Improving Nutritive Value of Native Warm-Season Grasses with the Plant Growth Regulator Trinexapac-Ethyl

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ABSTRACT

Livestock producers in the southeastern United States utilize native warm-season grasses (NWSG), however, the best management practice to not harvest during late-summer and fall results in large quantities of low quality forage. Gibberellin inhibitors can alter plant regrowth and forage value. This study assessed the impact of trinexapac-ethyl [TE; ethyl 4-(cyclopropyl-hydroxymethylene)-3,5-dioxo-cyclohexane-1-carboxylate] on fall NWSG forage. Application of TE occurred in late July at four levels (0, 0.3, 0.6, and 1.2 kg a.i. ha^{-1}) to switchgrass (SG; *Panicum virgatum* L.) and a mixed sward (BBIG) of big bluestem (*Andropogon gerardii* Vitman) and indiangrass (*Sorghastrum nutans* L.) during 2016 and 2017. Forage mass (FM) and nutritive value [crude protein (CP), neutral detergent fiber (NDF), in vitro true dry matter digestibility (IVTDMD)] were evaluated monthly. Application reduced fall FM (SG: 37%; BBIG: 42%). Switchgrass nutritive value did respond to TE application. Application of TE reduced BBIG NDF overall, but strong annual variation occurred due to a drought (2016). Analyzed separately, 2017 treated BBIG samples (1.2 kg a.i. ha^{-1}) exhibited altered FM (−57%), CP (up to 54%), NDF (−9.2%), and IVTDMD (11%). Further analysis provided tentative evidence that TE improved leaf nutritive value and increased leaf proportion, although overall leaf yield was not improved. Overall, TE improved BBIG nutritive value but at a substantial FM loss. Since poor nutritive content forage has negligible value regardless of quantity, growth regulators could improve outcomes of fall NWSG management by adding value to an unutilized resource.

Core Ideas

- Gibberellin inhibitors may decrease stem growth, improving late fall forage nutritive value during late summer and fall.
- Examining the short- and long-term impacts of suppressed stem growth or altered tiller number could result in improved forage nutritive traits.
- Warm-season grasses are characterized by high forage mass but low nutritive value, especially when mature.

FORAGE PRODUCERS in the southeastern United States rely heavily on cool season species, specifically non-native tall fescue [*Schedonorus arundinaceus* (Schreb.) Dumort.] (Ball et al., 1993). Despite strong persistence and production, TF has slow growth during mid-summer (Ball et al., 2007). A group of NWSG provides an alternative summer forage for producers, but adoption has been limited due to their lower nutritive value, shorter growing season, and high establishment cost compared to cool-season forage species. Another drawback is the fall rest period required to allow NWSG to build root reserves and resist cool season weed encroachment (Vogel and Bjugstad 1968; Owensby et al., 1977; Forwood and Magai 1992). The resulting dormant forage can be harvested or grazed, but has a large proportion of stem material and contains decreased CP content and greater fiber (Forwood and Magai 1992; Waramit et al., 2012). Forage with such poor nutritive value is not traditionally grazed or baled by livestock managers. Plant growth regulators which inhibit gibberellin synthesis offer a potential method to reduce stem elongation and improve grass digestibility (Rademacher, 2000). Therefore, late-summer application of a gibberellin inhibitor could improve nutritive value of fall grown NWSG forage. This could convert currently under-utilized forage into a resource for livestock managers during late fall and winter.

Research has evaluated applications of paired gibberellin and nitrogen fertilizer to pastures (Whitehead and Edwards, 2015; Bryant et al., 2016; Zaman et al., 2016). Gibberellin application improves FM but reduces aboveground CP and increases NDF (Bryant et al., 2016). Gibberellin also has a notable side-effect of reduced root storage and tillering (Zaman et al., 2016). Since gibberellin application is a useful strategy to stimulate productivity at the expense of lower forage quality, gibberellin inhibition may be useful in forage management to improve forage nutritive value when FM production is not a priority (Sawyer et al., 2012; Baron et al., 2014; Raynor et al., 2016). The forage nutritive value reduction due to gibberellin is attributed to increased allocation to aboveground growth, diluting nutritive value such as CP and increasing fiber content. Therefore, suppressing the gibberellin pathway could improve nutritive value during long-term rest periods (1–2 mo.). Since NWSG currently require a rest period that results in low nutritive value forage but

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Abbreviations: BB, big bluestem; BBIG, mixed sward of big bluestem and indianagrass; CP, crude protein; FM, forage mass; IG, indiangrass; IVTDMD, in vitro true dry matter digestibility (48 h); NIRS, near-infrared reflectance spectroscopy; NDF, neutral detergent fiber; NIRS, near infrared reflectance spectroscopy; NWSG, native warm-season grasses; SG, switchgrass; TE, trinexapac-ethyl.

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greater FM, this study will evaluate the potential benefits of gibberellin inhibition on aboveground growth during this period.

Gibberellin inhibitors are used in turfgrass management and seed production. Applications of TE to turfgrass systems result primarily in reduced aboveground growth and improved stress tolerance (Qian et al., 1998; Beasley and Branham, 2007; Xu and Huang, 2011). In forage seed crop production and grain production, TE applications reduce lodging and seed loss (Basra, 2000). Within forages, gibberellin inhibition studies have resulted in weakened apical dominance and increased tillering (White 1990; Ervin and Koski 1998). In pasture settings, mefluidide has improved animal intake, digestibility, and rate of gain (Goold et al., 1982; Moyer et al., 1988). More recent research has evaluated low-dose metsulfuron application in pasture settings to reduce tall fescue seedhead production (Israel et al., 2015). In warm-season annual forages such as millet (*Pennisetum glaucum* L.) and sorghum [*Sorghum bicolor* (L.) Moench], applications of mefluidide improved tillering, leaf/stem ratio and stem digestibility (Hernandez 1984; Bransby et al., 1986; Stair et al., 1991; Redmon et al., 2003). A study of mefluidide on caucasian bluestem (*Bothriochloa ischemum* L.) observed improved leaf/stem ratio and digestibility but with high between-plant variability (White, 1990).

The gibberellin inhibitor TE inhibits gibberellin synthesis later in the biosynthetic pathway relative to gibberellin inhibitors such as mefluidide and metsulfuron, and therefore is potentially less disruptive to growth (Marcum and Jiang, 1997; Ervin and Koski, 1998; Rademacher, 2000). Aboveground growth suppression is expected to occur with TE, but potentially at rates lower than other gibberellin inhibitors. The impact of TE on the forage nutritive value has not been evaluated in perennial species.

Switchgrass, big bluestem, and indiangrass are C_4 species used for biofuels, conservation, and forage (Zhang et al., 2015; Bhandari et al., 2015). They are characterized by high FM but low nutritive value, especially when mature. Therefore, a tradeoff of mass for nutritive value could be beneficial in C_4 swards during the fall rest period and should be evaluated as an alternative livestock forage production strategy. Application of TE could improve C_4 morphological traits, such as leaf/stem ratio or nutritive value (Griffin and Jung, 1983).

The objective of this study was to quantify forage nutritive value and production of late-summer and fall growth of native C_4 species treated with TE. Specifically, examining the short- and long-term impacts of suppressed stem growth or altered tiller number, which could result in improved forage nutritive traits over 1 to 3 mo.

MATERIALS AND METHODS

Site and Study Design

The study was performed on paddocks planted to switchgrass (cv. Alamo) and a 1:1 mixture of big bluestem (cv. OZ-70)/indiangrass (cv. Rumsey). During 2016, the paddocks were located at the University of Tennessee AgResearch and Education Center in Greeneville, TN (Dunmore loam; kaolinitic, mesic typic Paleudult) (36°6′34.114″ N, 82°51′41.957″ W; 440 m). During 2017, the paddocks were located at the Highland Rim AgResearch and Education center near Springfield, TN (Dickson silt loam; superactive, mesic typic Hapludoll) (36°28′47.798″ N, 86°49′50.835″ W; 220 m). In both locations, established adjacent unfertilized paddocks were divided into four replications of four levels of TE (PrimoMaxx, Syngenta Crop Science, Raleigh, NC; 0, 0.3, 0.6, and 1.2 kg a.i. ha^{-1}) in a randomized complete block design. Experimental units were 10 × 10 m with 2 m buffer zones and were blocked geographically to limit effects of slope and soil type. Plots were clipped to 20 cm on 5 July 2016 and 12 July 2017. Clipped biomass was raked off the experimental area. On 25 July (2016 and 2017), foliar applications of TE occurred. The TE was applied using a backpack sprayer with two flat fan tips calibrated to apply 325 L ha^{-1}. No precipitation occurred within 24 h of application during 2016 and 2017 and temperature on application dates were above average for both application years (2016: 32.2°C; 2017: 36.1°C).

Sampling Methods

Samples were collected 1 to 3 mo post application: 22 Aug. 2016, 21 Sept. 2016, 20 Oct. 2016, 25 Aug. 2017, 26 Sept. 2017, and 3 Nov. 2017. The October 2017 sampling was delayed to 3 November due to equipment failure but was not expected to be substantially different than the planned late-October sample and will be referred to as October.

Forage mass above 8 cm was collected and dried from two 0.1-m^2 areas in each experimental unit. Forage samples were dried at 60°C for 48 h up to constant weight and dry weights were recorded. A set of 0.1 m^2 subsamples were collected 2 and 3 mo post application (control and 1.2 kg a.i. ha^{-1}) and manually divided into stem and leaf portions to be analyzed separately.

Each sample was ground through a Wiley Mill Grinder (1 mm screen; Thomas Scientific, Swedesboro, NJ) for near-infrared reflectance spectroscopy (NIRS) analysis of forage nutritive value using a FOSS 6500 NIRS instrument (FOSS NIRS, Laurel, MD) to quantify CP, NDF, and IVDTMD at 48 h. Equations for the forage nutritive analyses were standardized and checked for accuracy with the 2017 mixed hay equation developed by the NIRS Forage and Feed Consortium (NIRSC, Hillsboro, WI). Software used for the NIRS analysis was Win ISI II (Infrasoft International, State College, PA). The global H statistical test compared the samples with the model and other samples within the database for accurate results.

Data Analysis

Results were analyzed using JMP statistical software (JMP Pro 12; SAS Institute Inc., Cary, NC). Results with $P < 0.05$ were considered significant. Comparisons were performed using a repeated-measure combined experiment model using experimental unit as subject and the main and interactive effects of application concentration and date post application as fixed effects and main and interactive effects of year and block as random effects. Due to TE concentration-year interaction within BBIG, this repeated-measures model was also run independently for BBIG response during 2016 and 2017. Dunnett's test was used to detect TE concentration differences relative to the mean.

Leaf and stem nutritive value were compared independently across sampling dates with a mixed model including TE application (control and 1.2 kg a.i. ha^{-1}) as the fixed effect and block as random effect. Leaf and stem sample size was insufficient to detect differences based on mass. Since leaf and stem nutritive value were less variable, a post-hoc equation was created to estimate leaf/stem ratio using nutritive value. By utilizing leaf, stem, and whole plant nutritive value, it was possible to compare leaf/stem ratios. The percentage of stem material in a sample was determined using the following equations:

$$\textit{Whole plant nutrient value} = (\textit{Stem nutrient value} \times \textit{Percent stem}) + (\textit{Leaf nutrient value} \times \textit{Percent leaf})$$

And since percentage stem plus percentage leaf equal one, this was rearranged into:

$$\textit{Percent stem} = \frac{(\textit{Whole plant nutrient value} - \textit{Leaf nutrient value})}{(\textit{Stem nutrient value} - \textit{Leaf nutrient value})}$$

This allowed a comparison the leaf/stem ratio of bulk sample, when provided a reliable (and preferably contrasting) nutritive value of bulk, leaf, and stem materials. Accuracy in this equation was dependent on stem and leaf nutritive value being distinct from each other and distinct from the whole plant value. This was the case with NWSG. This equation should be utilized conservatively and in this instance, only for estimation of TE effects. Since the equation used any nutritive value, NDF and IVTDMD results were averaged for comparison. Stem CP content approached zero and resulted in anomalous results.

RESULTS

Environmental Conditions

Weather data was collected from University of Tennessee AgResearch and Education Center weather stations. During the 2016 season, temperatures were greater than average and cumulative precipitation was lower than the 30-yr average (Fig. 1). The 2017 season at Springfield, TN, had similar temperature and 29% greater cumulative precipitation relative to the 30-yr average. These contrasting conditions resulted in strong annual variation (Table 1).

Forage Response

Application of TE reduced forage regrowth rates from 3000 kg ha^{-1} to 1720 kg ha^{-1} (42%; 1.2 kg a.i. ha^{-1}) for BBIG and 4770 kg ha^{-1} to 2990 kg ha^{-1} (37%; 1.2 kg a.i. ha^{-1}) for SG (Table 2). Nutritive value and rates of change did not differ from control in BBIG with the exception of TE applications reducing NDF at 0.6 kg a.i. ha^{-1}and 1.2 kg a.i. ha^{-1} (Table 2). No differences in nutritive value or nutritive value rates of change were detected in SG.

Interaction between TE application and year occurred for BBIG (Table 1). When years were analyzed separately, contrasting TE responses were found in BBIG samples for both 2016 and 2017. The 2016 BBIG 1.2 kg a.i. ha^{-1} samples had altered rates of change across sampling months compared to control for FM, CP, and IVTDMD (Table 3). The 2017 BBIG samples had superior nutritive value across all TE concentrations for CP and NDF (Table 3). The 2017 BBIG 0.6 a.i. ha^{-1} and 1.2 a.i. ha^{-1} samples had increased IVTDMD compared to control (Table 3).

Leaf CP, NDF, and IVTDMD improved due to TE application for BBIG in September 2017 (Table 4). Leaf-to-stem equations indicated a reduction from 38 to 22% stem material due to TE (1.2 kg a.i. ha^{-1}) in BBIG during September 2017, within the range found by Griffin and Jung (1983). The leaf/stem ratio multiplied by the FM for this sample indicated a BBIG yield of 2670 kg ha^{-1} leaf matter in control plots versus 2170 kg ha^{-1} leaf matter in TE plots during September 2017, an 18.7% reduction. No alterations occurred in SG leaf or stem nutritive value due to TE application (Table 4).

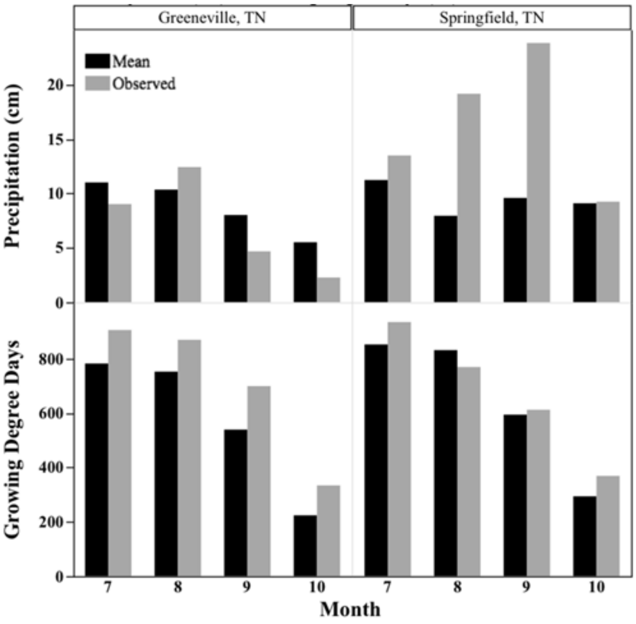

Fig. 1. Weather (including 30-yr average) for the 2016 growing season in Greeneville, TN, and for the 2017 growing season in Springfield, TN.

Visual observations noted greater variability in response to TE within BBIG swards compared to uniform morphological response to TE within SG. Individual BBIG bunchgrasses within sampling areas had severely depressed regrowth with no stem production, while other individual plants displayed minimal response (full seedhead growth). Variability could not be visually assigned to differences between big bluestem and indiangrass species.

DISCUSSION

The strong impact of year on forage variables can be attributed to the late-summer drought that impacted the region during 2016 (Fig. 1; Table 1). The drought altered the BBIG response to TE application. Irrespective of drought, SG did not have altered whole-plant nutritive value or morphological component nutritive value due to TE application. This was despite a reduction in FM that was of similar magnitude to BBIG. This indicated that SG was a poor candidate species for TE application irrespective of precipitation. Specifically, this could be due to lack of morphological plasticity and stronger apical dominance in SG (Sarath et al., 2014). Generally, limited stem suppression can be attributed to the late season application. Hormonal signaling for resource allocation to stem production is greater after stem growth initiation and altering this pathway through growth regulators may be challenging (Yamaguchi, 2008). Goold et al. (1982) found diminishing returns with late season stem growth suppression and Moyer et al. (1988) found the greatest response during early stem production in a C_3 pasture, rather than after stem production had fully initiated.

Effect of TE application was greater in BBIG paddocks, indicating more plasticity. In addition, individual plant variability was noted in BBIG fields relative to a uniform response in SG.

Table 1. ANOVA results (*F*-value) of full factorial analysis of forage variables across 2 yr and for a mixture of big bluestem (*Andropogon gerardii*)/indiangrass (*Sorghastrum nutans*) and switchgrass (*Panicum virgatum*).

Source	FM†	CP†	NDF†	IVTDMD†
	Big bluestem/indiangrass			
Date post application	**4.09**§	**354.44**	**27.61**	**115.14**
TE‡ kg a.i. ha^{-1}	**6.17**	**16.05**	**7.94**	**5.82**
Date post application × TE kg a.i. ha^{-1}	1.07	1.95	**3.25**	**2.99**
Year	**12.41**	**21.60**	**5.31**	**13.88**
Date post application × year	2.65	**12.83**	**17.65**	**5.35**
TE kg a.i. ha^{-1} × year	**2.98**	**10.05**	**4.89**	**3.98**
Date post application × TE kg a.i. ha^{-1} × year	0.59	**4.98**	2.41	2.57
	Switchgrass			
Date post application	**11.41**	**15.05**	3.13	1.51
TE kg a.i. ha^{-1}	**9.43**	1.54	0.84	0.17
Date post application × TE kg a.i. ha^{-1}	1.38	1.33	1.49	1.62
Year	**49.04**	**27.12**	**54.12**	**121.80**
Date post application × year	1.60	1.28	**42.89**	**20.95**
TE kg a.i. ha^{-1} × year	**3.03**	0.90	0.75	1.71
Date post application × TE kg a.i. ha^{-1} × year	0.44	0.50	0.32	0.58

† FM, forage mass; CP, crude protein; NDF, neutral detergent fiber; IVTDMD, in vitro true dry matter digestibility (48 h).

‡ TE, trinexapac-ethyl.

§ Bold values indicate indicates significant relationships ($P < 0.05$).

Table 2. Least-squared means for forage mass and nutritive value comparing control (0 kg a.i. ha^{-1}) and three concentrations of trinexapac-ethyl (TE) across three sampling months (Aug.–Oct.) and 2 yr for a mixture of big bluestem (*Andropogon gerardii*)/indiangrass (*Sorghastrum nutans*) and switchgrass (*Panicum virgatum*).

				Big bluestem/indiangrass				
TE	FM†		CP†		NDF†		IVTDMD†	
kg a.i. ha^{-1}	kg ha^{-1}	Δ mo^{-1}	g kg^{-1}	Δ mo^{-1}	g kg^{-1}	Δ mo^{-1}	g kg^{-1}	Δ mo^{-1}
0	3000		69.0		712	38.8	608	
0.3	2240		79.2		689	25.4	632	
0.6	1740*		87.3		674*	12.6	640	
1.2	1720*	325‡	86.5	–26.7	679*	9.3*	642	–47.4
				Switchgrass				
TE	FM		CP		NDF		IVTDMD	
kg a.i. ha^{-1}	kg ha^{-1}	Δ mo^{-1}	g kg^{-1}	Δ mo^{-1}	g kg^{-1}	Δ mo^{-1}	g kg^{-1}	Δ mo^{-1}
0	4770		60.6		716		582	
0.3	3920		67.9		699		586	
0.6	3440		67.8		707		586	
1.2	2990*	502	65.4	–6.72	706	–6.14	581	–7.45

* Differences from the control according to Dunnett's test ($P < 0.05$).

† FM, forage mass; CP, crude protein; NDF, neutral detergent fiber; IVTDMD, in vitro true dry matter digestibility. Models included the main and interactive effects of TE concentration and date as fixed effects and main and interactive effects of year and block as random effects.

‡ Single values in a column indicate that Δ mo^{-1} did not significantly differ between TE concentrations.

White (1990) also observed individual plant level variation in caucasian bluestem in response to mefluidide.

The BBIG paddocks responded to TE across both years (Table 2), but not in the same manner (Table 3). The 2016 drought delayed the response to TE applications until later sampling months, resulting in observations of alterations in nutritive value rate of change relative to control (1.2 kg a.i.$^{-1}$; CP, IVTDMD) (Table 3). However, these observations were associated with an anomalous negative forage growth observation due to near-zero overall growth and early fall senescence (Table 3). The 2017 results indicated more typical environmental conditions and TE responses and supported the conclusion that the largest impact of TE occurred during first month post-application.

Improved CP content in 2017 BBIG was consistent with prior observations of increased chlorophyll, a major pool of plant N, after TE applications (Luiz et al., 2015). Increased late-season CP could be counterproductive since NWSG translocate nitrogen in the fall. Delaying translocation of nitrogen is potentially useful for livestock managers that value retained CP (Craine et al., 2009; Raynor et al., 2016), but could reduce nitrogen efficiency and root reserves. Reductions in BBIG fiber content (NDF) and greater digestible content (IVTDMD) were also observed, indicating alterations beyond potentially delayed senescence. Measurements of perennial forage grass nutritive response to TE has not been documented before, but results were consistent with reports of overall reductions in NDF in pearl millet treated with mefluidide and sorghum treated with TE (Redmon et al., 2003; Macedo et al., 2017).

All leaf nutritive value measurements for BBIG were improved due to TE application during September 2017 (Table 4), in agreement with prior literature describing

Table 3. Least-squared means for forage mass and nutritive value comparing control (0 kg a.i. ha^{-1}) and three concentrations of trinexapac-ethyl (TE) across three sampling months (Aug.–Oct.) and between years for a mixture of big bluestem (*Andropogon gerardii*)/indiangrass (*Sorghastrum nutans*).

Big bluestem/indiangrass (2016)								
TE	FM†		CP†		NDF†		IVTDMD†	
kg a.i. ha^{-1}	kg ha^{-1}	Δ mo^{-1}	g kg^{-1}	Δ mo^{-1}	g kg^{-1}	Δ mo^{-1}	g kg^{-1}	Δ mo^{-1}
0	2030	235	71.2	–29.9	701		641	–66.7
0.3	1610	289	75.6	–19.7	685		662	–32.0
0.6	1500	216	79.1	–18.4	690		648	–28.5
1.2	1740	–337*	70.8	–9.5*	699	4.0‡	643	–6.6*
Big bluestem/indiangrass (2017)								
TE	FM		CP		NDF		IVTDMD	
kg a.i. ha^{-1}	kg ha^{-1}	Δ mo^{-1}	g kg^{-1}	Δ mo^{-1}	g kg^{-1}	Δ mo^{-1}	g kg^{-1}	Δ mo^{-1}
0	3980		66.7		725		575	
0.3	2860		82.8*		694*		601	
0.6	1970*		95.6*		659*		632*	
1.2	1700*	600	103*	–33.6	658*	39.1	640*	–61.0

* Differences from the control according to Dunnett's test ($P < 0.05$).

† FM, forage mass; CP, crude protein; NDF, neutral detergent fiber; IVTDMD, in vitro true dry matter digestibility. Models included the main and interactive effects of TE application and date post application as fixed effects and main and interactive effects of year and block as random effects.

‡ Single values in a column indicate that Δ mo^{-1} did not significantly differ between forage species.

Table 4. Least-square means for forage nutritive value on control and treated (1.2 kg a.i. ha^{-1} trinexapac-ethyl) plots from September and October leaf and stem components across 2 yr for a mixture of big bluestem (*Andropogon gerardii*) and Indiangrass (*Sorghastrum nutans*) and switchgrass (*Panicum virgatum*).†

	2016				2017			
	Switchgrass		Big bluestem/indiangrass		Switchgrass		Big bluestem/indiangrass	
	Control	Treated	Control	Treated	Control	Treated	Control	Treated
Sept.								
Leaf								
CP‡ (g kg^{-1})	108.7	3.1	74.5	0.9	73.6	16.0	83.7	15.9*
NDF (g kg^{-1})	580.1	–7.6	653.5	–1.2	640.1	–36.4	659.3	–40.5*
IVTDMD (g kg^{-1})	732.4	6.0	665.3	–2.8	636.2	19.6	624.2	58.1*
Stem								
Crude Protein (g kg^{-1})	30.3	7.2	19.5	3.3	7.1	2.7	5.8	12.7
NDF (g kg^{-1})	789.3	–21.9	848.8	–20.1	881.5	–16.3	817.0	11.4
IVTDMD (g kg^{-1})	514.9	14.9	487.8	1.6	497.5	7.1	479.6	–11.1
Oct.								
Leaf								
CP (g kg^{-1})	105.8	6.2	61.0	–3.5	63.7	–4.6	42.8	16.5
NDF (g kg^{-1})	594.9	–17.8	690.8	7.2	699.3	40.0	724.8	–39.4
IVTDMD (g kg^{-1})	692.7	16.5	587.6	–13.3	557.4	–21.7	560.6	9.3
Stem								
CP (g kg^{-1})	42.2	5.7	24.8	–3.0	4.7	–1.3	3.7	6.3
NDF (g kg^{-1})	673.7	3.6	802.4	20.5	794.5	20.3	876.7	–20.1
IVTDMD (g kg^{-1})	620.8	3.8	494.4	–16.0	478.8	–22.8	427.9	–11.2

* Differences from the control by species on each sampling date and year according to Dunnett's test ($P < 0.05$).

† Treated values presented as difference from control.

‡ CP, crude protein; NDF, neutral detergent fiber; IVTDMD, in vitro true dry matter digestibility.

improved digestibility (Redmon et al., 2003; Macedo et al., 2017). However, no improvements were found in stem nutritive value for either species (Table 4). The lack of stem response could be attributed to either the perennial growth of NWSG, the late season application, or the adaptation of C_4 species to grazing, which promotes flexible regrowth. Alterations in leaf nutritive value were insufficient to explain alterations to bulk nutritive value. The unaccounted variation could be attributed to altered leaf/stem ratios (38% stem to 22% stem) or alterations in stem nutritive value that did not reach statistical significance (+218% treated stem CP; BBIG September 2017; Table 4)

The range of TE application concentrations did not indicate an optimum TE rate. Annual warm-season grasses had greater responses per unit TE, defined as lost FM and improved nutritive value (Stair et al., 1991; Redmon et al., 2003). Therefore, further research should evaluate optimizing forage response at reduced rates. The high application rates in the study (0.6 and 1.2 kg a.i. ha^{-1}) facilitated expression of the impact of TE on forage traits in BBIG, but are unlikely to be economically viable as a management technique. Specifically, the leaf yield of the treated (1.2 kg a.i. ha^{-1}) September 2017 BBIG plots were only 18.7% less than control plots, compared to an overall FM reduction of 57%. Reduced TE rates may balance FM loss with elevated leaf content.

Further research on gibberellin inhibition in warm-season grasses could be productive to determine the impacts of TE on overall sward health, spring production, or nitrogen cycling. In addition, the lowered canopy height of TE treated native grasses could facilitate cool-season annual over-seeding, a common strategy to produce off-season forage on warm-season pastures (Freeman et al., 2014; Bennett, 2017). Due to the large loss in FM relative to improved nutritive value, further benefits will have to be identified to make gibberellin inhibition a useful tool in this setting.

CONCLUSION

Application of TE reduced overall FM by up to 42% in BBIG and reduced NDF by 4.6% compared to control. Discounting data collected during a drought, TE applications reduced BBIG FM by up to 57%, with improved CP (up to 54%), NDF (−9.2%), and IVTDMD (11%) relative to control. Forage nutritive value was unaffected by TE application in SG, despite reductions in FM up to 37%. No differences were detected in leaf or stem CP, NDF, or IVTDMD for SG, while all nutritive value improved in BBIG leaf samples in September 2017. The leaf/stem ratio also improved by TE application on this sampling date (78 vs. 62% leaf mass). While the tradeoff between FM and nutritive value was substantial, the value of low nutritive content forage is negligible and therefore large losses in FM could be productive if nutritive content remains above a management-specific threshold. Future research could evaluate lower TE concentrations, alternative TE timing, and quantify the impact of growth regulators on root growth, tillering, and subsequent spring regrowth. Evidence of improvements to long-term productivity or sward health would be required to make gibberellin inhibitors a useful tool for NWSG management.

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