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Using a browntop millet companion crop to aid native grass establishment

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Abstract

The lack of forage production during the seedling year is a barrier to wide-scale adoption of native warm-season grasses (NWSG). To address this, two NWSG establishment experiments were conducted in Knoxville, TN, 2016–2018, to determine the efficacy of big bluestem (BB; *Andropogon gerardii* Vitman) and switchgrass (SG; *Panicum virgatum* L.) establishment with browntop millet [BTM; *Urochloa ramosa* (L.) Nguyen] as a companion crop. Each experiment was a randomized complete block arranged as a 2 × 3 factorial. Two defoliation strategies [(1) harvests based on BTM maturity (boot to heading stage) for hay (HAY) or (2) clipping to control BTM competition by maintaining >50% sunlight reaching BB and SG seedlings (CLIP)] were coupled with three BTM seeding rates [0 (control), 11.2 (half-recommended rate), and 22.4 (full-recommended rate) kg pure live seed (PLS) ha^{-1}]. Only BTM seeding rate affected BB and SG plant density at dormancy. In all cases, the control had greater BB and SG plant density than the full-recommended rate, indicating that BTM impeded BB and SG establishment. All BTM seeding rates resulted in acceptable stands (≥5.4 plants m^{-2}) of BB (both years) and SG (2017 only). Only the control allowed for acceptable stands of SG in 2016 (8.5 plants m^{-2}). Managing BTM for HAY produced a mean cumulative dry matter (DM) yield of 3.15 and 2.68 Mg ha^{-1} in 2016 and 2017, respectively. These findings show that BTM can be a companion crop that helps offset production losses during BB and SG establishment.

1 | INTRODUCTION

In recent years, considerable attention has been focused on native warm-season grass (NWSG) such as big bluestem (BB; *Andropogon gerardii* Vitman) and switchgrass (SG; *Panicum virgatum* L.) because of their potential contributions to forage for livestock (Backus et al., 2017; Burns & Fisher, 2013; Tracy et al., 2010), biomass for bioenergy (McLaughlin & Kszos, 2005; Sanderson et al., 2012), and integrated forage–biomass production systems (Guretzky et al., 2011; Lowe et al., 2015; McIntosh et al., 2015; Mosali et al., 2013). These grasses are desirable because of their drought tolerance (Buttrey et al., 2011; Sanderson & Reed, 2000), low input requirements (Boyer et al., 2012; Kering et al., 2012; Vogel et al., 2002), potential for achieving conservation goals (Gilley et al., 2000; Harper et al., 2015; West et al., 2016), and high resilience against climate variability (McLaughlin & Walsh, 1998; Owensby et al., 1999). Despite these many advantages,

Abbreviations: BB, big bluestem; BTM, browntop millet; DAP, days after planting; DM, dry matter; NWSG, native warm-season grass; PLS, pure live seed; SG, switchgrass

NWSG have not been widely re-adopted into production systems of the humid southeastern United States.

One obstacle to integration of NWSG into forage and/or biomass production systems is stand establishment (Miesel et al., 2012; Schmer et al., 2006; West & Kincer, 2011), which likely is the greatest barrier for producer adoption of NWSG (Aiken & Springer, 1995; Keyser et al., 2021; Parrish & Fike, 2005). Past researchers have identified competition control as a major contributor to failed establishment (Curran et al., 2011; Hedtcke et al., 2014; McKenna et al., 1991). Past researchers have explored planting NWSG following a cool-season annual cereal cover crop to aid in NWSG establishment (Hedtcke et al., 2014; Keyser et al., 2016a). In many situations, cover crops can double as companion crops and can offset establishment losses during the establishment of perennial plants and may reduce weed competition (Milchunas et al., 2011; Singh et al., 2003). At higher latitudes, cool-season annuals may serve as companion crops. For example, Jungers et al. (2015) seeded a NWSG polyculture with barley (*Hordeum vulgare* L.) and oat (*Avena sativa* L.) in Minnesota and found average plant density >50 plants m^{-2} after harvesting the companion crop for forage in July or August. Similarly, Miesel et al. (2012), also working in the Upper Midwest of the United States, evaluated an oat companion crop and reported that treatments using herbicides were more effective at reducing weed pressure and increasing yield of native grasses than treatments with the cool-season companion crop.

While prior experiments have focused on planting NWSG following or into cool-season annuals, research using warm-season companion crops has been limited to date. Warm-season annual plants can provide forage during the year of establishment. Hintz et al. (1998) , working in Iowa, successfully established both BB and SG with a corn (*Zea mays* L.) companion crop achieving stand densities typically in excess of 20 plants m^{-2}, well above thresholds required for production stands. Establishment in their study was successful irrespective of corn density or harvest date, but in all cases included atrazine [6-chloro-N-ethyI-*N′*-(l-methylethyl)-l,3,5-triazine-2,4-diamine], a product no longer labeled for native grass establishment. Similarly, Anderson et al. (2016), working in Illinois, reported SG stand densities that exceeded 20 plants m^{-2} when planted with a corn companion crop. Cossar and Baldwin (2002) found fall-recorded SG plant density to be inversely related to sorghum [*Sorghum bicolor* (L.) Moench]–sudangrass [*Sorghum bicolor* (L.) Moench ssp. *drummondii* (Nees ex Steud.) de Wet & Harlan] companion crop seeding rates in Mississippi. While they noted greater SG biomass yield when planted alone, Horton et al. (2004) later reported no difference in SG biomass yield with respect to sorghum–sudangrass seeding rates when replicating the study at a different site.

Therefore, because of the paucity of published data, two NWSG experiments were implemented to investigate the potential of a warm-season annual companion crop, browntop millet (BTM), to aid in BB and SG establishment and provide harvestable forage in the establishment year. We hypothesized that by using BTM as the companion crop, its more diminutive stature relative to other commonly used summer annual forage crops and less robust regrowth following initial harvest would provide less competition to developing NWSG seedlings. Specifically, objectives were to evaluate BB (Exp. 1) and SG (Exp. 2) plant density and post-dormancy biomass yield (following the 2nd year) based on (a) two BTM defoliation strategies and (b) three BTM seeding rates.

Core Ideas

- Browntop millet nurse crop may offset lost forage production during big bluestem or switchgrass establishment.
- Recommended browntop millet seeding rate reduced big bluestem and switchgrass establishment.
- Half millet seeding rate had minimal effect on big bluestem and switchgrass establishment.
- Millet cutting regimes did not affect big bluestem or switchgrass establishment success.

2 | MATERIALS AND METHODS

2.1 | Site description

Two NWSG (BB and SG) studies were conducted concurrently at the UTIA East Tennessee AgResearch and Education Center-Plant Science Unit (35°54′06.74″N, 83°57′27.11″W) in Knoxville, TN, from 2016 to 2017 (Site 1) and repeated at a second site on the same property during 2017–2018 (Site 2). The soil type for Site 1 was an Etowah silt loam (fine-loamy, siliceous, semiactive, thermic Typic Paleudult). This site previously grew turfgrasses, predominantly bermudagrass [*Cynodon dactylon* (L.) Pers.]. The soil type for Site 2 was dominated by Nonaburg channery silt loam (clayey, mixed, active, thermic, shallow Inceptic Hapludalf) with Heiskell silt loam (fine-loamy, mixed, semiactive, thermic Aquic Hapludalf) also being prevalent. This site had previously been planted in soybean [*Glycine max* (L.) Merr.].

2.2 | Experimental design

Each experiment was a randomized complete block in a 2 × 3 factorial arrangement of treatments with four

TABLE 1 Harvest dates for browntop millet defoliation strategies for big bluestem and switchgrass at each site at East Tennessee AgResearch and Education Center-Plant Science Unit, Knoxville, TN, during establishment experiments in 2016 and 2017

	Site 1		Site 2	
BTM Defoliation strategy[a]	Big bluestem	Switchgrass	Big bluestem	Switchgrass
HAY	27 June 22 July	12 Aug.	10 July	20 July
CLIP	21 June 22 July	22 July 12 Aug.	10 July	10 July

[a]Browntop millet (BTM) defoliation strategy [HAY = harvests based on BTM maturity (boot to heading stage) for hay or CLIP = clipping to reduce BTM competition by maintaining >50% sunlight reaching big bluestem and switchgrass seedlings].

replicates. Treatment combinations of two defoliation strategies and three BTM seeding rates were assigned to 1.5 by 7.6 m plots. Defoliation strategies were (a) harvests based on BTM maturity (boot to heading stage) for hay (HAY) or (b) clipping to reduce BTM competition by maintaining >50% sunlight reaching BB and SG seedlings (CLIP). Both strategies were conducted when visual estimates met defoliation parameters. Browntop millet seeding rates were 0 (control), 11.2 (half-recommended rate), and 22.4 (full-recommended rate) kg pure live seed (PLS) ha^{-1}. Browntop millet defoliations were conducted using a Carter forage harvester (Carter Manufacturing Company, Inc.) at a 30.5-cm cutting height to reduce the probability of cutting developing BB or SG seedlings during the initial year of each experiment. Defoliation events are listed in Table 1. For BB only, imazapic {(±)−2-[4,5-dihydro-4-methyl-4-(1-methylethyl)−5-oxo-1*H*imidazol-2-yl]−5-methyl-3-pyridinecarboxylic acid} was also evaluated at a rate of 146 ml ha^{-1} a.i., a commonly used approach to competition control during establishment for this species. Imazapic was not included in any models or statistical analysis, but solely used for numerical comparison. Establishment locations differed (Site 1 vs. Site 2) to avoid confounding results caused by germination and emergence of dormant seed from the preceding year.

Both BB and SG were no-till drilled on 20 Apr. 2016 and 11 May 2017 using an Almaco eight-row no-till plot drill following an application of glyphosate [N-(phosphonomethyl) glycine, isopropyl-amine salt] at a rate of 2.2 kg ha^{-1} a.i. Browntop millet was drilled perpendicular to BB and SG to minimize disturbance to BB or SG seed or emerging seedlings on 9 May 2016 and 1 June 2017. Due to an equipment malfunction in 2016, SG was replanted on 8 June 2016. The site was conventionally prepared and BTM reseeded on 21 June 2016. Big bluestem and SG (cultivars OZ 70 and Alamo, respectively; Bamert Seed Co.) were drilled at 6.7 and 10.1 kg PLS ha^{-1}, respectively, at a 0.6-cm seeding depth. All plots in both experiments received 67.3 kg N ha^{-1} in the form of urea [$CO(NH_2)_2$] during the second growing season only. Applying N fertilizer during the establishment year is not recommended for NWSG establishment to avoid accentuating weed competition (Keyser et al., 2011). Nitrogen was the only macronutrient applied during all experiments.

2.3 | Data collection

Mean monthly air temperature and precipitation for each year were collected at a weather station located on ETREC (550–650 m from experiment locations) and compared to the 30-yr means for that location (NOAA, 2020). Seedling counts for BB, SG, BTM, and weeds (both broadleaf and grass species) were conducted using a 0.45 by 0.45 m quadrat at five random areas per experimental unit. Then, plant density for each evaluated species was calculated. Plant density data were collected at 30 and 60 days after planting (DAP) BB or SG and only for BB and SG in mid-December of the 1st year – dormant period. Following the second growing season of each experiment, plots were harvested during dormancy (late November–early December) to obtain aboveground biomass yield (Mg ha^{-1}) using a Carter forage harvester with a 91.4-cm cutting width at a 20.3-cm cutting height (Ashworth et al., 2015). In spring of the 2nd year, we evaluated each experiment for the need for operational weed control. As stands had minimal competition at this point, no herbicides were deemed necessary, and none were applied. Thus, by the end of the second growing season, harvested biomass was clean and representative of normal production stands and no separations of crop and weed components were needed. Subsamples of BB and SG were collected from each plot at harvest, weighed, dried at 49 ˚C in a forced-air oven (Wisconsin Oven Corporation) for at least 72 h, and re-weighed to determine percentage moisture (averaged 11% for BB and 21–25% for SG) for use in calculating dry matter (DM) yield (Ashworth et al., 2015). Biomass yield is reported accordingly.

2.4 | Statistical analysis

Establishment-year plant density (BB, SG, weed, and BTM + weed m^{-2} for 30 and 60 DAP and BB and SG seedlings during

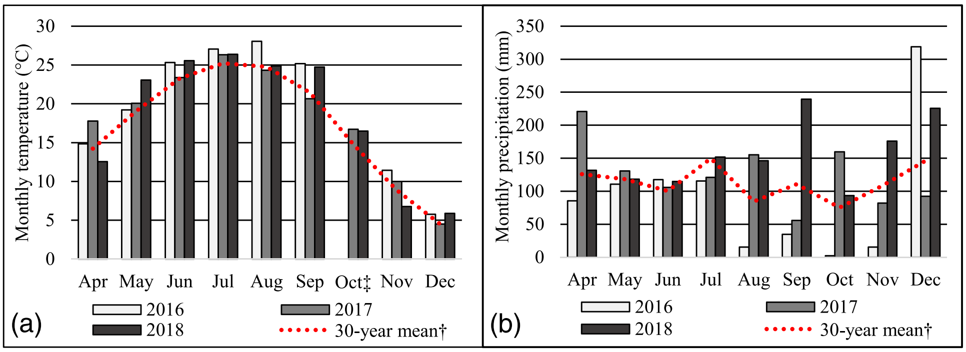

FIGURE 1 (a) Mean monthly air temperature (°C) and 30-yr mean and (b) total monthly precipitation (mm) and 30-yr mean for East Tennessee AgResearch and Education Center-Plant Science Unit, Knoxville, TN, 2016–2018. †Some months' data are missing in overall 30-yr mean from 1988 to 2018. ‡No data were reported in 2016

dormancy) and 2nd-year biomass DM yield data were analyzed under an ANOVA model in SAS v.9.4 (SAS Institute, 2013) using PROC MIXED to determine differences ($\alpha = .05$) among main effects and interactions. Fixed effects were defoliation strategy and BTM seeding rate, and block was a random effect for each NWSG experiment. Defoliation strategy was not incorporated into 30 and 60 DAP establishment-year plant density statistical analysis since neither HAY nor CLIP had occurred prior to conducting these counts. Based on results from past studies (Keyser et al., 2016a, 2016b), and the potential influence from annual air temperature and timing differences, experimental years were analyzed separately for each study. All models were tested for normality of residuals using Shapiro–Wilk test ($W \geq 0.90$). Fisher's least significant difference was used for mean separations. Post-hoc regressions were conducted using PROC REG to determine the relationship between BTM + weed plant density and BB or SG plant density (at 30 and 60 DAP combined across sites), as well as for BB and SG plant density at dormancy and Year 2 biomass DM yield for each site. These tests allowed us to explore potential relationships in competition that could affect establishment success, as well as minimum stand density thresholds for seedling-year stands.

3 | RESULTS

3.1 | Environmental conditions

During the 3 yr of the study, growing-season (April through September) mean monthly air temperatures remained near or above 30-yr means (Figure 1a). Monthly precipitation during May and June of all 3 yr was similar to 30-yr means (Figure 1b). However, July through September were abnormally dry in 2016 while April and August in 2017 were atypically wet (75 and 74% >30-yr mean, respectively). August was then followed by a drier than normal September. In 2018, July through September received greater than or equal to 30-yr mean amounts of rainfall (NOAA, 2020).

3.2 | Big bluestem

3.2.1 | Establishment-year plant density

Plant density during dormancy of BB did not differ for either defoliation strategy at either site (Table 2). However, BB establishment-year plant density differed by BTM seeding rate at 60 DAP and dormancy, but at Site 1 only (Table 2), with control plots having the greatest BB plant density in both cases (Figures 2 and 3). At Site 1, establishment-year weed plant density did not differ at 30 DAP but was reduced where BTM was planted by 60 DAP (Table 2). Browntop millet seeding rate affected BTM + weed establishment-year plant densities for both sites. At Site 1, the full-recommended rate had the greatest BTM + weed plant density at 30 DAP (342.5 seedlings m^{-2}) and 60 DAP (235.0 seedlings m^{-2}; Figure 2). For Site 2, a compensatory effect on establishment-year weed plant density from BTM was not observed. Given that establishment-year weed plant density never differed at Site 2, it was apparent that BTM simply added to the overall level of competition without influencing BB plant density. Overall, there was a weak linear relationship between BB and BTM + weed establishment-year plant density at 30 (P = .013; r^2 = .13; m = −0.03 seedling seedling^{-1}) and 60 (P = .029; r^2 = .10; m = −0.02 seedling seedling^{-1}) DAP. When using imazapic, BB plant density at Sites 1 and 2 (10.8 and 34.0 seedlings m^{-2}, respectively) was numerically greater than all BTM seeding rates (Figure 3). Big bluestem establishment-year plant density across all BTM seeding rates was 7.8 and 17.1 seedlings m^{-2} for Sites 1 and 2, respectively.

TABLE 2 Mixed-effects ANOVA model results for establishment-year plant density of big bluestem seedlings, weeds, and browntop millet (BTM) + weeds at each site at East Tennessee AgResearch and Education Center-Plant Science Unit, Knoxville, TN, 2016–2017, during a big bluestem establishment experiment

Effect	Site 1						Site 2					
	30 DAP[a]		60 DAP		Dormancy		30 DAP		60 DAP		Dormancy	
	F value[b]	*P* > *F*	*F* value	*P* > *F*	*F* value	*P* > *F*	*F* value	*P* > *F*	*F* value	*P* > *F*	*F* value	*P* > *F*
Big bluestem												
HARV[c]	–	–	–	–	1.82	.197	–	–	–	–	2.00	.178
RATE	0.07	.937	7.68	**.022**[d]	4.36	**.032**	0.72	.523	0.79	.495	1.80	.200
HARV × RATE	–	–	–	–	3.06	.077	–	–	–	–	0.74	.495
Weeds												
RATE	2.45	.167	9.93	**.013**	–	–	0.55	.603	0.16	.859	–	–
BTM ± Weeds												
RATE	74.48	**<.001**	12.99	**.007**	–	–	16.41	**.004**	6.84	**.028**	–	–

[a]Establishment-year plant density at 30 and 60 days after planting (DAP) of big bluestem and big bluestem plant density during dormancy. Since both browntop millet (BTM) defoliation strategy treatments had not been conducted prior to 30 and 60 DAP seedling counts, HARV was not incorporated into the model as a dependent variable.
[b]df num/den = Big bluestem – HARV 1/15, RATE 2/15, HARV × RATE 2/15; Weeds – RATE 2/6; BTM + Weeds – RATE 2/6.
[c]HARV = BTM defoliation strategy (harvested for hay, harvested for competition control); RATE = BTM seeding rate (0, 11.2, and 22.4 kg pure live seed [PLS] ha^{-1}).
[d]Bold values are significant at α = .05.

3.2.2 | Biomass dry matter yield

For 2nd-year BB biomass DM yield, only BTM seeding rate at Site 1 was significant (Table 3). Plots without BTM had the greatest yield (3.58 Mg ha^{-1}; Figure 4a) while the half- and full-recommended BTM seeding rates had similar yields (2.35 and 1.96 Mg ha^{-1}, respectively). All BTM seeding rates produced similar BB yields at Site 2. Second-year biomass DM yield was positively related to BB establishment-year plant density at dormancy at Site 1 (P = .009; r^2 = .28; m = 0.104 Mg seedling^{-1}) and Site 2 (P = .017; r^2 = .23; m = 0.026 Mg seedling^{-1}).

3.3 | Switchgrass

3.3.1 | Establishment-year plant density

Browntop millet seeding rate influenced plant density of SG, weeds, and BTM + weeds at Site 1 and BTM + weeds at Site 2 (Table 4). The 0 kg ha^{-1} BTM seeding rate had the greatest establishment-year plant density of BTM + weeds at 30 DAP (272 seedlings m^{-2}) at Site 1 and both 30 and 60 DAP (158 and 145 seedlings m^{-2}, respectively; Figure 5) at Site 2. Browntop millet + weeds plant density for the half- and full-recommended BTM seeding rates did not differ at any of these times. Furthermore, SG plant density did not differ at 30 DAP at Site 1 or 30 and 60 DAP at Site 2. However, at 60 DAP for Site 1, BTM + weeds plant density as well as SG plant density were greater for the 0 kg ha^{-1} BTM seeding rate than either the half or full BTM seeding rates. Regression analysis for SG and BTM + weed establishment-year plant density at 30 DAP was not significant (P = .080) while there was a weak, positive relationship (P = .008; r^2 = .14; m = 0.15 seedling seedling^{-1}) at 60 DAP.

3.3.2 | Biomass dry matter yield

For 2nd-year biomass DM yield of SG, defoliation strategy was only significant for Site 2 (Table 3). Yield for HAY (2.69 Mg ha^{-1}) was slightly greater than CLIP (2.44 Mg ha^{-1}). However, both SG defoliation strategies only occurred once with HAY taking place 10 d after CLIP (Table 1). On the other hand, BTM seeding rate affected 2nd-year biomass DM yield for both sites (Table 3). For Site 1, plots without BTM had the greatest yield (5.10 Mg ha^{-1}; Figure 4b). Where establishment-year plant densities were low at Site 1 in the presence of BTM, 2nd-year biomass DM yields were reduced substantially relative to the control. At Site 2, only biomass DM yields for the control (2.67 Mg ha^{-1}) and full-recommended (2.40 Mg ha^{-1}) BTM seeding rate differed. There was a positive relationship between biomass DM yield and SG plant density during dormancy at Site 1 (P < .001; r^2 = .74; m = 0.306 Mg seedling^{-1}) but not Site 2 (P = .583).

3.4 | Browntop millet

Across both experiments (BB and SG), HAY produced a BTM mean cumulative DM yield of 2.92 ± 0.27 Mg ha^{-1}

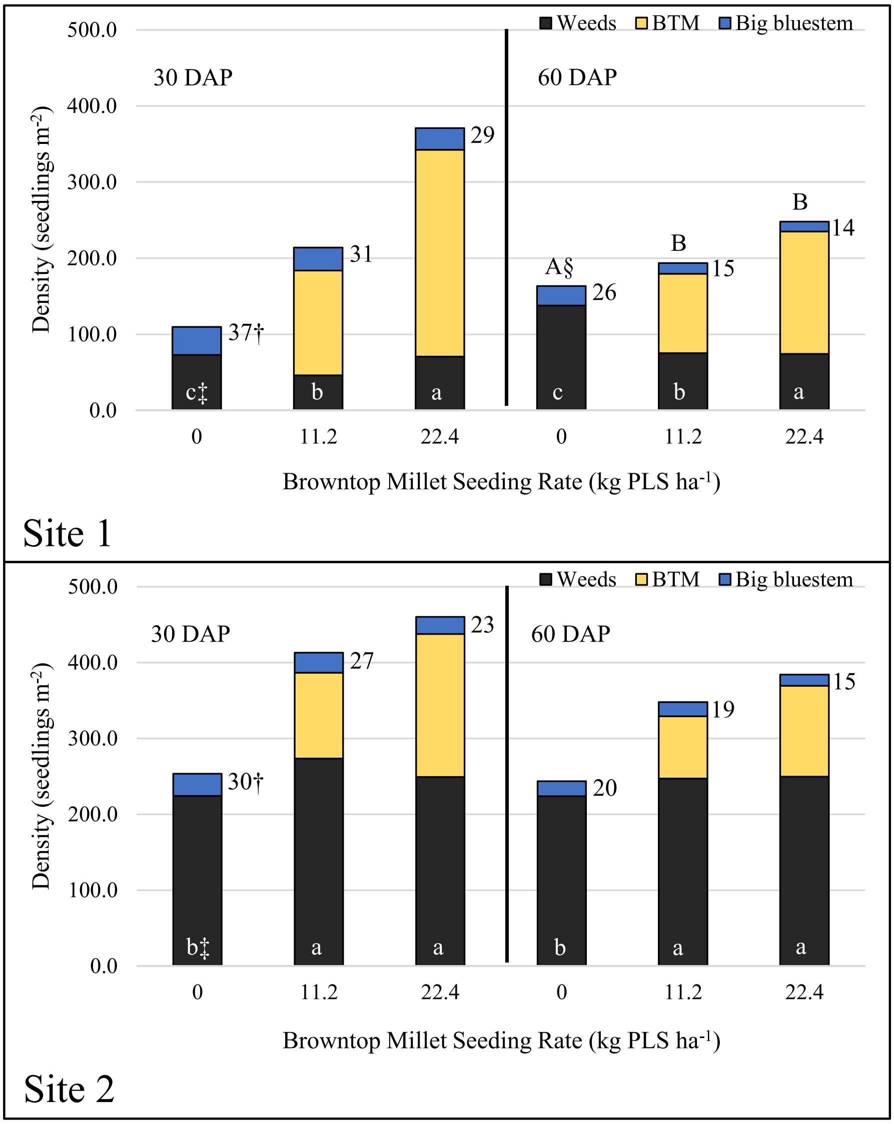

FIGURE 2 Establishment-year plant density (seedlings m^{-2}) for big bluestem (BB), browntop millet (BTM), and weeds by BTM seeding rate (kg pure live seed [PLS] ha^{-1}) at 30 and 60 days after planting (DAP) BB for Site 1 (top) and Site 2 (bottom) at East Tennessee AgResearch and Education Center-Plant Science Unit, Knoxville, TN. †Number of BB seedlings per BTM seeding rate at 30 and 60 DAP. ‡Different lowercase letters indicate significant differences among weed + BTM seedling totals by BTM seeding rates at 30 and 60 DAP within site. §Different UPPERCASE letters indicate significant differences for BB seedlings by BTM seeding rate at 30 and 60 DAP within site

(half-recommended seeding rate) and 3.37 ± 0.29 Mg ha^{-1} (full-recommended seeding rate) at Site 1. Yields at Site 2 were comparable and resulted in 2.72 ± 0.48 Mg ha^{-1} (half-recommended seeding rate) and 2.64 ± 0.43 Mg ha^{-1} (full-recommended seeding rate).

4 | DISCUSSION

To date, only four published studies (Anderson et al., 2016; Cossar & Baldwin, 2002; Hintz et al., 1998; Horton et al., 2004) addressed the use of a warm-season annual companion crop, with two having used corn and two sorghum–sudangrass. Our studies showed contrasting results when evaluating BTM as a companion crop for BB and SG. Yields of BTM were less than those (4.3–10.4 Mg ha^{-1}) presented by McLaughlin et al. (2004) when seeding a BTM monoculture using the full-recommended rate. However, producers could benefit from forage production during BB and SG establishment by using the half-recommended BTM seeding rate since BTM yield loss was negligible between the full- and half-recommended rates. If producers do not need to compensate for lost forage production during the BB or SG establishment year, then not planting BTM will likely result in denser stands of BB or SG.

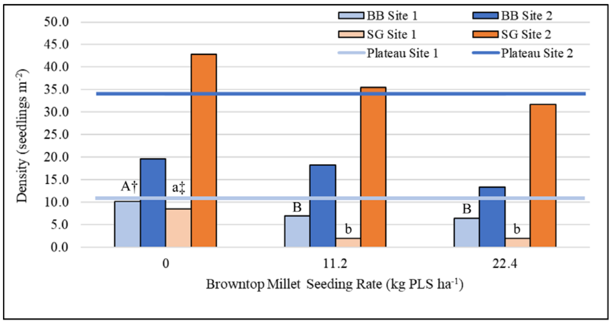

FIGURE 3 Establishment-year plant density (seedlings m^{-2}) at dormancy for big bluestem (BB) and switchgrass (SG) by browntop millet (BTM) seeding rate (kg pure live seed [PLS] ha^{-1}) compared to using imazapic (Plateau) for Site 1 (2016) and Site 2 (2017) at East Tennessee AgResearch and Education Center-Plant Science Unit, Knoxville, TN. Plant density for imazapic treatment (BB only) are horizontal lines; not compared statistically to other BB treatments. †Different UPPERCASE letters indicate significant differences for BB plant density by BTM seeding rate within site. ‡Different lowercase letters indicate significant differences for SG plant density by BTM seeding rate within site

4.1 | Establishment-year plant density

Big bluestem establishment-year plant density at dormancy was not influenced by defoliation strategy. At Site 1, BB was harvested twice for both defoliation strategies with only 6 d separating the first harvest for each. This narrow window, which was a result of the rapid development of the BTM at this time of year and an inability to implement CLIP due to rainfall and field conditions, precluded any meaningful advantage from CLIP. At Site 2, only one defoliation occurred on all BB and SG plots with all BB plots harvested on the same day. Persistent rains delayed planting BTM at Site 2 in spring 2017 while allowing an abundant weed population to develop. As a result, BTM was slow to develop because of the heavy weed pressure already in place. Because of the lack of regrowth of the BTM following the initial defoliation for both defoliation strategy treatments, no additional harvests were implemented at Site 2. Thus, there would not have been an expectation that HAY or CLIP would influence plant density, especially at Site 2. Clearly, timing of planting BTM relative to BB planting and timing of HAY and CLIP were sensitive and critical factors with this system.

In the case of SG at Site 1, the earlier harvest date for the initial CLIP defoliation preceded the first HAY harvest by 21 d. Nevertheless, SG establishment-year plant density was not improved by this harvest interval. Given the later SG planting date at Site 1, the timing of the initial CLIP defoliation may have been too soon after BTM planting to be beneficial. Furthermore, the rapid development of BTM between the first and second CLIP could have been substantial enough that the 12 Aug. 2016 harvests occurred after the BTM had already suppressed the SG seedlings. This underscores the importance of timing in such CLIP defoliations. It also may suggest that there is a critical point in seedling development that occurs between 30 and 60 DAP as was apparent for BB in the context of BTM seeding rate.

When BTM seeding rate affected BB and SG density, unplanted controls had greater BB and SG density than the BTM companion crop. Likewise, Cossar and Baldwin (2002) reported greater end-of-season SG plant density when planted alone than with a sorghum–sudangrass companion crop. Anderson et al. (2016) also found that SG plant density was greater when SG was established alone as compared with a corn companion crop in Illinois. In contrast, Hintz et al. (1998) found reduced post-dormancy plant density in the 1st year of their study when BB was planted alone vs. with a corn + atrazine companion crop. However, in the 2nd year of their study, there was no difference in plant density based on these treatments.

In the current study, there was also a lack of consistency between sites with respect to SG plant density. At Site 1, the use of BTM appeared to increase competition at 30 DAP (Figure 5). Regardless, this competition did not influence SG plant density at this stage of stand development. Yet by 60

TABLE 3 Mixed-effects ANOVA model results for big bluestem and switchgrass 2nd-year biomass dry matter yield for each site at East Tennessee AgResearch and Education Center-Plant Science Unit, Knoxville, TN, during establishment experiments. Harvests were conducted in 2017 and 2018 for Sites 1 and 2, respectively

Effect	Big bluestem				Switchgrass			
	Site 1		Site 2		Site 1		Site 2	
	F value[a]	*P* > *F*	*F* value	*P* > *F*	*F* value	*P* > *F*	*F* value	*P* > *F*
HARV[b]	0.29	.596	0.88	.362	0.75	.400	8.22	**.012**[c]
RATE	12.27	**<.001**	1.77	.205	29.99	**<.001**	3.70	**.049**
HARV × RATE	0.05	.953	0.29	.751	0.07	.931	3.07	.076

[a]df num/den = HARV, 1/15; RATE, 2/15; HARV × RATE, 2/15.

[b]HARV = browntop millet (BTM) defoliation strategies (harvest for hay, harvest for competition control); RATE = BTM seeding rate (0, 11.2, and 22.4 kg pure live seed [PLS] ha^{-1}).

[c]Bold values are significant at α = .05.

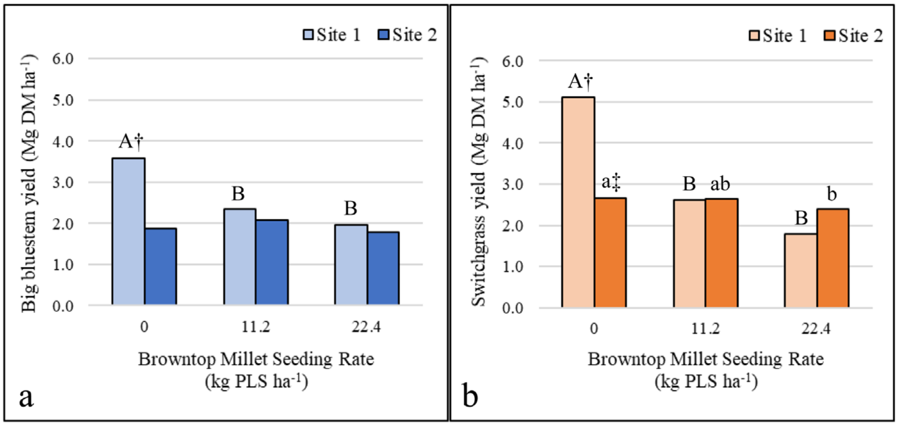

FIGURE 4 Biomass dry matter (DM) yield (Mg DM ha^{-1}) for (a) big bluestem and (b) switchgrass by browntop millet (BTM) seeding rate (kg pure live seed [PLS] ha^{-1}) following the 2nd year of each study at Site 1 (2017) and Site 2 (2018) at East Tennessee AgResearch and Education Center-Plant Science Unit, Knoxville, TN. †Different UPPERCASE letters indicate significant differences among Site 1 (2017) DM biomass yield among BTM seeding rate per species. ‡Different lowercase letters indicate significant differences among Site 2 (2018) DM biomass yield among BTM seeding rate per species

TABLE 4 Mixed-effects ANOVA model results for establishment-year plant density of switchgrass seedlings, weeds, and browntop millet (BTM) + weeds at each site at East Tennessee AgResearch and Education Center-Plant Science Unit, Knoxville, TN, 2016–2017 during a switchgrass establishment experiment

Effect	Site 1						Site 2					
	30 DAP[a]		60 DAP		Dormancy		30 DAP		60 DAP		Dormancy	
	F value[b]	*P* > *F*	*F* value	*P* > *F*	*F* value	*P* > *F*	*F* value	*P* > *F*	*F* value	*P* > *F*	*F* value	*P* > *F*
Switchgrass												
HARV[c]	–	–	–	–	0.05	.832	–	–	–	–	1.70	.212
RATE	0.46	.653	6.88	**.028**[d]	8.22	**.004**	0.33	.729	3.13	.117	0.88	.435
HARV × RATE	–	–	–	–	0.53	.599	–	–	–	–	0.18	.835
Weeds												
RATE	8.48	**.018**	43.46	**<.001**	–	–	1.08	.396	1.19	.368	–	–
BTM + Weeds												
RATE	13.01	**.007**	6.25	**.034**	–	–	12.77	**.007**	13.95	**.006**	–	–

[a]Establishment-year plant density at 30 and 60 days after planting (DAP) of switchgrass and switchgrass plant density during dormancy. Since both browntop millet (BTM) defoliation strategy treatments had not been conducted prior to 30 and 60 DAP seedling counts, HARV was not incorporated into the model as a dependent variable.
[b]df num/den = Switchgrass – HARV 1/15, RATE 2/15, HARV × RATE 2/15; Weeds – RATE 2/6; BTM + Weeds – RATE 2/6.
[c]HARV = BTM defoliation strategy (harvested for hay, harvested for competition control); RATE = BTM seeding rate (0, 11.2, and 22.4 kg pure live seed [PLS] ha^{-1}).
[d]Bold values are significant at α = .05.

DAP, SG density for both half- and full-recommended BTM seeding rates was reduced to 50% or less of that of the control. The greater SG density in the control (30 seedlings m^{-2}) at 60 DAP suggests that BTM presented more effective competition than weeds to SG seedlings. The more effective competition of the BTM at Site 1 compared to Site 2 was likely the result of the later planting date of SG at Site 1 due to the initial stand failure. In any case, SG plant densities for the half- and full-recommended (1.9 seedlings m^{-2} for both) BTM seeding rates at Site 1 during dormancy were well below desirable targets for production while those at Site 2 were more than adequate.

At Site 1, BTM had the desired effect of suppressing weed populations for BB at 60 DAP. In this case though, BB seedlings, which had not been suppressed at 30 DAP became so by 60 DAP. This suggests that the negative impact of the additional competition (i.e., light and space) from the BTM did not become a factor until the BTM canopy had become more developed at 60 DAP. Also, the lack of any difference in BB plant density between the full- and half-recommended

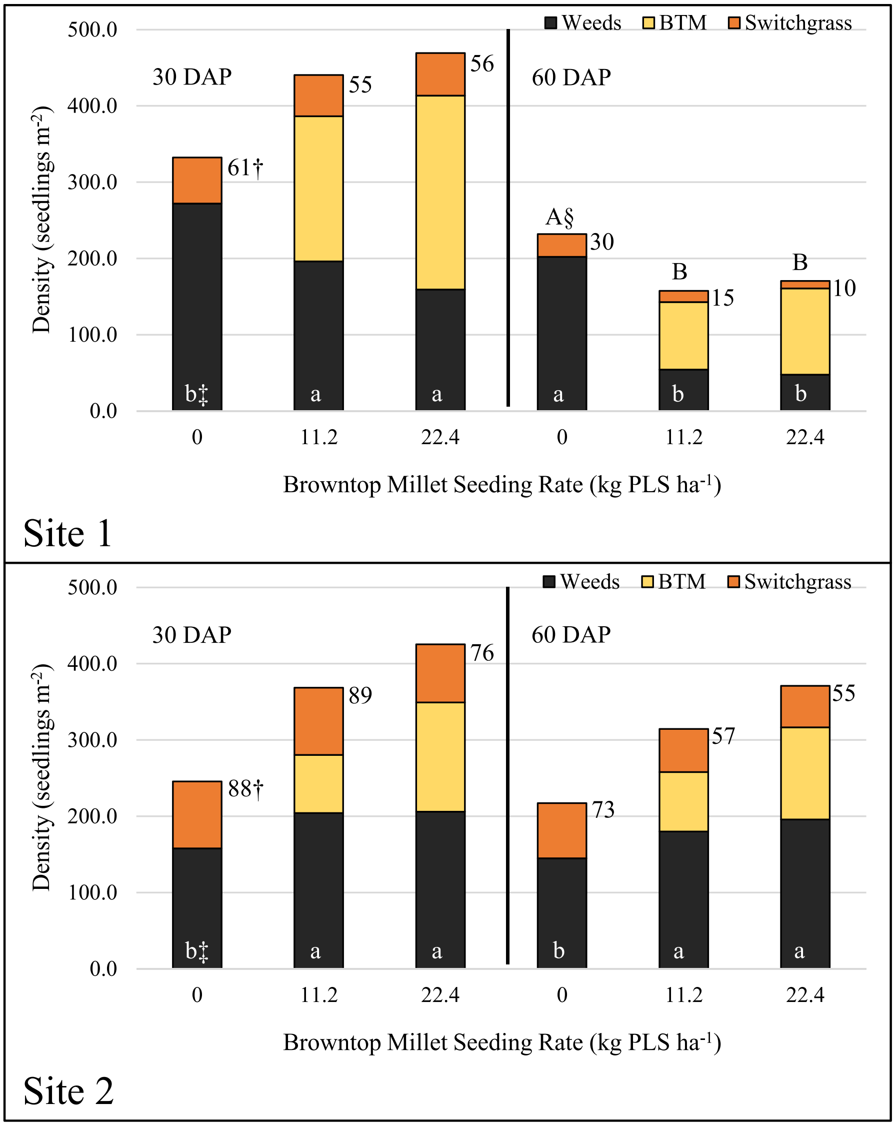

FIGURE 5 Establishment-year plant density (seedlings m^{-2}) for switchgrass (SG), browntop millet (BTM), and weeds by BTM seeding rate (kg pure live seed [PLS] ha^{-1}) at 30 and 60 days after planting (DAP) SG for Site 1 (top) and Site 2 (bottom) at East Tennessee AgResearch and Education Center-Plant Science Unit, Knoxville, TN. †Number of SG seedlings per BTM seeding rate at 30 and 60 DAP. ‡Different lowercase letters indicate significant differences among weed + BTM seedling totals by BTM seeding rate at 30 and 60 DAP within site. §Different UPPERCASE letters indicate significant differences for SG seedlings by BTM seeding rate at 30 and 60 DAP within site

BTM seeding rates at 60 DAP at Site 1 may have been because a threshold was possibly reached using half-recommended rate. Therefore, any additional competition from the full BTM seeding rate had no additional impact.

At Site 2, the competition from BTM on BB seedlings was negligible likely because of the late start for BTM and the already heavy weed pressure. That the patterns observed for BB density at 60 DAP carried through to dormancy (Figure 3) at both sites suggests stand development may be largely determined by 60 DAP. The lack of a stronger linear relationship between BB and BTM + weed plant densities at 30 and 60 DAP may have been due to the variability in BTM stand development and, in turn, its influence on BB seedling recruitment.

The half- and full-recommended BTM seeding rates at Site 1 produced BB plant densities at dormancy below the target threshold of 10 plants m^{-2}. Using imazapic allowed for greater BB plant density than all BTM seeding rates at both sites. This finding further reinforces the impact of competition on seedling recruitment.

For both species examined, negative effects of competition were more apparent at 60 DAP than at 30 DAP suggesting an important stage in stand development. Indeed, patterns apparent at 60 DAP carried through to fall dormancy for both sites. Browntop millet appeared to have been more problematic for competition than the weeds. This was borne out by the fact that when BTM development was limited at Site 2, SG densities were well above target plant densities, regardless of BTM seeding rate. Moreover, BTM at Site 2 appeared only to provide additive competition for BB, having no effect on weed plant density during the establishment year.

4.2 | Biomass dry matter yield

Big bluestem biomass DM yields were comparable (3.83 Mg ha^{-1}) to those reported by Rushing et al. (2019) when harvesting 2nd-year BB stands in Mississippi. At both sites, BB yield exhibited the same pattern as plant density at dormancy following the establishment year. The regression relationship only explained a modest amount of the variability in yield at either site. Previously, Keyser et al. (2016a) observed a relationship between establishment-year plant density and 2nd-year yield in SG, but also found that there was great variability. They attributed this to density-dependent responses of individual plants and their ability to produce larger and more tillers. This same plant density-dependent process may be important for BB as well. The variability in the plant density-yield relationship may also be a function of the level of competition within a given plot based on weed size and/or density. These differences did not appear to be particularly influenced by variability in air temperature or rainfall between years, at least for treatments that included BTM, because yields for both the half- and full-recommended BTM seeding rates were similar at both sites.

Switchgrass biomass DM yields were also similar to those reported in previous studies, ranging from 4.0 to 8.0 Mg ha^{-1} (Hedtcke et al., 2014; Keyser et al., 2016a, 2016b). Yields from the SG experiment were consistent with those reported by Cossar and Baldwin (2002). However, yields were contrary to those later reported by Horton et al. (2004) which found no difference in SG biomass yield when replicating the Cossar and Baldwin (2002) study. Keyser et al. (2016b) noted SG biomass yield increased until a threshold of 8 plants m^{-2} and plateaued at densities beyond 10 plants m^{-2}. Similarly, in the current study, SG biomass DM yield increased until reaching 8 plants m^{-2} at Site 1 and plateaued beyond 10 plants m^{-2} at Site 2. The concept of stocking threshold for yield was further reinforced by the sizeable difference in biomass DM yield for the unplanted controls between Site 1 (5.10 Mg ha^{-1}) and Site 2 (2.67 Mg ha^{-1}). Despite the five-fold greater number of seedlings at Site 1 (42.9 seedlings m^{-2}) than at Site 2 (8.5 seedlings m^{-2}), yields were only 1.9 times greater. Although this may have been the result of factors other than SG plant density, it may also suggest a plant density-dependent threshold for SG plant population. Another reasonable explanation is that the plants in the Site 2 control were not as individually vigorous or well developed as those from Site 1. Mean monthly air temperature and total monthly precipitation, which were greater than the 30-yr mean for April and May for Site 2, may have moderated the difference in yield between the two sites. Lee and Boe (2005) found a strong linear relationship between maximum SG biomass production and April through May precipitation in South Dakota.

5 | CONCLUSIONS

Defoliation strategy did not affect BB or SG seedling establishment. Timelier implementation of canopy treatments may have had a greater impact on the results. Furthermore, the rapid growth rate of the well-established BTM at Site 1 made more precise timing of treatments difficult. Conversely, the lack of a consistent effect from defoliation strategies may suggest producers could have some flexibility in implementing these treatments. All BTM seeding rates resulted in acceptable stands (≥5.4 plants m^{-2}; Keyser et al., 2011) of BB at Site 1 and both BB and SG at Site 2, whereas only the control allowed for acceptable stands of SG (8.5 ± 2.1 plants m^{-2}) at Site 1. Timing of BTM plantings and precipitation patterns appear to be an important consideration for using this species as a companion crop for improving BB or SG establishment. Precipitation between seeding the NWSG and BTM at Site 2 was greater than that at Site 1 leading to substantially greater weed germination prior to emergence of BTM at Site 2. Thus, Site 1 BTM stands were more developed and appeared to be more competitive with weed seedlings. At Site 2, on the other hand, weeds were well developed by the time BTM seedlings emerged in large numbers, thus reducing BTM vigor. Regardless, lower BTM seeding rates produced greater BB and SG dormancy plant density and greater 2nd-year biomass DM yields at Site 1, but not at Site 2.

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AUTHOR CONTRIBUTIONS

Jonathan Daniel Richwine: Data curation; Formal analysis; Investigation; Methodology; Resources; Writing-original draft; Writing-review & editing. Pat Keyser: Conceptualization; Data curation; Formal analysis; Funding acquisition; Investigation; Methodology; Project administration; Resources; Supervision; Writing-original draft; Writing-review & editing. Dennis W. Hancock: Conceptualization; Funding acquisition; Methodology; Writing-review & editing. Amanda J. Ashworth: Conceptualization; Funding acquisition; Methodology; Writing-review & editing.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

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REFERENCES

Aiken, G. E., & Springer, T. L. (1995). Seed size distribution, germination, and emergence of six switchgrass cultivars. *Journal of Range Management*, *48*, 455–458. https://doi.org/10.2307/4002252

Anderson, E. K., Bollero, G. A., Maughan, M. W., Parrish, A. S., Voigt, T. B., & Lee, D. K. (2016). Establishing switchgrass with a corn companion crop to improve economic profitability. *Agronomy Journal*, *108*, 662–669. https://doi.org/10.2134/agronj2015.0318

Ashworth, A. J., Allen, F. L., Keyser, P. D., Tyler, D. D., Saxton, A. M., & Taylor, A. M. (2015). Switchgrass yield and stand dynamics from legume intercropping based on seeding rate and harvest management. *Journal of Soil and Water Conservation*, *70*, 374–384. https://doi.org/10.2489/jswc.70.6.374

Backus, W. M., Waller, J. C., Bates, G. E., Harper, C. A., Saxton, A., McIntosh, D. W., Birckhead, J., & Keyser, P. D. (2017). Management of native warm-season grasses for beef cattle and biomass production in the Mid-South USA. *Journal of Animal Science*, *95*, 3143–3153.

Boyer, C. N., Tyler, D. D., Roberts, R. K., English, B. C., & Larson, J. A. (2012). Yield response functions and profit maximizing nitrogen rate by soil types. *Agronomy Journal*, *104*, 1579–1588. https://doi.org/10.2134/agronj2012.0179

Burns, J. C., & Fisher, D. S. (2013). Steer performance and pasture productivity among five perennial warm-season grasses. *Agronomy Journal*, *105*, 113–123. https://doi.org/10.2134/agronj2012.0142

Buttrey, E. K., & Bean, B. W. (2011). Yield, water use efficiency, and nutritive value of six warm-season perennial grasses in response to irrigation level. *Forage and Grazinglands*, *9*(1), 1–8. https://doi.org/10.1094/FG-2011-1021-01-RS

Cossar, R. D., & Baldwin, B. S. (2002). Establishment of switchgrass with sorghum-sudangrass. In J. Randall & J. C. Burns (Eds.), Proceedings of the Third Eastern Native Grass Symposium*,* 1–3 October, Chapel Hill, NC (pp. 98–102). Madison, WI: Omnipress.

Curran, W. S., Ryan, M. R., Myers, M. W., & Adler, P. R. (2011). Effectiveness of sulfosulfuron and quinclorac for weed control during switchgrass establishment. *Weed Technology*, *25*, 598–603. https://doi.org/10.1614/WT-D-11-00010.1

Gilley, J. E., Eghball, B., Kramer, L. A., & Moorman, T. B. (2000). Narrow grass hedge effects on runoff and soil loss. *Journal of Soil and Water Conservation*, *55*, 190–196

Guretzky, J. A., Biermacher, J. T., Cook, B. J., Kering, M. K., & Mosali, J. (2011). Switchgrass for forage and bioenergy: Harvest and nitrogen rate effects on biomass yields and nutrient composition. *Plant and Soil*, *339*, 69–81. https://doi.org/10.1007/s11104-010-0376-4

Harper, C. A., Birckhead, J. L., Keyser, P. D., Waller, J. C., Backus, M. M., Bates, G. E., Holcomb, E. D., & Brooke, J. M. (2015). Avian habitat following grazing native warm- season forages in the Mid-South United States. *Rangeland Ecology & Management*, *68*, 166–172. https://doi.org/10.1016/j.rama.2015.01.005

Hedtcke, J. L., Sanford, G. R., Hadley, K. E., & Thelen, K. D. (2014). Maximizing land use during switchgrass establishment in the north central United States. *Agronomy Journal*, *106*, 596–604. https://doi.org/10.2134/agronj2013.0410

Hintz, R. L., Harmoney, K. R., Moore, K. J., George, J. R., & Brummer, E. C. (1998). Establishment of switchgrass and big bluestem in corn with atrazine. *Agronomy Journal*, *90*, 591–596. https://doi.org/10.2134/agronj1998.00021962009000050004x

Horton, D. S., Baldwin, B. S., & Cossar, R. D. (2004). Yield and population density changes of switchgrass established under sorghum/sudangrass. In T. J. Barnes (Ed.), *Proceedings of the Fourth Eastern Native Grass Symposium. , 3–6 Oct. 2004*, Lexington, KY (pp. 36–40).,

Jungers, J. M., Wyse, D. L., & Sheaffer, C. C. (2015). Establishing native perennial bioenergy crops with cereal grain companion crops. *BioEnergy Research*, *8*, 109–118. https://doi.org/10.1007/s12155-014-9498-5

Kering, M. K., Butler, T. J., Biermacher, J. T., Mosali, J., & Guretzky, J. A. (2012). Effect of potassium and nitrogen fertilizer on switchgrass productivity and nutrient removal rates under two harvest systems on a low potassium soil. *BioEnergy Research*, *6*, 329–335. https://doi.org/10.1007/s12155-012-9261-8

Keyser, P. D., Ashworth, A. J., Allen, F. L., & Bates, G. E. (2016a). Evaluation of small grain cover crops to enhance switchgrass establishment. *Crop Science*, *56*, 2062–2071. https://doi.org/10.2135/cropsci2015.12.0783

Keyser, P. D., Ashworth, A. J., Allen, F. L., & Bates, G. E. (2016b). Dormant-season planting and seed-dormancy impacts on switchgrass establishment and yield. *Crop Science*, *56*, 474–483. https://doi.org/10.2135/cropsci2015.03.0144

Keyser, P. D., Harper, C. A., Bates, G. E., Waller, J. C., & Holcomb, E. D. (2011). *Establishing native warm-season grasses for livestock forage in the Mid-south* (Extension Publication SP731-B). Knoxville: University of Tennesse.

Keyser, P., Schexnayder, S., Wilcox, A., Bates, G., & Boyer, C. (2021). Identifying barriers to forage innovation: Native grasses and producer knowledge. *Journal of Extension*, *57*, article no. 6RIB4.

Lee, D. K., & Boe, A. (2005). Biomass production of switchgrass in central South Dakota. *Crop Science*, *45*, 2583–2590. https://doi.org/10.2135/cropsci2005.04-0003

Lowe II, J. K., Boyer, C. N., Griffith, A. P., Bates, G. E., Keyser, P. D., Waller, J. C., Larson, J. A., & Backus, W. M. (2015). Profitability of beef and biomass production from native warm-season grasses in Tennessee. *Biomass and Bioenergy. Agronomy Journal*, *107*, 1733–1740.

Mcintosh, D. W., Bates, G. E., Keyser, P. D., Allen, F. L., Harper, C. A., Waller, J. C., Birckhead, J. L., & Backus, W. M. (2015). The impact of harvest timing on biomass yield from native warm-season grass mixtures. *Agronomy Journal*, *107*, 2321–2326. https://doi.org/10.2134/agronj15.0251

Mckenna, J. R., Wolf, D. D., & Lentner, M. (1991). No-till warm-season grass establishment as affected by atrazine and carbofuran. *Agronomy Journal*, *83*, 311–316. https://doi.org/10.2134/agronj1991.00021962008300020010x

McLaughlin, S. B., & Adams Kszos, L. (2005). Development of switchgrass (*Panicum virgatum*) as a bioenergy feedstock in the United States. *Biomass Bioenergy*, *28*(6), 515–535. https://doi.org/10.1016/j.biombioe.2004.05.006

McLaughlin, M. R., Fairbrother, T. E., & Rowe, D. E. (2004). Forage yield and nutrient uptake of warm-season annual grasses in a swine effluent spray field. *Agronomy Journal*, *96*(6), 1516–1522. https://doi.org/10.2134/agronj2004.1516

McLaughlin, S. B., & Walsh, M. E. (1998). Evaluating environmental consequences of producing herbaceous crops for bioenergy. *Biomass Bioenergy*, *14*, 317–324. https://doi.org/10.1016/S0961-9534(97)10066-6

Miesel, J. R., Renz, M. J., Doll, J. E., & Jackson, R. D. (2012). Effectiveness of weed management methods in establishment of switchgrass and a native species mixture for biofuels in Wisconsin. *Biomass Bioenergy*, *36*, 121–131. https://doi.org/10.1016/j.biombioe.2011.10.018

Milchunas, D. G., Vandever, M. W., Ball, L. O., & Hyberg, S. (2011). Allelopathic cover crop prior to seeding is more important than subsequent grazing/mowing in grassland establishment. *Rangeland Ecology & Management*, *64*, 291–300. https://doi.org/10.2111/REM-D-10-00117.1

Mosali, J., Biermacher, J. T., Cook, B., & Blanton, J. (2013). Bioenergy for cattle and cars: A switchgrass production system that engages cattle producers. *Agronomy Journal*, *105*, 960–966. https://doi.org/10.2134/agronj2012.0384

NOAA. (2020). *NOWData – NOAA online weather data*. Knoxville, TN: Knoxville Experiment Station. Retrieved from https://w2.weather.gov/climate/xmacis.php?wfo=mrx (accessed 4 June 2020).

Owensby, C. E., Ham, J. M., Knapp, A. K., & Auen, L. M. (1999). Biomass production and species composition change in tallgrass prairie ecosystem after long-term exposer to elevated atmospheric CO_2. *Global Change Biology*, *4*, 497–506. https://doi.org/10.1046/j.1365-2486.1999.00245.x

Parrish, D. J., & Fike, J. H. (2005). The biology and agronomy of switchgrass for biofuels. *Critical Reviews in Plant Sciences*, *24*, 423–459. https://doi.org/10.1080/07352680500316433

Rushing, J. B., Lemus, R. W., White, J. A., Lyles, J. C., & Thornton, M. T. (2019). Yield of native warm-season grasses in response to nitrogen and harvest frequency. *Agronomy Journal*, *111*, 193–199. https://doi.org/10.2134/agronj2018.01.0009

Sanderson, M. A., & Reed, R. L. (2000). Switchgrass growth and development: Water, nitrogen, and plant density effects. *Journal of Range Management*, *53*, 221–227. https://doi.org/10.2307/4003287

Sanderson, M., Schmer, M., Owens, V., Keyser, P., & Elbersen, W. (2012). Crop management of switchgrass. In A. Monti (Ed.), *Switchgrass: A valuable biomass crop for energy* (pp. 87–112). London: Springer-Verlag.

SAS Institute. (2013). *The SAS system for Windows* (Version 9.4). Cary, NC: SAS Institute.

Schmer, M. R., Vogel, K. P., Mitchell, R. B., Moser, L. E., Eskridge, K. M., & Perrin, R. K. (2006). Establishment thresholds for switchgrass grown as a bioenergy crop. *Crop Science*, *46*, 157–161. https://doi.org/10.2135/cropsci2005.0264

Singh, H. P., Batish, D. R., & Kohli, R. K. (2003). Allelopathic interactions and allelochemicals: New possibilities for sustainable weed management. *Critical Reviews in Plant Sciences*, *22*, 239–311 https://doi.org/10.1080/713610858

Tracy, B. F., Maughan, M., Post, N., & Faulkner, D. B. (2010). Integrating annual and perennial warm-season grasses in a temperate grazing system. *Crop Science*, *50*, 2171–2177. https://doi.org/10.2135/cropsci2010.02.0110

Vogel, K. P., Brejda, J. J., Walters, D. T., & Buxton, D. R. (2002). Switchgrass biomass production in the Midwest USA: Harvest and nitrogen management. *Agronomy Journal*, *94*, 413–420. https://doi.org/10.2134/agronj2002.0413

West, A. S., Keyser, P. D., Lituma, C. M., Buehler, D. A., Applegate, R. D., & Morgan, J. (2016). Grasslands bird occupancy of native warm-season grass. *Journal of Wildlife Management*, *80*, 1081–1090. https://doi.org/10.1002/jwmg.21103

West, D. R., & Kincer, D. R. (2011). Yield of switchgrass as affected by seeding rates and dates. *Biomass Bioenergy*, *35*, 4057–4059. https://doi.org/10.1016/j.biombioe.2011.06.048

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