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Evaluation of five C_4 forage grasses in the tall Fescue Belt

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Abstract

Across much of the eastern United States, tall fescue [TF; *Schedonorus arundinaceus* (Schreb.) Dumort.], a cool-season (i.e., C_3) perennial grass, is the primary forage for pasture systems, thereby leaving producers vulnerable to reduced summer forage production and drought. Warm-season (i.e., C_4) forages can complement existing production systems by supplementing summer forage production and drought resiliency. Therefore, our objective was to compare five, C_4 forage options in a grazing trial: switchgrass (SW; *Panicum virgatum* L.), eastern gamagrass (EG; *Tripsacum dactyloides* L.), a big bluestem (*Andropogon gerardii* Vitman) and indiangrass (*Sorghastrum nutans* L. Nash) blend (BBI), bermudagrass (BG; *Cynodon dactylon* L. Pers), and crabgrass (CG; *Digitaria sanguinalis* L. Scop.). Research was conducted 2014–2016 at two locations in Tennessee. Weaned beef heifers (237–242 kg initial weight) grazed 1.2-ha pastures with three replications per species and location. Average daily gains (kg d^{-1}) (0.62 [BBI], 0.41 [BG], 0.44 [CG], 0.42 [EG], 0.51 [SW]), grazing days (d ha^{-1}) (412 [BBI], 459 [BG], 455 [CG], 664 [EG], 617 [SW]), and total gain (kg ha^{-1}) (259 [BBI], 186 [BG], 200 [CG], 276 [EG], 315 [SW]) all varied among forages ($P < .001$). Similarly, forage nutritive values differed ($P < .001$) among forages: season-long crude protein ranged from 94 (BG) to 115 (CG and EG) g kg^{-1}, neutral detergent fiber (NDF), 601 (CG)–680 (SW) g kg^{-1}, and acid detergent fiber (ADF) 379 (BG)–417 (EG) g kg^{-1}. These forage options should be evaluated in the context of TF pastures to establish a broader understanding of their contribution within an overall forage system.

Abbreviations: ADF, acid detergent fiber; ADG, average daily gain; AREC, Ames AgResearch and Education Center; BBI, big bluestem–indiangrass blend; BG, bermudagrass; BW, body weight; CG, crabgrass; EG, eastern gamagrass; FM, forage mass; FNV, forage nutritive value; HRREC, Highland Rim AgResearch and Education Center; IVTDMD48h, in-vitro true dry matter digestibility 48 h; NDF, neutral detergent fiber; NWSG, native warm-season grass; SW, switchgrass; TF, tall fescue.

1 | INTRODUCTION

Much of the forage production in the eastern United States is based on a cool-season (i.e., C_3) perennial, tall fescue [TF; *Schedonorus arundinaceus* (Schreb.) Dumort.] (Kallenbach, 2015; Stuedemann & Hoveland, 1988). There are an estimated 14 million hectares of TF within this region (Buckner et al., 1979; Stuedemann and Hoveland, 1988), giving this forage production area its moniker, the Fescue Belt. However, as a C_3 species, its productivity is reduced during summer leaving a gap in pasture productivity which could be filled by warm-season (i.e., C_4) species (Burns & Fisher, 2013; Kallenbach et al., 2012; Tracy et al., 2010). Furthermore, as a C_3, TF is more vulnerable to summer drought than are C_4 grasses, an attribute that may be of substantial importance based on forecasts for this region that indicate droughts are likely to become more frequent and severe in coming years (Easterling et al., 2017; Vose et al., 2017).

Selection of C_4 grasses that can provide an effective complement to TF systems should be based on a variety of factors including forage nutritive value (FNV), animal performance, forage productivity, economic returns, and drought resiliency (Backus et al., 2017; Boyer et al., 2020; Brazil et al., 2022; Gelley et al., 2020; Keyser et al., 2016). Data exists on a number of these factors for native C_4 grasses (native warm-season grasses, NWSG) such as switchgrass (SW; *Panicum virgatum* L.), eastern gamagrass (EG; *Tripsacum dactyloides* L.), and big bluestem (BB; *Andropogon gerardii* Vitman) (Backus et al., 2017; Keyser et al., 2016; Rushing et al., 2020) and bermudagrass [BG; *Cynodon dactylon* (L.) Pers.; Kallenbach et al., 2012; McLaren et al., 1983]. However, few have directly compared these forages to one another (Burns & Fisher, 2013). Summer annuals can also play a strategic role in providing summer pasture (Dillard et al., 2018; Keyser et al., 2020; Teutsch et al., 2005) and should also be evaluated directly against the aforementioned perennials. Furthermore, grazing data for a prospectively valuable summer annual, crabgrass (CG; *Digitaria* spp.) are lacking (Dillard et al., 2018).

Therefore, we compared five summer forage options, three NWSG, BG, and an improved CG cultivar at two Fescue Belt locations. As a part of this study, we documented economic returns (Boyer et al., 2020) and water-use efficiency (Gelley et al., 2020). Here we report on FNV, animal performance, and pasture productivity for these five forage options from these experiments. We hypothesized that the annual would have the greatest FNV (Dillard et al., 2018), big bluestem/indiangrass (*Sorghastrum nutans* L. Nash) blend (BBI) the greatest animal performance (Backus et al., 2017; Burns & Fisher, 2013; Keyser et al., 2016), and BG the greatest pasture productivity (Burns & Fisher, 2013; McLaren et al., 1983), all based on previously published research regarding these species.

Core Ideas

- The C_4 grasses provide a beneficial complement to C_3-dominated pasture systems.
- Native grasses tended to have greater rates of gain and grazing days than bermudagrass or crabgrass.
- Overall, rates of gain for the forages in this study were lower than in comparable studies.
- Native grasses had greater total gain per hectare than bermudagrass or crabgrass.
- Bermudagrass and crabgrass provided more grazing days during late summer than native grasses.

2 | MATERIALS AND METHODS

2.1 | Study area

This study was conducted at two locations during three consecutive summers (2014–2016): Ames AgResearch and Education Center (AREC), located near Grand Junction, TN (35°6′ N, 89°13′ W), and Highland Rim AgResearch and Education Center (HRREC), located near Springfield, TN (36°28′ N, 86°50′ W). At HRREC, EG was not present and, therefore, only four forages were compared: SW (‘Alamo’), BB (‘OZ 70’) and indiangrass (‘Rumsey’) mixture (BBI), BG (‘Cheyenne II’), or CG (*D. sanguinalis* L. Scop.; ‘Red River’). Bermudagrass was not grazed at HRREC in 2014 due to limited establishment from winterkill. Pastures at AREC were on a Memphis silt loam soil (fine-silty, mixed, active, thermic, Typic Hapludalf) while those at HRREC were dominated by Dickson and Sango silt loams (fine- and coarse-silty, siliceous, semiactive, thermic, Glossic Fragidult, respectively). These sites were previously described by Backus et al. (2017).

Both AREC and HRREC recorded daily weather data, including air temperatures and precipitation. Temperature at AREC remained near 30-yr means except for August 2014 and May 2015 (below) and June–August 2015 (above) (Figure 1a). By contrast, temperature at HRREC was below 30-yr means in July 2014, August 2015, and May 2016 while they were above those means for 11 of the 15 mo encompassing the experiment (April–June 2014, April–July 2015, and April, June–August 2016; Figure 1b). Precipitation at AREC was only appreciably below (June 2016) or above (July 2014, June 2015) 30-yr means during a total of 3 mo (Figure 2a). Similarly, deviations from long-term precipitation patterns at HRREC only occurred in 6 mo with those below and above 30-yr means being equally represented (Figure 2b).

2.2 | Pastures

Native C_4 grasses were established in 2008 at both locations into pastures that had been dominated by TF for many years preceding the initiation of that study as described by Backus et al. (2017). Eastern gamagrass (‘Pete’) [13.5 kg ha^{-1} pure live seed (PLS)], SW (6.7 kg ha^{-1} PLS), BG (10 kg ha^{-1}), and CG (7 kg ha^{-1}) were planted as pure stands into individual pastures. The BBI was planted at 65% big bluestem and 35% indiangrass by seed mass (total for both species combined, 11.2 kg ha^{-1} PLS). Each forage was planted in

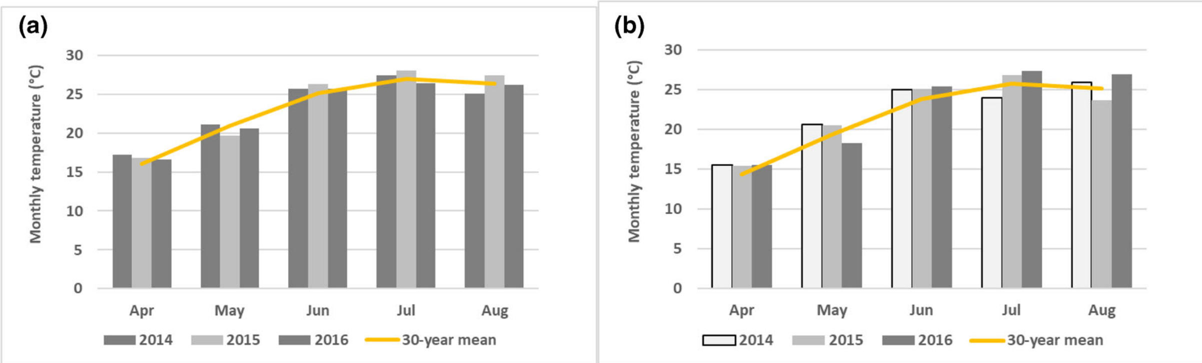

FIGURE 1 Mean monthly and 30-yr mean air temperature (˚C) for (a) Ames, Grand Junction, TN, and (b) Highland Rim, Springfield, TN, AgResearch and Education Centers, 2014–2016

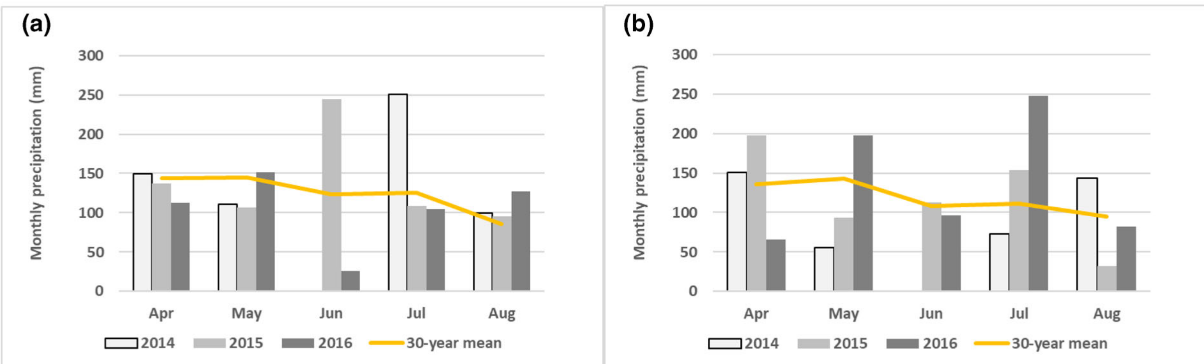

FIGURE 2 Mean monthly and 30-yr mean precipitation (mm) for (a) Ames, Grand Junction, TN, and (b) Highland Rim, Springfield, TN, AgResearch and Education Centers, 2014–2016. Data missing for June 2014 at both locations

three, replicated 1.2-ha pastures at each location resulting in 15 (five forages with three replications) experimental units at AREC, and 12 (four forages with three replications) at HRREC. Bermudagrass was seeded May 2013 at both locations. However, due to winterkill, BG was re-established at HRREC in 2014. Crabgrass was seeded yearly at both locations. Bermudagrass and CG were planted in a prepared seedbed, discing followed by a cultipacker.

All pastures received 67 kg ha^{-1} of N in the form of ammonium nitrate (NH_4NO_3) following green-up, and P and K levels were adjusted periodically per soil test results to maintain a medium level of these nutrients. Based on soil tests, 67 kg ha^{-1} of P was applied in the form of diammonium phosphate [$(NH4)_2HPO_4$] to indicated pastures at AREC (no additional K was required). Pastures at HRREC required addition of P ranging from 33 to 67 kg ha^{-1} and 67–135 kg ha^{-1} of K. Crabgrass pastures at HRREC received 33 kg P ha^{-1} every year.

2.3 | Cattle management

At AREC, Angus and Angus-cross weaned heifers weighing 237 kg (227, 243, and 240 kg for 2014, 2015, and 2016, respectively) at initiation of the grazing season were used as the model animal. Heifers grazed NWSG at AREC on average 94 d, from 9 May to 11 August (13 May–4 Aug. 2014, 8 May–17 Aug. 2015, and 6 May–12 Aug. 2016). Heifers grazed BG and CG at AREC on average 72 d, from 5 June to 16 August (6 June–18 Aug. 2014, 5 June–17 Aug. 2015, and 3 June–12 Aug. 2016).

At HRREC, grazing animals were fall-born dairy-beef cross heifers (2014 only) and in 2015–2016, commercial, fall-born beef heifers provided by Tennessee Livestock Producers (Columbia, TN). Heifers received from Tennessee Livestock Producers were backgrounded for at least 45 d to mitigate shipping stress and reduce the likelihood of illness during the study. Heifer starting body weights (BW) averaged 242 kg (202, 274, and 249 kg for 2014, 2015, and 2016, respectively). Grazing season for the NWSG at HRREC averaged 101 d, from 14 May–23 August (16 May–8 Aug. 2014, 15 May–31 Aug. 2015, and 12 May–29 Aug. 2016). Grazing season for BG and CG averaged 70 d, from 14 June–23 August (20 June–8 Aug. 2014, 12 June–31 Aug. 2015, and 9 June–31 Aug. 2016).

Four testers were randomly allotted to each pasture based on initial BW. These four testers remained on their assigned pasture throughout the grazing period. Target canopy heights during the grazing period were 60–76 cm for SW, 40–46 cm for BBI, and 45–60 cm for EG (Burns and Fisher, 2010; 2013; Keyser et al., 2016, 2020). Bermudagrass and CG target height was 7–20 cm. To maintain target grazing heights, additional heifers (grazers) were added and removed based on forage height criteria above (i.e., "put-and-take" grazing) when BW measurements were taken after each sample collection. Heifer care and management was conducted under UT–IACUC Protocol no. 2258-0414 approved on 14 Apr. 2014 by the Institutional Animal Care and Use Committee.

2.4 | Data collection

Forage samples were taken at the initiation of grazing and every 28 d thereafter until grazing for the season was concluded. Aboveground biomass of 10, 0.25 m2 randomly located quadrats were sampled throughout each pasture. At each plot, forage height was measured and then clipped to designated stubble heights depending on species. Sampling heights were assigned based on the grasses' growth characteristics with the intention of measuring forage nutritive values within the actual grazing horizon. In NWSG pastures, (EG, SW, and BBI) forage samples were collected at 41 cm and above (grazing horizon) and 20–40 cm (subcanopy). For BG and CG pastures, forage samples were collected from a single horizon (above 5.0 cm). All forage samples were dried at 55 ˚C for 72 h to determine dry matter. Total forage mass (FM) was estimated using the total weight of forage collected (both horizons for NWSG) per pasture. Grab samples were taken from each sample and ground through a Wiley Mill (Thomas-Wiley Laboratory Mill Model 4, Arthur H. Thomas Co.) to pass through a 2-mm screen and then ground using a UDY Mill (UDY Corporation) to pass through a 1-mm screen. Ground samples were analyzed using Near-Infrared Spectroscopy technology (FOSS 5000, FOSS NIRSystems, Inc.) for crude protein (CP), neutral detergent fiber (NDF), acid detergent fiber (ADF), and in-vitro true dry matter digestibility 48 h (IVTDMD48h) with all predicted results presented at 100% dry matter (DM). Equations for the forage nutritive analysis were standardized and checked for accuracy using the 2016 Grass Hay calibration developed by the NIRS Forage and Feed Consortium (NIRSC). 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). The University of Tennessee Forage Nutrition Lab was certified by the National Forage and Testing Association (NFTA) during the course of this study.

Animal performance data were collected from four weaned heifers in each pasture that had been designated as testers. Prior to the initiation of grazing, testers were fed an equilibration ration at 2.25% of BW for four consecutive days to decrease variation in gut fill as described by Backus et al. (2017). The equilibration ration was composed of cottonseed hulls, soyhulls, citrus pulp, dried distillers' grains, and molasses and contained 12.9% CP and 27.2% crude fiber on an as-fed basis.

Starting BW was based on the mean of two weights collected on consecutive days, the final day of the ration and the day they were placed on the pastures. Tester BW was recorded every 28 d throughout the grazing period. At termination of grazing for each forage, testers were again fed the equilibration diet, and ending BW was assessed with the same protocol described for initiation of grazing. Based on the testers, we calculated average daily gain (ADG) for the full grazing period each year by subtracting beginning from ending weights of each tester divided by total number of days on test. For pasture productivity, we calculated total grazing days ha^{-1} (testers and all grazers combined), total gain (kg ha^{-1}), which was calculated by multiplying ADG of the testers by total grazing days ha^{-1} for each paddock, and stocking rate (head ha^{-1}).

2.5 | Statistical analysis

The experiment was a randomized complete block design, except EG was only used at one location (AREC), resulting in an incomplete block analysis. Experimental unit was the 1.2-ha pasture. Data for forage FNV (CP, NDF, ADF, and IVTDMD48h), canopy height, and FM were analyzed using SAS 9.4(SAS Institute) using generalized linear mixed models (PROC GLIMMIX) within the DandA macro (Saxton, 2013). Fixed effects were species (BBI, SW, EG, BG, and CG) and sampling period (May, June, July, and August), and their interactions. Random effects were location, year, and block (based on soils). For NWSG, grazing horizon and subcanopy samples (CP, ADF, NDF, IVTDMD48h) were also analyzed separately under the same model. The same model was also used for animal performance (ADG) and pasture productivity measures (grazing days, total gain, stocking rate) except that ADG and total gain were not analyzed by period. Breed of animal differed at Highland Rim in 2014, but because year and location were blocking factors, breed effects were accounted for within blocks. Means separations were accomplished using Fisher's Least Significant Differences ($P < .05$).

3 | RESULTS

3.1 | Forage performance

3.1.1 | Season-long

Within the grazing horizon, CG had greater ($P < .001$) CP than SW and BG (Table 1). No differences were observed within the grazing horizon in ADF content among the three

TABLE 1 Mean forage measurements, for big bluestem/indiangrass blend (BBI), bermudagrass (BG), crabgrass (CG), eastern gamagrass (EG), and switchgrass (SW) pastures, 2014–2016, Highland Rim and Ames AgResearch and Education Centers, TN

Forage	CP	NDF	ADF	IVTDMD48h	Canopy height	FM
	g kg^{-1}			%	cm	Mg ha^{-1}
BBI	107ABC	664C	411B	67B	39B	0.91CD
BG	94CDE	615D	379C	68AB	24C	1.09BC
CG	115A	601D	388C	71A	25C	1.39AB
EG	115AB	679ABC	417AB	63CDE	38B	0.66D
SW	103BCD	680ABC	392C	66BC	54A	1.68A

Note. ADF, acid detergent fiber; CP, crude protein; FM, forage mass; IVTDMD48h, in-vitro true dry matter digestibility 48 h; NDF, neutral detergent fiber. Data are pooled across all sample periods and years. Means without common letters differ ($P < .05$).

TABLE 2 Mean forage nutritive quality for two canopy strata for big bluestem/indiangrass blend (BBI), eastern gamagrass (EG), and switchgrass (SW) pastures, 2014–2016, Highland Rim and Ames AgResearch and Education Centers, TN

Forage	Strata	CP	NDF	ADF	IVTDMD48h
		g kg^{-1}			%
BBI	Grazing horizon	106A	663C	411B	67A
	Subcanopy	92BC	674BC	435A	65AB
EG	Grazing horizon	114A	681ABC	418AB	63BC
	Subcanopy	102AB	692AB	424AB	62C
SW	Grazing horizon	102AB	681ABC	391C	66AB
	Subcanopy	84C	699A	419AB	62C

Note. ADF, acid detergent fiber; CP, crude protein; IVTDND48h, in-vitro true dry matter digestibility 48 h; NDF, neutral detergent fiber. Grazing horizon samples were taken from that portion of the canopy above 41 cm and those for subcanopy were taken from 20 to 41 cm. Data are pooled across all sample periods and years. Means without common letters differ ($P < .05$).

NWSG and all three had greater ADF than BG and CG. However, BBI and EG contained higher concentrations ($P < .001$) of NDF than BG and CG; SW was similar to BG and CG (Table 1). Crabgrass had greater ($P < .001$) IVTDMD48h than the NWSG within the grazing horizon but was similar to BG (Table 1). Of the NWSG, SW had greater ($P < .001$) canopy height than BBI and EG (Table 1). Heights for BG and CG did not differ and were lower than the NWSG (Table 1). Switchgrass and CG developed more ($P < .001$) FM than BBI and EG (Table 1). With the exception of ADF, FNV were always less desirable ($P < .05$) within the subcanopy of SW compared with the grazing horizon. For BBI only CP and NDF differed between the two strata (Table 2). No differences were detected for any of the FNV parameters between horizons for EG (Table 2).

3.1.2 | Monthly forage comparisons

For all species, CP declined ($P < .05$) through the season reaching lows of 77 g kg^{-1}(SW) and 79 g kg^{-1} (BG) in August (Figure 3a). For EG, CP remained above 106 g kg^{-1} for July and August. During June, the less mature swards of BG and CG had the greatest CP levels at 131 and 158 g kg^{-1}, respectively. Fibers (ADF and NDF) for the NWSG were greater ($P < .05$) in June than those for the less mature BG and CG (Figure 3b,c). The NWSG had greater NDF levels in July but in August, EG did not differ from either BG or CG. In July, ADF for SW was similar to CG; BG had the lowest NDF. In August, CG, EG, and SW did not differ with respect to ADF; BG had the least amount of NDF. As was observed for CP, IVTDMD48h values declined across the season for all forages with CG having the greatest value in August at 66% (Figure 3d). Bermudagrass (64%) at this time only differed ($P < .05$) from SW, which had 60.5% IVTDMD48h.

Forage canopy heights were greatest for NWSGs during May and declined thereafter (Table 3). Both BBI and EG exceeded target heights during this initial period. Canopy heights for EG were substantially reduced during June and July, showing some recovery in August. From June–August, BBI remained well below target heights. In contrast, the shorter stature species, BG and CG generally maintained consistent canopy heights through the season.

Similarly, FM for all three NWSGs were at their greatest numerical values in May (Table 3). During July and August, FM for EG remained low at 0.45 and 0.43 Mg ha^{-1}. The BBI blend also dropped throughout the season reaching a low in August of 0.51 Mg ha^{-1}. In contrast, SW recovered to levels similar to May after a decline in June. Crabgrass followed a pattern similar to BBI and EG,

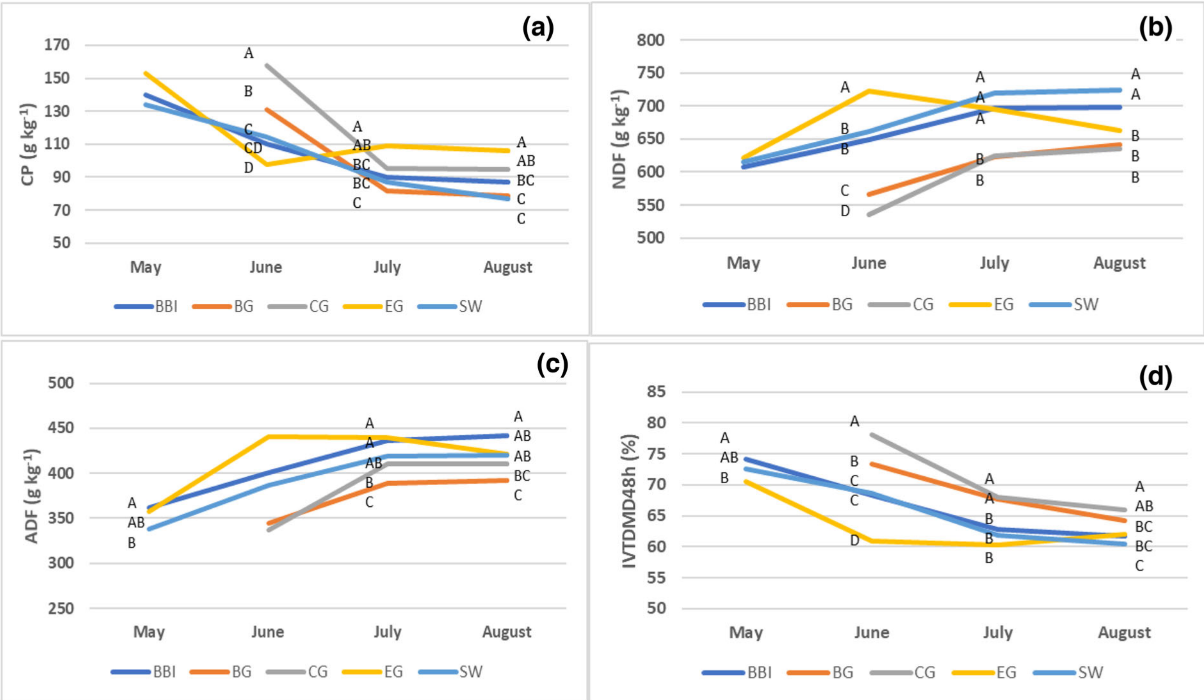

FIGURE 3 Mean monthly (May–August) forage nutritive values (a, crude protein [CP]; b, neutral detergent fiber [NDF]; c, acid detergent fiber [ADF]; d, in-vitro true dry matter digestibility 48 h [IVTDMD48h]) for big bluestem/indiangrass blend (BBI), bermudagrass (BG), crabgrass (CG), eastern gamagrass (EG), and switchgrass (SW) pastures, 2014–2016, Highland Rim and Ames AgResearch and Education Centers, TN. Forage samples were collected from grazing horizon (>41 cm for BBI, EG, and SW; >5 cm for BG and CG). Data are pooled across years. Means within each month with differing letters differ ($P < .05$)

TABLE 3 Mean monthly canopy height and forage mass for big bluestem/indiangrass blend (BBI), bermudagrass (BG), crabgrass (CG), eastern gamagrass (EG), and switchgrass (SW) pastures, 2014–2016, Highland Rim and Ames AgResearch and Education Centers, TN

Forage	May	June	July	August
	Canopy height cm			
BBI	52CD	32FG	38EF	34EFG
BG		29GH	23HI	19I
CG		29GH	23HI	22HI
EG	63AB	30FGH	19I	37EFG
SW	66A	41E	49D	58BC
	Forage mass Mg ha^{-1}			
BBI	1.87ABC	0.99C–F	0.72EFG	0.51GH
BG		0.94B–H	1.52A–E	0.91E–H
CG		2.49A	1.4B–E	0.77FGH
EG	1.35A–F	0.75E–H	0.45 H	0. 43H
SW	2.63A	0.95D–G	1.81A–E	1.75A–D

Note. Data are pooled across years. Means for each metric without common letters differ ($P < .05$).

declining throughout the season reaching a low ($P < .05$) in August of 0.77 Mg ha^{-1}. On the other hand, FM of BG did not differ by month. There were no differences in FM among BBI, EG, and SW for the month of May (Table 3). Crabgrass had the greatest ($P < .001$) FM in June; the other four forages had similar FM during this period. Eastern gamagrass had the lowest ($P < .001$) FM in July, but no differences were observed among the other species. Lastly, in August, SW had the greatest ($P < .001$) FM compared with the other species with the other four not differing from one another.

3.1.3 | Monthly forage performance for native warm-season grass horizons

Seasonally, differences in FNV between the grazing horizon and subcanopy were more apparent earlier in the summer grazing season. During August, there were no differences ($P > .05$) for any forage parameter for any of the three species between canopy strata (Table 4). During July, only BBI had differences between the grazing horizon and subcanopy; in all cases, FNV was less desirable in the subcanopy. In contrast, all three species demonstrated differences for at least one parameter during May and for SW, all four parameters differed. The BBI blend was most persistent with respect to maintaining differences between strata for CP and NDF, which remained different through July.

TABLE 4 Mean monthly (May–August) forage nutritive values for two canopy strata for big bluestem/indiangrass blend (BBI), eastern gamagrass (EG), and switchgrass (SW) pastures, 2014–2016, Highland Rim and Ames AgResearch and Education Centers, TN

Forage	Strata	CP	NDF	ADF	IVTDMD48h
May					
BBI	Grazing horizon	142AC	609B	361BC	74A
	Subcanopy	123BD	635AB	388A	72ABC
EG	Grazing horizon	146AB	631AB	367ABC	70ABC
	Subcanopy	124CD	653A	377AB	69BC
SW	Grazing horizon	138ABC	609B	333C	73AB
	Subcanopy	113D	650A	375AB	69C
June					
BBI	Grazing horizon	105CD	649C	412BC	67CD
	Subcanopy	87E	672BC	439A	65DE
EG	Grazing horizon	87DE	742A	457A	59F
	Subcanopy	97CDE	710AB	451A	61EF
SW	Grazing horizon	118BC	653C	383CD	69BC
	Subcanopy	85DE	703AB	427AB	62EF
July					
BBI	Grazing horizon	88AB	691B	436BCD	63BC
	Subcanopy	69C	714AB	473A	59DE
EG	Grazing horizon	94ABC	720AB	462AB	59DE
	Subcanopy	76ABC	740A	477A	56E
SW	Grazing horizon	83ABC	727A	423C	61CD
	Subcanopy	72BC	728A	440BC	59DE
August					
BBI	Grazing horizon	85AB	698AB	446A	62BCD
	Subcanopy	86AB	681B	446A	63ABC
EG	Grazing horizon	90AB	688AB	443A	60CD
	Subcanopy	84AB	716AB	445A	58D
SW	Grazing horizon	77AB	717A	419ABC	61CD
	Subcanopy	73B	714AB	434AB	59D

Note. ADF, acid detergent fiber; CP, crude protein; IVTDND48h, in-vitro true dry matter digestibility 48 h; NDF, neutral detergent fiber. Grazing horizon samples were taken above 41 cm and those for subcanopy were taken from 20 to 41 cm. Data are pooled across years. Means within a month without common letters differ ($P < .05$).

3.2 | Animal performance and pasture productivity

3.2.1 | Season-long

Among the five forages, BBI had the greatest and BG the lowest ($P < .001$) ADG (Table 5). Total grazing days (testers and grazers) was greatest ($P < .001$) for EG and SW; the other three forages did not differ from one another. Total gain per hectare was greatest for SW ($P < .001$) followed by EG (similar to both SW and BBI), then BBI. Bermudagrass and CG had the least ($P < .001$) amount of gain per hectare. Lastly, the average stocking rate was similar for SW, EG, BG, and CG. However, BBI had significantly lower ($P < .001$) stocking rate compared with the other species (Table 5).

TABLE 5 Mean average daily gain (ADG), grazing days ha^{-1}, gain ha^{-1}, and stocking rate (head ha^{-1}) for weaned heifers grazing big bluestem/indiangrass blend (BBI), bermudagrass (BG), crabgrass (CG), eastern gamagrass (EG), and switchgrass (SW) pastures, 2014–2016, Highland Rim and Ames AgResearch and Education Centers, TN

Forage	ADG	Grazing days	Gain	Stocking rate
	kg d^{-1}	d ha^{-1}	kg ha^{-1}	head ha^{-1}
BBI	0.62A	412B	259B	5B
BG	0.41C	459B	186C	7A
CG	0.44BC	455B	200C	7A
EG	0.42BC	664A	276AB	8A
SW	0.51B	617A	315A	7A

Note. Data are pooled across all sample periods and years. Means without common letters differ ($P < .05$).

TABLE 6 Mean monthly (May–August) grazing days and stocking rate (head ha^{-1}) for weaned heifers grazing big bluestem/indiangrass blend (BBI), bermudagrass (BG), crabgrass (CG), eastern gamagrass (EG), and switchgrass (SW) pastures, 2014–2016, at Highland Rim and Ames AgResearch and Education Centers, TN

Forage	May	June	July	August
	Grazing days d ha^{-1}			
BBI	120FG	139EF	103G	61I
BG		160DE	198BC	113FG
CG		177CD	200BC	95GH
EG	250A	238A	148DEF	48I
SW	217AB	223AB	123FG	67HI
	Stocking rate head ha^{-1}			
BBI	6.4EF	4.8G	3.7H	3.7H
BG		7.1CDE	6.9DE	6.3EF
CG		8.6B	7.4CD	4.9G
EG	11.6A	8.5BC	5.3FG	4.9GH
SW	11.6A	7.7BCD	4.6GH	4.0GH

Note. Data are pooled across years. Means for each metric without common letters differ ($P < .05$).

3.2.2 | Monthly comparison among species

Switchgrass and EG had the greatest ($P < .001$) number of grazing days in May and June while CG and BG had the greatest ($P < .001$) number in July (Table 6). Bermudagrass had greater ($P < .001$) grazing days in August but did not differ from CG, which was similar to SW. For the NWSG, grazing days were greatest ($P < .001$) in May and June with decreases in July and again in August. Bermudagrass grazing days increased ($P < 0.001$) from June to July and then decreased in August. Grazing days for CG remained similar in June and July, followed by a decrease in August; all five species produced their lowest number of grazing days in August.

Similar to the pattern for grazing days, EG and SW had the greatest ($P < .001$) stocking rate during May (Table 6). During June, BBI had reduced stocking rate relative to the other forages with BG similar to EG and SW but less than CG. Crabgrass and BG had the greatest ($P < .001$) stocking rate in July. Bermudagrass had the greatest ($P < .001$) stocking rate for August. Stocking rate for BG remained similar across all 3 mo while CG declined each month. Switchgrass, BBI, and EG likewise declined each month except August, which was similar to July for all three species.

4 | DISCUSSION

This study provided valuable insight into five C_4 forages that could serve as a complement to TF during summer when that cool-season species has reduced productivity. All forages differed in important ways with respect to FNV, FM, animal performance, and pasture productivity. Furthermore, there were clear temporal patterns over the summer grazing season that differentiated these forages. Differences in FNV among canopy horizons for the tall-growing NWSG validated the need to concentrate sampling for these parameters within the actual grazing horizon.

As expected for C_4 grasses, FNV was moderate and followed expected patterns associated with advancing plant maturity through the course of summer. For example, all five forages, had high CP levels (140–158 g kg^{-1}, depending on species) during the initial month of grazing and declined (77–106 g kg^{-1}, depending on species) by July, remaining unchanged through August. Likewise, fiber content increased, and digestibility decreased for July and August. The ranges observed were generally consistent with that reported previously for BBI (Backus et al., 2017; Brazil et al., 2020; Rushing et al., 2020) and SW (Backus et al., 2017; Burns & Fisher, 2013). For EG, there was more variability among studies (Backus et al., 2017; Burns & Fisher, 2010; Keyser et al., 2020), perhaps indicating that for this species, grazing management to maintain specific canopy targets may be more challenging than for the other species. In the case of BG, our estimate of CP (94 g kg^{-1}, full season mean) was below those reported by Burns and Fisher (2010) (136 g kg^{-1}), Burns and Fisher (2013) (134 g kg^{-1}), and McLaren et al. (1983) (135 g kg^{-1}). However, in those three studies, N was applied at 235, 360, and 254 kg ha^{-1}, respectively, while we applied only 67 kg ha^{-1}. We are aware of no other grazing studies for CG but the levels of CP and fiber we observed are consistent with those reported in recent studies that relied on mechanical harvest of this species (Beck et al., 2007; Gelley et al., 2016; Teutsch et al., 2005).

Among the five forages evaluated, CP did not vary widely, remaining between 94 and 115 g kg^{-1} for the season-long mean. For the one annual in our study, CG, values for CP, ADF, and NDF were always similar to or more favorable than those of the perennials for the full season as well as monthly intervals. During July and August, BBI and EG had similar CP to CG. In the case of EG, the higher CP content was likely a result of the heavy use of this species early in the season resulting in these stands maintaining a vegetative condition much later in the summer. Bermudagrass and CG were almost always lower in fiber than the NWSG for the full season as well as monthly periods.

Our data on FNV between the two canopy horizons for NWSG indicated important differences in seasonal means, as well as patterns among months and species. Except for CP in May, no differences in FNV were detected for EG. In this particular case, this may have been a function of the heavy use of this species and consequent vegetative condition throughout the growing season. If plants had developed more mature leaf tissue, there may have been greater differences between strata for this species. For SW, season-long CP, ADF, and digestibility differed between strata. Furthermore, for May and June, SW differed for these three FNV measures as well as NDF. In July and August, when the SW plants had become more mature, there were no differences detected for FNV. In the case of BBI, it was not until August that all FNV measures converged, perhaps an indication of the leafiness of this forage relative to the taller, more robust and stemmy, lowland SW. Regardless of the variable patterns among these three forages, selection of FNV samples from the grazing horizon is clearly appropriate for these species.

With respect to FM, our season means were notably lower than what has been previously reported for the three NWSG (Backus et al., 2017; Burns & Fisher, 2013; Keyser et al., 2016) and BG (Burns & Fisher, 2010; Burns & Fisher, 2013; McLaren et al., 1983). For EG, the degree of variability reported in the literature was, once again, much more pronounced than with the other forages. While Backus et al. (2017) and Burns and Fisher (2013) reported FM for EG near 5.0 Mg ha^{-1}, Aiken (1997) had 5.0–8.0 Mg ha^{-1} and Burns and Fisher (2010) reported only 1.1 Mg ha^{-1}. In terms of monthly patterns, BG and SW remained relatively stable while the other three forages, particularly BBI and CG, declined through the summer. This may suggest, in contrast to our observation above regarding EG, that BG and SW may be more resilient to variation in grazing management.

Animal performance in the current study was well below most other reported rates for these same forages. However, direct comparisons are difficult because the other research projects used steers (Backus et al., 2017; Burns & Fisher, 2013; Kallenbach et al., 2012; Scaglia & Boland, 2014) or yearling heifers (Keyser et al., 2016, 2020). The only other study that evaluated weaned heifers used only BBI (Brazil et al., 2020) and, for that forage, reported ADGs of 0.81–0.89 kg d^{-1}; they did not apply any N during that experiment. Among the five forages in our study, BBI had the greatest ADG, with BG being the lowest. It is notable that these two forages did not differ in FM or digestibility, but BBI had slightly greater CP (107 vs. 94 g kg^{-1}), ADF (411 vs. 379 g kg^{-1}), and NDF (664 vs. 615 g kg^{-1}). Taken together, these measure of FNV would not suggest the nearly 50% advantage in ADG observed for BBI. In a comparison of bahiagrass (*Paspalum notatum* L.) and a blend of NWSG similar to our BBI, Rushing et al. (2020) reported that despite greater CP (by about 20 g kg^{-1} for most of the grazing season) and lower ADG (by a similar margin) for the former species, the NWSG produced greater rates of gain (i.e., 1.0 vs. 0.45, 0.73 vs. 0.42, and 0.55 vs. 0.40 kg d^{-1}, respectively, for three grazing intervals starting in early May). This apparent paradox has been noted previously and may be explained by by-pass protein fractions in the NWSG (Blasi et al., 1991; Mullahey et al., 1992; Redfearn & Jenkins, 2000) or underestimates of digestibility with existing laboratory analytics (Griffin et al., 1980; Jung et al., 1985). Although we are unaware of any published grazing studies using CG, Blount et al. (2003) mentioned ADGs of 0.63 in Oklahoma, and in Florida, 0.50 and 0.86 kg d^{-1}, all of which were above the levels we observed.

Comparing pasture productivity in our study to other published studies based on grazing days per hectare is also somewhat problematic given that most used steers, larger animals, and had differing N rates. However, where N rates were not markedly different or initial animal mass substantially greater, grazing days were reasonably similar (e.g., Backus et al., 2017). Among these five forages, SW and EG produced the most grazing days for the full season. When evaluated by month, however, it becomes clear that the grazing days (and stocking rate) for the NWSG are concentrated more during the first half of the summer while those for BG and CG peak in July. Part of the advantage for the NWSG was that they were ready to graze, on average, 29 d sooner (11 May vs. 10 June) than BG and CG. During August, grazing days for all forages declined relative to July as the plants reached maturity and growth slowed. Burns and Fisher (2013) reported a similar pattern in their study comparing BG to big bluestem, EG, SW. They reported NWSG were ready to graze 12 d sooner (21 April vs. 3 May) than Tifton-44 BG and produced (averaged across NWSG species) 836 whereas BG produced 771 animal d ha^{-1}. When those same comparisons were made for the period June–August, BG produced the most days, 867 vs. 488 d ha^{-1} for the NWSG, averaged across species (Burns & Fisher, 2013). In the current study, when pasture productivity was evaluated based on total per hectare gain, the NWSG produced the most based on a combination of more grazing days and higher ADGs. Despite the higher ADG for BBI, the lower number of days it produced vs. EG and SW led to less gain for BBI. Bermudagrass and CG produced comparable amounts of gain to one another.

We did not account for the gain that would have been accumulated on a cool-season forage during the 29-d period before the BG and CG were grazed. Indeed, within the Fescue Belt, C_3 species such as TF remain productive during May when we had initiated NWSG grazing. This trade-off was evaluated in two studies where NWSG were compared with a BG plus tall fescue (BG+TF) system. In both of these studies, the BG+TF system had a 14-d longer grazing season than the NWSG. In one case, the NWSG outproduced the BG+TF system (Burns & Fisher, 2013) and in the other, produced comparable gain (Burns et al., 1984). However, grazing TF during late spring and early summer must take into account impacts of TF toxicosis (Kallenbach, 2015), especially for reproductive animals (Drewnoski et al., 2009; Paterson et al., 1995).

In a companion study, Boyer et al. (2020) evaluated the returns associated with our grazing data and determined that SW (US$430 ha^{-1}) performed best with similar outcomes for BBI and EG ($248 and $285 ha^{-1}, respectively). Primarily because of annual establishment costs, CG fared the worst in their analysis. However, in most circumstances, CG can be effective in reseeding itself each spring and, in that scenario, the returns would be more favorable. It is also worth noting that we only applied a moderate level of N compared with some other investigators and, consequently, our cost of production estimates may have been low. On the other hand, the higher rates of N would have increased production and, potentially, returns. Where N costs are low and prices for calves are high, increased N fertilization could have a net favorable outcome; otherwise, it likely would not (Brazil et al., 2022).

In another companion study, Gelley et al. (2020) measured instantaneous water-use efficiency of these five forages during our grazing experiments. The greatest values were for SW (74.5 µmol CO_2 mol H_2O^{-1}) and CG (74.1 µmol CO_2 mol H_2O^{-1}), which did not differ from one another but were greater than BBI (64.6 µmol CO_2 mol H_2O^{-1}); EG and BG fell between these two upper and lower extremes. However, because precipitation patterns during the study did not produce drought conditions, drawing firm conclusions about which forage option would be most resilient under such extremes remains somewhat uncertain (Gelley et al., 2020).

5 | CONCLUSIONS

Selection of any of the five forages evaluated should be based on producer objectives. For highest rates of gain, an important consideration in grass-finishing operations and for heifer development, the BBI would be an optimum summer forage. For summer-long gain, EG and SW will be the best options. They also appear to provide the best economic return to the operation. For improved grazing days during late summer, BG and CG are most favorable. All five forages would improve operational drought resiliency over TF (or other C_3 forages) through the summer although, SW and CG may be preferable in such a role. All five forage options could also contribute to alleviating impacts associated with TF toxicity. However, the three native options would allow producers to be off toxic endophyte-infected TF as much as 29 d sooner and, during a time when toxin levels are elevated. Differences in establishment should also be considered with perennials (i.e., BBI, BG, EG, and SW) requiring over a year to establish before they can be grazed while an annual (i.e., CG) can be grazed the same year it is planted. On the other hand, most annual species have to be planted each spring, increasing long-term cost and incurring the repeated risk of stand failure. Each of these forage options can make a valuable contribution to summer forage production within the Fescue Belt.

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AUTHOR CONTRIBUTIONS

Pat Keyser: Conceptualization; Funding acquisition; Investigation; Project administration; Writing – review & editing. Katelynn E. Zechiel: Data curation; Formal analysis; Investigation. Gary Bates: Conceptualization; Methodology. Amanda J. Ashworth: Conceptualization; Funding acquisition; Methodology; Writing – review & editing. Renata Nave: Investigation; Methodology; Writing – review & editing. Justin Rhinehart: Conceptualization; Funding acquisition; Investigation; Project administration; Writing – original draft; Writing – review & editing. David Weston McIntosh: Data curation; Investigation; Methodology; Resources.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

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