above 40 cm following rotations, the duration of our grazing intervals (8 d on average) allowed for differential grazing pressure on individual plants. In 2013, greater mean residual canopy heights (60 cm) led to increased overall plant maturity and concentration of grazing pressure on smaller, less mature plants within the stand, often reducing such plants to 25–30 cm in height. As a result, these plants were weakened and stands thinned. Maintenance of more consistent grazing pressure through shorter grazing intervals with longer rest periods likely could have mitigated this problem by reducing selectivity. Regardless, the plant populations we observed remained within the range reported by Springer, Dewald, Sims, and Gillen (2003) for optimum yield.

Increased N inputs appeared to have only modest influence on pasture characteristics with CP being slightly higher and NDF slightly lower numerically at 134 vs. 67 kg ha$^{-1}$ N. These observations are consistent with those reported by Waramit et al. (2012) and Moyer and Sweeney (2016) when examining N rates similar to ours with modest gains in CP (14–27 g kg$^{-1}$ N) and limited sensitivity with respect to fibers. Conversely, we did observe higher AD and consequently, GAIN, for both cultivars during a summer that was particularly dry in the latter part of the grazing period (July and August). The greater AD also may explain why we did not see a large response in FM with the cattle consuming any additional growth. Other studies have reported limited yield response to N for EG including a 15% increase (50 vs. 100 kg ha$^{-1}$ N) in a drier environment (Kansas; Moyer & Sweeney, 2008) to no response (56 vs. 112 kg ha$^{-1}$ N) for one year on deep sandy soils (Rushing et al., 2019). On the other hand, in 2 of 3 years yields of EG increased from 78% to 194% with 150 vs. 0 kg ha$^{-1}$ N in Missouri (Brejda et al., 1997). However, none of these other studies were conducted under grazing management. Our results suggest greater N inputs could be beneficial for achieving greater pasture production.

From a cost of gain perspective, EG was a lower cost alternative compared to SXS in most years as was also reported by Tracy et al. (2010). Greater overall gain (due to more grazing days rather than rate of gain) for EG and the impact of accumulated annual establishment costs for SXS were the most influential factors in the differences in cost of gain for these two forages. In our study, neither forage received N amendments despite the fact that typical production recommendations (Keyser et al., 2015) include N for both species. Although this lack of N may have led to a modest reduction in CP and perhaps ADG for both forages, the most likely result would have been a reduction in AD. Thus, our results may be conservative with respect to productivity of these two forages. Based on our limited data, it appears that cost of gain for EG was improved with N application across the range of inputs we evaluated. However, additional field studies will be necessary to clarify this relationship.

## 5 | CONCLUSIONS

Both species provided acceptable summer forage for bred beef heifers during our study. Forage mass remained between 1645 and 7575 kg ha$^{-1}$ throughout the three summers providing adequate grazing. Grazing management should maintain consistent grazing pressure among individual plants with residual canopies above 40 cm to ensure stand vigor. Although forage fiber content was high for both forages for much of each grazing season, bred heifers did perform at levels acceptable for successful maintenance of pregnancy except for EG in 2013. From the standpoint of cost, the perennial, EG, proved to be more efficient for producing gain at a lower cost (except during 2013 when animal performance was so low). Producers within the transition zone should consider use of these forages as a complement to their cool-season forage base, especially the more cost-effective perennial.

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