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Forage Nutritive Value and Herbage Mass Relationship of Four Warm-Season Grasses

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ABSTRACT

To provide animals with high quality forage, practical methods are needed to estimate nutritive value to optimize harvest timing. The objective of this study was to develop such models to estimate warm-season forage nutritive value in the southeastern United States. The experiment was conducted at the University of Tennessee Plateau AgResearch and Education Center in Crossville, TN, from 2013 to 2015. Four warm-season forages were evaluated separately, each in a randomized complete block design and, each for 2 yr: switchgrass [*Panicum virgatum* (L.) 'Alamo'- a lowland variety from Texas with high forage quality and biomass production], sorghum–sudangrass [*Sorghum bicolor* (L.) Moench ×*Sorghum sudanese* (P.) Stapf, 'FSG208BMR'- a vigorous, drought tolerant variety with improved digestibility], bermudagrass [*Cynodon dactylon* (L.) Pers. 'Vaughn's # 1'- a cold tolerant, upright variety] and crabgrass [*Digitaria sanguinalis* (L.) 'Quick-N-Big'- a fast germinating variety with a quick growth rate]. Monthly initiations were established based on cutting timing, in which a single cut was made at the beginning of the assigned month with nutritive value and herbage mass (HM) of the regrowth observed in the following weeks. Results determined that HM was influential on crude protein (CP) and neutral detergent fiber digestibility (NDFD) for all species tested, except crabgrass. Based on differences in nutritive value and morphological composition by maturity, as well as the successful prediction of CP and NDFD from HM through linear regression, it was determined that June and July initiations are preferred for switchgrass and bermudagrass, while July initiation is preferable for sorghum–sudangrass.

Core Ideas

- Nutritive value was analyzed over time for four warm-season forage grasses.
- Herbage mass accumulation was estimated for each management strategy.
- Nutritive value can be predicted from herbage mass for most species.
- Early initiation cuts are preferable to produce forage of high value in all cases.

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Warm-season grasses (C_4) can be used to increase herbage yield, extend the grazing season, and utilize soils of poor fertility and/or low water availability in the southern United States. However, cool-season grass (C_3) species are often recommended for use in ruminant production systems because they have perceived greater forage quality than warm-season grasses. In general, C_3 grasses have high nutritive value (Ball et al., 2008; Nave et al., 2013). However, in the southeastern United States, cool-season grass productivity is reduced during the summer months and the amount of forage available for grazing animals or hay production declines. To extend the grazing season and reduce the need to store forage, the use of warm-season grasses can be considered a good alternative.

Once established, perennial C_4 grasses, such as bermudagrass and switchgrass, can be reliable choices for producers. With adequate management, these grasses will produce good quality forage. In addition, these grasses are resilient to changes in weather and can be beneficial to the soil (Corre et al., 1999). Annual C_4 grasses, such as sorghum–sudangrass and crabgrass, are useful for short-term forage production. These grasses accumulate herbage mass quickly and can be used in rotation with other crops in the production system. Integrating these grasses into a forage system can be beneficial for the producer, the livestock and the ecosystem, given they are managed appropriately.

Previous studies have confirmed that forage nutritive value declines with maturity and that forage digestibility may decrease following the first harvest (Moore et al., 1991; Burns et al., 1997; Difante et al., 2008; Nave et al., 2014; Richner et al., 2014). In response to warm temperatures and low available water, C_4 grasses mature quickly developing high levels of fiber, especially lignin (Buxton and Fales, 1994). With appropriate management, warm-season forage can be harvested or grazed at a point where forage nutritive value and yield meet the goals of the production system. However, few practical field methods for estimating forage nutritive value have been developed.

Methods for practical estimation of neutral detergent fiber (NDF) and CP for C_3 grasses based on age, morphology, and weather have been studied (Fick et al., 1994). Nave et al. (2013)

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Abbreviations: ADF, acid detergent fiber; C_3, cool-season grasses; C_4, warm-season grasses; CP, crude protein; DM, dry matter; HM, herbage mass; HMA, herbage mass accumulation; IVTDMD, in-vitro dry matter digestibility; NDF, neutral detergent fiber; NDFD, neutral detergent fiber digestibility; NIRS, near-infrared spectroscopy; PREC, Plateau AgResearch and Education Center.

found a relationship between herbage accumulation rate and NDFD in stands of C_3 grasses. This enabled the fitting of a linear model to estimate NDFD from herbage mass. Previous research has yet to further explore these relationships for C_4 grasses. Real-time estimations of CP content in bermudagrass have been made successfully via canopy reflectance analysis (Starks et al., 2006). However, this method requires specialized equipment to create predictions. Developing and improving practical predictive models for C_4 grass nutritive value and herbage accumulation, similar to those developed for cool-season species, has the potential to improve grazing management in the Southeast.

The objective of this study was to develop practical estimations of C_4 grasses nutritive value based on the relationship between HM and nutritive value variables. It was hypothesized that as HM increased, forage nutritive value would decrease linearly. Detected relationships between forage nutritive value variables and HM could assist in explaining differences in forage nutritive value across the growing season of C_4 grasses and assist in determining the best time for forage harvest.

MATERIALS AND METHODS

Site Description

This study was conducted at the Plateau AgResearch and Education Center (PREC) in Crossville, TN (36°0′ N, 85°7′ W, 580-m elevation) from June to September 2013 to 2015. Four experiments (one for each species) were conducted with experimental units that were 3 by 4.5 m plots arranged in a randomized complete block design with four replications. Soil conditions on location were Lonewood loam (fine-loamy, siliceous, semiactive, mesic Typic Hapludult) (loamy residuum weathered from sandstone, 2–5% slopes, well-drained, 40–80 inches to paralithic bedrock) and Ramsey loam (loamy, siliceous, subactive, mesic Lithic Dystrudept) (loamy residuum weathered from sandstone, 5–12% slopes, somewhat excessively drained) (NRCS, 2014). Initial soil nutrient levels of the experimental site were pH = 5.8, P = 33 kg ha^{-1}, K = 122 kg ha^{-1}, Ca = 2345 kg ha^{-1} and Mg = 117 kg ha^{-1}.

In 2013, three species were tested: switchgrass, sorghum-sudangrass, and bermudagrass. In 2014, crabgrass was added to the experiment, bermudagrass omitted due to winterkill, and both switchgrass and sorghum–sudangrass were tested for a second year. In 2015, bermudagrass and crabgrass were tested for a second year.

Before the experiment began, all vegetation from the perennial plant species was removed and annual plots were tilled and seeded for initial establishment. Switchgrass and bermudagrass plots were previously established in 2008 and managed for studies on hay production. Due to winterkill during the winter of 2013/2014, bermudagrass was re-established via sprigging at 0.87 m^3 ha^{-1} in May 2014. Sorghum–sudangrass was broadcast seeded at 50.41 kg ha^{-1} on 6 June 2013 and on 3 June 2014. Crabgrass was broadcast seeded at 5.61 kg ha^{-1} on 27 May 2014 and 20 May 2015. Nitrogen fertilizer was applied each year at the rate of 67 kg ha^{-1} to all plots. In 2013, fertilization took place on 5 June for sorghum–sudangrass and on 6 June for switchgrass and bermudagrass. In 2014, switchgrass was fertilized on 6 May, and sorghum–sudangrass and crabgrass on 20 May in 2014. In 2015, bermudagrass and crabgrass were fertilized on 1 May.

Three monthly cutting initiations were imposed on each warm-season perennial species, and two monthly cutting initiations were imposed on each warm-season annual species. In 2013, monthly initiations for switchgrass and bermudagrass were 5 June, 1 July, and 1 August, and for sorghum–sudangrass 1 July and 1 August. In 2014, monthly initiations for switchgrass were 6 June, 1 July, and 1 August, and 1 July and 1 August for sorghum–sudangrass and crabgrass. In 2015, bermudagrass monthly initiations were on 4 June, 6 July, and 3 August and crabgrass monthly initiations were on 13 July and 3 August.

On each monthly initiation, swards were cut to designated stubble heights using a custom mechanical short row harvester, which were selected based on the location of the meristem for each species. Switchgrass and sorghum–sudangrass were cut to 20 cm and bermudagrass and crabgrass were cut to 8 cm. Based on the findings of Burns and Fisher (2008), which determined that maintaining a bermudagrass canopy height above 5 cm results in better animal performance, 8 cm was chosen in our study to be the appropriate sampling and cutting height to support active herbage growth and capture the section of canopy that is most likely to be grazed by cattle in bermudagrass and crabgrass stands.

Weather

In 2013, June through September temperature was 0.3°C below the 30-yr average. Precipitation in 2013 from June through September was 28% above the 30-yr average (449 mm). In 2014, June through September temperature was 0.7°C above the 30-yr average. Precipitation in 2014 from June through September was 10% higher than the 30-yr average. In 2015, June through September temperature was 0.9°C above the 30-yr average. Precipitation in 2015 from June to September was 69% higher than the 30-yr average (Fig. 1).

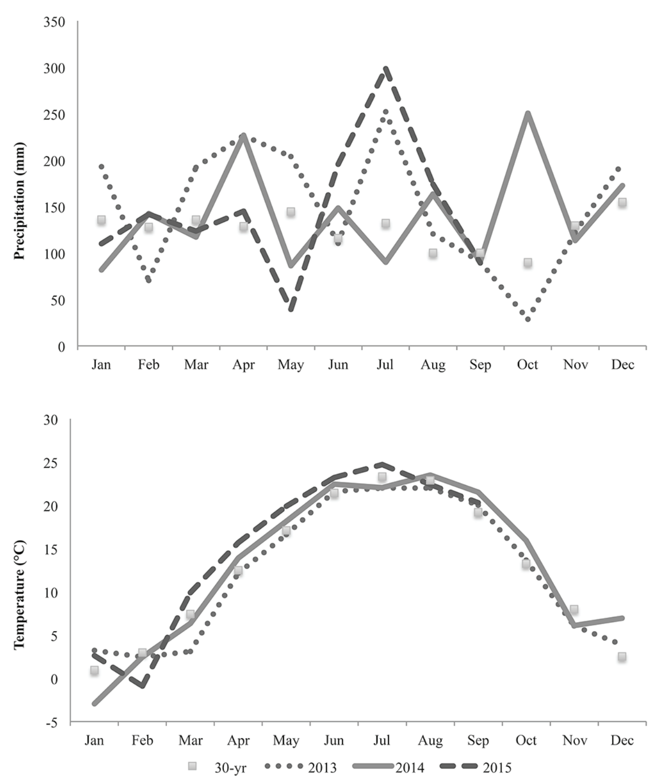

Fig. 1. Weather for Crossville, TN, including 30-yr average, 2013, 2014, and 2015.

Measurements

Forage samples were collected weekly from June through July (corresponding to periods of rapid regrowth) and on alternate weeks from August to September (corresponding to periods of slow regrowth) to characterize morphological composition and forage nutritive value. One 0.1 m^2 sample was taken within each experimental unit per sampling date. Sample quadrants were selected randomly on each sampling date while never repeatedly sampling the same area. The vertical subsamples were then separated by morphological components (green-lamina, dead material, stem+sheath) and dried at 60°C for 72 h to determine the proportion of each morphological component. Subsamples were recombined with their corresponding components and dry matter (DM) of the whole sample was used to determine HM for the experimental unit before forage nutritive value analysis.

Samples were ground to 1-mm particle size with a Wiley Mill Grinder (Thomas Scientific, Swedesboro, NJ) in preparation for near-infrared spectroscopy (NIRS). Samples were analyzed for multiple quality factors on a DM basis, with CP, acid detergent fiber (ADF), neutral detergent fiber (NDF), and NDFD of particular interest for this experiment, using a FOSS 5000 NIRS instrument (FOSS NIRS, Laurel, MD). Equations for the forage nutritive analyses were standardized and checked for accuracy using the 2013 Mixed Hay Equation developed by the *NIRS Forage and Feed Consortium* (NIRSC, Hillsboro, WI), which included all species utilized in this study. Software used for NIRS analysis was Win ISI II supplied by Infrasoft International LLC (State College, PA). The Global H statistical test compared the samples against the model and samples from distinct datasets within the database for accurate results, where all forage samples fit the equation ($H < 3.0$) and are reported accordingly (Murray and Cowe, 2004).

Statistical Analysis

Differences between least squares means for all nutritive value variables and all species were evaluated using the PROC MIXED procedures of SAS (SAS for Windows V 9.4, SAS Institute, 2009). For each analysis, the dependent variable was CP, ADF, NDF, or NDFD. Fixed effects were monthly initiation (monthly initiations serve as the “treatments” in this experiment) and stage of maturity (weeks post initiation). Year and block were random effects. However, there were significant year × initiation interactions for each species for at least one dependent variable. Therefore, results of this experiment are displayed separately by year for all variables. Herbage mass during each initiation date (HM, a dependent variable), during each year, was fitted to time (t, an independent variable) using the Gompertz equations Eq. [1] with PROC NLIN of SAS (SAS for Windows V 9.4, SAS Institute, 2009) to best fit the data (Nave et al., 2013). PROC NLIN used the option Method = Newton, since this had the most reliable convergence. These models were developed in order for HM to be integrated with nutritive value data collected across all species throughout the season. Parameter estimation by PROC NLIN had less error when the three-parameter model Eq. [1] was used rather than a four-parameter model, and curve fitting was simplified by assigning H_{min} as the lowest herbage mass measured.

Table 1. Parameters for Gompertz curves predicting herbage mass accumulation patterns (Fig. 2 and 3).

Forage species	Monthly initiation	Asymptotic herbage mass (H_{Δ})†	Shape coefficient† (a)	Curvature coefficient† (b)
		kg DM‡ ha^{-1}		
Switchgrass				
	June 2013	16,312	–3.12	0.017
	July 2013	7,978	–4.00	0.042
	August 2013	6,397	–4.90	0.046
	June 2014	16,285	–16.27	0.041
	July 2014	16,468	–7.58	0.036
	August 2014	9,913	–8.46	0.058
Sorghum–sudangrass				
	July 2013	16,297	–4.87	0.036
	August 2013	4,978	–4.96	0.044
	July 2014	13,371	–4.61	0.019
	August 2014	3,355	–4.55	0.050
Bermudagrass				
	June 2013	6,645	–2.33	0.029
	July 2013	2,912	–2.55	0.051
	August 2013	2,720	–2.62	0.083
	June 2015	4,120	–27.37	0.144
	July 2015	1,873	–2.72	0.084
	August 2015	6,202	–2.69	0.016
Crabgrass				
	July 2014	1,888	–5.26	0.064
	August 2014	4,925	–2.99	0.011
	July 2015	2,022	–2.40	0.050
	August 2015	7,501	–2.95	0.013

† H_{Δ}, maximum (asymptotic) herbage mass. Parameters a and b are parameters that determined the shape of the Gompertz curve.
‡ DM, dry matter.

Table 2. Nutritive value of switchgrass monthly initiations by maturity during the 2013 and 2014 growing seasons at Plateau AgResearch and Education Center, Crossville, TN.

2013 Switchgrass					2014 Switchgrass				
	Weeks post monthly initiation					Weeks post monthly initiation			
Month	2	4	6	8	Month	2	4	6	8
		CP†, g kg^{-1}					CP, g kg^{-1}		
June	118.5a‡	127.5a	98.3a	69.8a	June	174.6a	150.7a	108.5a	83.4b
July	145.2a	92.3b	92.8a	70.7a	July	175.1a	138.1b	108.2a	92.4ab
August	130.3a	120.1ab	98.5a	83.0a	August	164.6a	154.7a	104.2a	101.6a
P	0.0654	0.0248	0.4457	0.1176	*P*	0.8830	0.0003	0.7752	0.0153
		ADF, g kg^{-1}					ADF, g kg^{-1}		
June	405.9a	377.4b	414.4b	474.5a	June	345.9a	367.4a	406.2b	444.0a
July	387.2a	436.4a	457.0a	481.7a	July	327.8a	368.0a	417.1b	440.5a
August	374.6a	422.4ab	437.9ab	468.2a	August	365.8a	373.1a	440.3a	424.0a
P	0.0831	0.0155	0.0124	0.2662	*P*	0.3369	0.5413	0.0058	0.2851
		NDF, g kg^{-1}					NDF, g kg^{-1}		
June	620.7a	599.9b	647.1a	711.3a	June	519.1a	557.3b	632.5a	656.9a
July	586.9ab	661.1a	682.5a	718.0a	July	485.4a	574.7a	618.2a	659.3a
August	558.1b	634.4ab	659.1a	700.2a	August	552.1a	569.5ab	634.3a	633.4a
P	0.0252	0.0646	0.0646	0.4316	*P*	0.2414	0.0216	0.3545	0.1283
		NDFD, g kg^{-1}					NDFD, g kg^{-1}		
June	544.4ab	584.4a	533.1a	450.2a	June	639.4a	640.9a	577.9a	488.4a
July	590.3a	492.2b	450.1b	400.9b	July	665.7a	618.4a	506.0b	471.2a
August	535.5b	498.6b	460.6b	414.6ab	August	668.0a	652.9a	489.3b	477.4a
P	0.0390	0.0019	0.0010	0.0404	*P*	0.7653	0.1422	0.0004	0.4010

† CP, crude protein; ADF, acid detergent fiber; NDF neutral detergent fiber; NDFD, neutral detergent fiber digestibility.

‡ Means within a column without a common letter differ ($P < 0.05$).

Table 3. Nutritive value of sorghum–sudangrass monthly initiations by maturity during the 2013 and 2014 growing seasons at Plateau AgResearch and Education Center, Crossville, TN.

2013 Sorghum–sudangrass					2014 Sorghum–sudangrass				
	Weeks post monthly initiation					Weeks post monthly initiation			
Month	2	4	6	8	Month	2	4	6	8
		CP†, g kg^{-1}					CP, g kg^{-1}		
July	116.0a‡	93.0b	77.8b	70.0b	July	165.5a	122.1a	98.9b	97.8a
August	131.6a	127.9a	97.7a	97.7a	August	115.2b	147.4a	127.9a	113.1a
P	0.0589	0.0065	0.0065	0.0304	*P*	0.0284	0.2722	0.0248	0.2028
		ADF, g kg^{-1}					ADF, g kg^{-1}		
July	424.6a	442.9a	461.8a	464.5a	July	358.4b	396.4a	447.2a	453.9a
August	458.6a	416.9b	443.0b	427.4b	August	480.3a	454.5a	457.8a	455.0a
P	0.2436	0.036	0.0016	0.049	*P*	0.0100	0.1098	0.4927	0.9285
		NDF, g kg^{-1}					NDF, g kg^{-1}		
July	630.8a	665.2a	696.3a	701.8a	July	537.2b	604.7a	656.6a	696.7a
August	627.2a	599.6b	654.6b	658.7b	August	688.4a	656.3a	676.6a	663.0a
P	0.9152	0.0032	0.0111	0.0098	*P*	0.0113	0.2270	0.2981	0.0747
		NDFD, g kg^{-1}					NDFD, g kg^{-1}		
July	564.7a	597.3a	555.6a	521.5a	July	528.9a	520.9a	458.7a	475.3a
August	522.6a	519.4b	509.2b	522.4a	August	468.4a	465.2a	482.6a	443.7b
P	0.1564	<0.0001	0.0003	0.9674	*P*	0.0928	0.0854	0.2705	0.0253

† CP, crude protein; ADF, acid detergent fiber; NDF neutral detergent fiber; NDFD, neutral detergent fiber digestibility.

‡ Means within a column without a common letter differ ($P < 0.05$).

Table 4. Nutritive value of bermudagrass monthly initiations by maturity during the 2013 and 2015 growing seasons at Plateau AgResearch and Education Center, Crossville, TN.

2013 Bermudagrass					2015 Bermudagrass				
	Weeks post monthly initiation					Weeks post monthly initiation			
Month	2	4	6	8	Month	2	4	6	8
	CP†, g kg^{-1}					CP, g kg^{-1}			
June	156.8a‡	120.2a	82.4a	75.0b	June	203.5a	150.7a	116.1a	88.7a
July	102.8b	111.5a	87.0a	80.9a	July	115.8b	80.0b	77.4a	84.5a
August	65.5c	76.9b	81.4a	71.5ab	August	79.6b	106.1b	94.5a	.
P	0.0002	0.0026	0.2774	0.0110	*P*	<0.0001	0.0007	0.0793	0.6258
	ADF, g kg^{-1}					ADF, g kg^{-1}			
June	361.0c	352.3c	393.6b	426.8b	June	291.4b	343.0b	367.8b	348.9b
July	421.3b	405.5b	395.7b	405.2b	July	407.6a	424.5a	439.4a	420.2a
August	485.8a	459.8a	452.2a	472.4a	August	438.3a	416.5a	408.9ab	.
P	<0.0001	<0.0001	0.0003	0.0004	*P*	<0.0001	0.0028	0.0042	0.0135
	NDF, g kg^{-1}					NDF, g kg^{-1}			
June	586.6c	582.4c	623.5b	656.8b	June	505.3b	576.1b	577.6b	551.1b
July	655.0b	641.0b	621.3b	629.5c	July	623.7a	628.0a	648.7a	631.4a
August	716.6a	686.8a	678.9a	711.0a	August	634.6a	652.0a	634.0a	.
P	<0.0001	0.0002	0.0007	<0.0001	*P*	0.0003	0.0013	0.0061	0.006
	NDFD, g kg^{-1}					NDFD, g kg^{-1}			
June	517.2a	551.5a	487.4a	405.1a	June	627.0a	614.5a	541.5a	509.9a
July	447.5b	446.7b	437.6b	420.1a	July	491.9b	424.4b	419.7b	449.2a
August	327.1c	352.7c	359.1c	332.2b	August	383.9b	436.9b	431.8b	.
P	<0.0001	<0.0001	0.0001	0.0003	*P*	0.0007	<0.0001	0.0007	0.098

† CP, crude protein; ADF, acid detergent fiber; NDF neutral detergent fiber; NDFD, neutral detergent fiber digestibility.
‡ Means within a column without a common letter differ ($P < 0.05$).

Table 5. Nutritive value of crabgrass monthly initiations by maturity during the 2014 and 2015 growing seasons at Plateau AgResearch and Education Center, Crossville, TN.

2014 Crabgrass					2015 Crabgrass			
	Weeks post monthly initiation					Weeks post monthly initiation		
Month	2	4	6	8	Month	2	4	6
	CP†, g kg^{-1}					CP, g kg^{-1}		
July	165.5a‡	116.0a	105.3b	92.0a	July	108.6a	92.5b	101.8a
August	96.7b	160.9a	148.7a	98.6a	August	77.9b	124.0a	112.6a
P	0.0031	0.0854	0.0499	0.6748	*P*	0.0040	0.0422	0.4076
	ADF, g kg^{-1}					ADF, g kg^{-1}		
July	385.8b	385.8a	430.6a	443.1a	July	456.5a	437.2a	465.4a
August	501.3a	433.5a	412.0a	466.7a	August	499.8a	411.0b	418.7a
P	0.0051	0.2586	0.4796	0.6873	*P*	0.2270	0.0174	0.0976
	NDF, g kg^{-1}					NDF, g kg^{-1}		
July	544.0b	569.2a	623.2a	602.0a	July	657.9a	625.9a	651.9a
August	671.8a	602.0a	585.4a	622.3a	August	688.8a	619.7a	634.6a
P	0.0047	0.4283	0.1423	0.7218	*P*	0.4094	0.6970	0.5147
	NDFD, g kg^{-1}					NDFD, g kg^{-1}		
July	497.4a	541.5a	503.0a	435.9a	July	504.6a	481.0a	481.9a
August	380.3b	421.5b	501.5a	403.0a	August	447.4a	496.5a	504.3a
P	0.0038	0.0035	0.9757	0.3275	*P*	0.1314	0.6654	0.3281

† CP, crude protein; ADF, acid detergent fiber; NDF neutral detergent fiber; NDFD, neutral detergent fiber digestibility.
‡ Means within a column without a common letter differ ($P < 0.05$).

$$H = H_{\Delta} e^{ae^{bt}} + H_{\min} \qquad [1]$$

in which H_{Δ} was the maximum (asymptotic) herbage mass and a and b were parameters that determined the shape of the Gompertz curve (Table 1). Simple regression analysis (PROC REG) in SAS (SAS for Windows V 9.4, SAS Institute, 2009) was used to determine the relationship between three variables of interest, HM and CP, as well as, between HM and NDFD for each initiation. Differences between least squares means by treatment for morphological composition variables (green-lamina proportion, dead material proportion, and stem+sheath proportion) were tested for each species by year and by maturity using the PROC MIXED procedures of SAS (SAS for Windows V 9.4, SAS Institute, 2009). For each analysis, the dependent variable was green-lamina proportion, dead material proportion, or stem+sheath proportion. Treatment was a fixed effect. Pearson Correlation Coefficients (PROC CORR) were used in SAS (SAS for Windows V 9.4, SAS Institute, 2009) to test existent relationships between forage nutritive value (CP and NDFD) and morphological composition variables (green-lamina proportion, dead material proportion, stem+sheath proportion, and HM) for each species by year. All results were evaluated for significance at $P < 0.05$.

RESULTS

Forage Nutritive Value by Maturity

When nutritive value variables (CP, ADF, NDF, and NDFD) of each species were compared by treatment, by each state of maturity (weeks posttreatment initiation), and by year, nutritive value differed among initiations and year. For switchgrass, differences existed among all variables (Table 2). For CP of switchgrass in both years, there were differences among initiations at 4 wk postinitiation, with June having a greater value of CP than July, and at 8 wk postinitiation, CP was greater for the August initiation than June (Table 2). For NDF of switchgrass in both years, differences were detected among initiations at 4 wk postinitiation, with July having more NDF than June. For NDFD of switchgrass in both years, differences among initiations existed at 6 wk with June having a greater amount of NDFD than July and August. For sorghum–sudangrass, differences also existed among all variables, although the differences among initiations for ADF, NDF, and NDFD, were not consistent between years (Table 3). For sorghum–sudangrass CP during both years, there were differences among initiations at 6 wk post initiation, with August having greater CP values than July. Additionally, for bermudagrass, differences existed among all variables (Table 4). In both years, differences in CP occurred at 2 and 4 wk postinitiation, with June greater than July. In both years, ADF differed at 2 and 4 wk postinitiation with August greater than June. For NDF in both years, August was greater than June at 2, 4, and 6 wk postinitiation. In both years, NDFD followed the same pattern from 2 through 6 wk postinitiation, with June greater than July and August. For crabgrass monthly initiations, differences existed among all variables in 2014, but in 2015 there were no differences in NDF or NDFD, and differences among initiations for ADF varied by year (Table 5). In both 2014 and 2015, CP differed at 2 wk post initiation, with July greater than August.

Herbage Mass Accumulation

Estimated herbage mass accumulation (HMA) of each species differed between years. Values for HMA were variable among initiation dates and among species, with greater

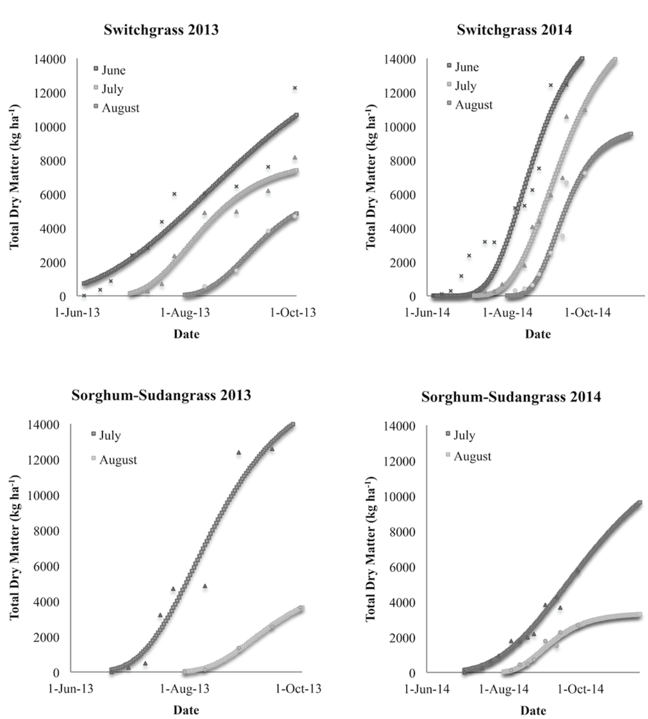

Fig. 2. Estimated herbage mass accumulation of tall growing species by management strategy during the 2013 and 2014 growing seasons at Plateau AgResearch and Education Center, Crossville, TN.

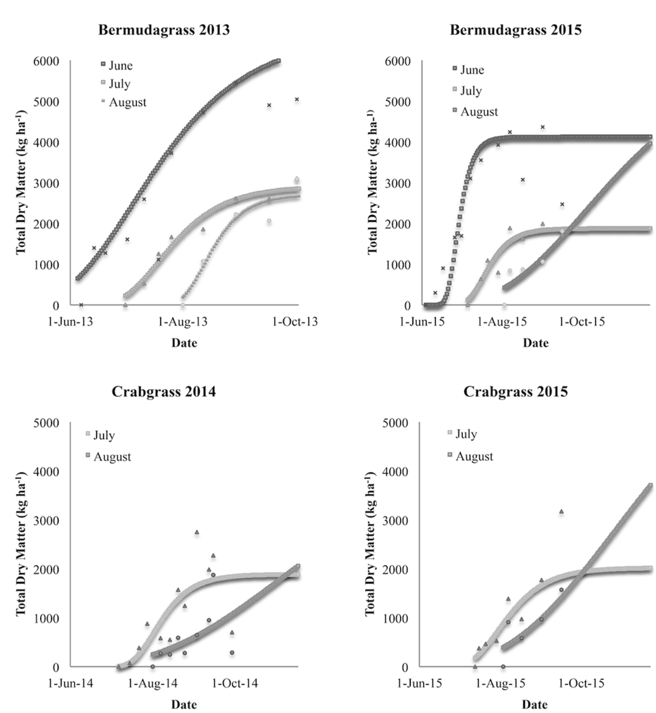

Fig. 3. Estimated herbage mass accumulation of short growing species by management strategy during the 2013, 2014, and 2015 growing seasons at Plateau AgResearch and Education Center, Crossville, TN.

accumulation of HM occurring in June for the warm-season perennials (switchgrass and bermudagrass) (Fig. 2 and 3). Switchgrass HMA of each treatment peaked with greater yields in 2014 than 2013 (Fig. 2). Bermudagrass HMA peaked with higher yields in 2013 than 2015 with the exception of the August initiation, in which HMA was estimated to be greater in 2015 (Fig. 3).

Sorghum–sudangrass had greater accumulation occurring in July, while high accumulation of HM for crabgrass occurred in August. Sorghum–sudangrass HMA peaked with greater yields in 2013 than 2014 (Fig. 2). Crabgrass July initiation HMA was similar in 2014 and 2015, while August initiation HMA was estimated to be greater in 2015 (Fig. 3). In all cases, except for bermudagrass and crabgrass during 2015, HMA decreased with later cutting initiations (Fig. 2 and 3).

Relationships of Forage Nutritive Value and Herbage Mass

With the exception of crabgrass, HM predicted CP in at least 1 yr of each species tested (Fig. 4 through 7). For switchgrass, CP was negatively affected by HM for June and July initiations in 2013 ($r^2 = 0.5520$ and $r^2 = 0.8416$, respectively) and 2014 ($r^2 = 0.5805$ and $r^2 = 0.7942$, respectively) (Fig. 4). For sorghum–sudangrass, CP was negatively affected by HM for the July initiations in 2013($r^2 = 0.7036$) and 2014 ($r^2 = 0.5478$) (Fig. 5). For bermudagrass there was a negative relationship between CP and HM in 2013 for June ($r^2 = 0.6965$) and for June ($r^2 = 0.4926$) and July initiations ($r^2 = 0.7729$) in 2015 (Fig. 6). No relationships were found for CP and HM of crabgrass in either 2014 or 2015 (Fig. 7).

Regression relationships between NDFD and HM were significant in at least 1 yr of each species tested (Fig. 4 through 7). For switchgrass, NDFD was negatively affected by HM for June and July initiations in 2013 ($r^2 = 0.7749$ and $r^2 = 0.8590$, respectively) and 2014 ($r^2 = 0.6814$) and $r^2 = 0.8797$, respectively) (Fig. 4). For sorghum–sudangrass, NDFD was negatively affected by HM for the July initiations in 2013($r^2 = 0.7522$) and 2014 ($r^2 = 0.6957$) (Fig. 5). For bermudagrass there was a negative relationship between NDFD and HM in 2013 for June ($r^2 = 0.4622$) and for July ($r^2 = 0.6870$) in 2015 (Fig. 6). For crabgrass, NDFD was negatively affected by HM for the July initiation during 2014 ($r^2 = 0.3814$) (Fig. 7).

Morphological Composition

Morphological composition differed among initiations and year when proportions of green-lamina, dead material, and stem+sheath were compared by corresponding stages of maturity in all species tested (Tables 6–9). For both years switchgrass was studied, differences in proportions of green-lamina, dead material, and steam+sheath by initiation differed (Table 6). For sorghum–sudangrass, differences between initiations by maturity differed by year for green-lamina and dead material, however for stem+sheath, July initiation had a greater proportion than August at 4 and 8 wk post initiation in both 2013 and 2014 (Table 7). Differences in green-lamina proportion for bermudagrass during both 2013 and 2015 occurred at 2 wk, with June greater than July and July greater than August, and also at 4 wk, with June and July greater than August (Table 8). Differences in dead material among initiations of bermudagrass, occurred in both years at 2 wk, with August greater than June, at 4 wk and 6 wk, with August greater than June and July, and at 8 wk postinitiation, with August greater than June. For crabgrass, differences among initiations differed by year for all morphological components (Table 9).

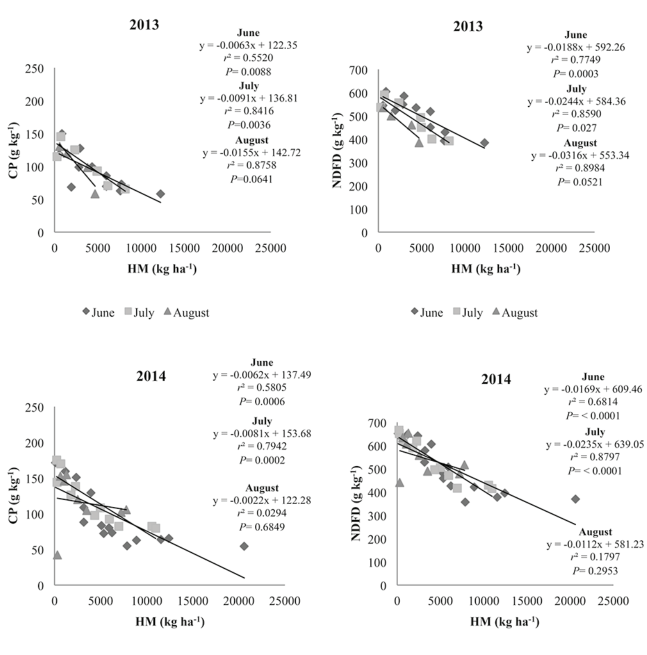

Fig. 4. Switchgrass regression relationships between crude protein (CP) and herbage mass (HM) and neutral detergent fiber digestibility (NDFD) and HM for monthly initiations during the 2013 and 2014 growing seasons at Plateau AgResearch and Education Center, Crossville, TN.

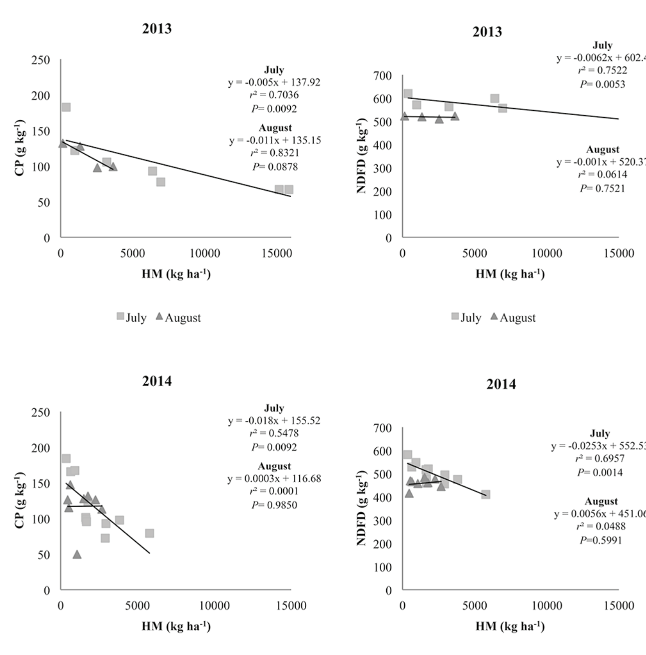

Fig. 5. Sorghum–sudangrass regression relationships between crude protein (CP) and herbage mass (HM) and neutral detergent fiber digestibility (NDFD) and HM for monthly initiations during the 2013 and 2014 growing seasons at Plateau AgResearch and Education Center, Crossville, TN.

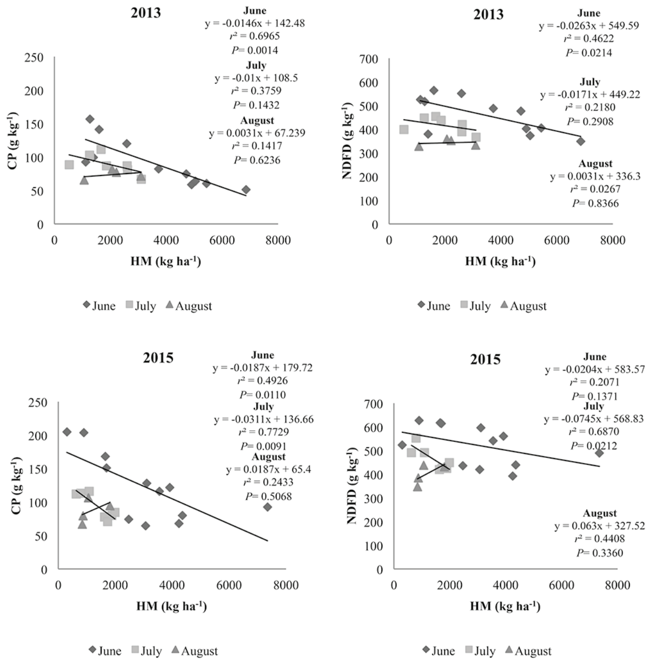

Fig. 6. Bermudagrass regression relationships between crude protein (CP) and herbage mass (HM) and neutral detergent fiber digestibility (NDFD) and HM for monthly initiations during the 2013 and 2015 growing seasons at Plateau AgResearch and Education Center, Crossville, TN.

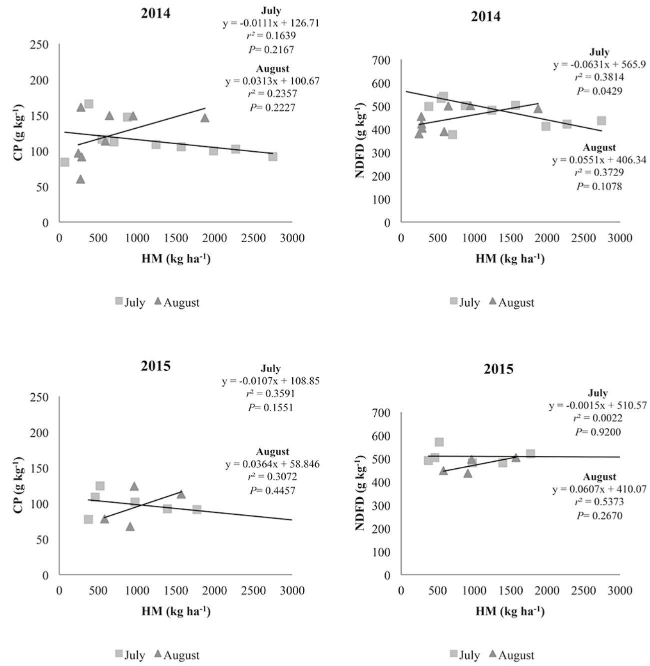

Fig. 7. Crabgrass regression relationships between crude protein (CP) and herbage mass (HM) and neutral detergent fiber digestibility (NDFD) and HM for monthly initiations during the 2014 and 2015 growing seasons at Plateau AgResearch and Education Center, Crossville, TN.

Correlations

Significant correlations were found between nutritive value variables, HM, and morphological components for all species tested. Significant correlations of switchgrass in both 2013 and 2014 were: CP to green-lamina ($r = 0.8741$ and $r = 0.8606$, respectively), CP to stem+sheath ($r = -0.8688$ and $r = -0.8853$, respectively), CP to HM ($r = -0.7962$ and $r = -0.7144$, respectively), NDFD to green-lamina ($r = 0.8827$ and $r = 0.8305$, respectively), NDFD to HM ($r = -0.8018$ and $r = -0.8102$, respectively), green-lamina to HM ($r = -0.8292$ and $r = -0.6000$, respectively), and stem+sheath to HM ($r = 0.8513$ and $r = 0.8567$, respectively). Results of sorghum–sudangrass for 2013 and 2014 revealed significant correlations between the following variables: CP to green-lamina ($r = 0.8675$ and $r = 0.7258$, respectively), CP to stem+sheath ($r = -0.9066$ and $r = -0.6476$, respectively), CP to HM ($r = -0.8254$ and $r = -0.5475$, respectively), NDFD to green-lamina ($r = 0.6941$ and $r = 0.6166$, respectively), and stem+sheath to HM ($r = 0.8545$ and $r = 0.6178$, respectively). In both 2013 and 2015, the following relationships existed in bermudagrass: to green-lamina ($r = 0.8520$ and $r = 0.6925$, respectively), NDFD to green-lamina ($r = 0.7670$ and $r = 0.7301$, respectively), and NDFD to dead material ($r = -0.7398$ and $r = -0.7848$, respectively).

Table 6. Morphology of switchgrass monthly initiations by maturity during the 2013 and 2014 growing seasons at Plateau AgResearch and Education Center, Crossville, TN.

2013 Switchgrass					2014 Switchgrass				
	Weeks post monthly initiation					Weeks post monthly initiation			
Month	2	4	6	8	Month	2	4	6	8
	green-lamina, g kg^{-1}					green-lamina, g kg^{-1}			
June	723.0a†	744.8a	716.7a	475.5a	June	951.5a	756.0b	679.3a	556.8a
July	751.5a	624.8a	442.3b	313.7a	July	823.0a	701.0b	662.0a	603.0a
August	833.5a	633.0a	500.3b	418.3a	August	518.3b	972.0a	602.3a	589.0a
P	0.2764	0.0521	0.0038	0.1314	*P*	0.0035	0.0058	0.3374	0.6788
	dead material, g kg^{-1}					dead material, g kg^{-1}			
June	51.3a	0.0a	163.3b	39.8b	June	0.0a	0.0a	31.00a	35.0a
July	45.5a	18.8a	100.5a	181.3a	July	119.0a	105.0a	27.8a	29.3a
August	0.00a	68.5a	91.5a	192.3a	August	334.5a	0.0a	37.0a	35.00a
P	0.1898	0.2312	0.0127	0.0015	*P*	0.0820	0.0581	0.8047	0.2245
	stem+sheath, g kg^{-1}					stem+sheath, g kg^{-1}			
June	225.8a	255.3a	267.0b	484.8a	June	48.5a	244.0a	289.7a	407.8a
July	203.3a	356.5a	457.0a	505.7a	July	58.0a	194.0a	310.0a	367.8a
August	166.5a	298.3a	408.3ab	389.3a	August	147.0a	28.0b	360.5a	354.3a
P	0.4952	0.1550	0.0279	0.1879	*P*	0.4367	0.0005	0.4288	0.6158

† Means within a column without a common letter differ ($P < 0.05$).

Table 7. Morphology of sorghum-sudangrass monthly initiations by maturity during the 2013 and 2014 growing seasons at Plateau AgResearch and Education Center, Crossville, TN.

2013 Sorghum–sudangrass					2014 Sorghum–sudangrass				
	Weeks post monthly initiation					Weeks post monthly initiation			
Month	2	4	6	8	Month	2	4	6	8
	green-lamina, g kg^{-1}					green-lamina, g kg^{-1}			
July	1000.0a†	471.3b	61.3a	238.3b	July	626.3a	610.3a	621.0a	443.5a
August	520.8a	812.8a	432.3a	439.0a	August	308.0a	504.8a	741.0a	446.3a
P	0.0533	0.0219	0.7284	0.0002	*P*	0.0576	0.2040	0.2265	0.9530
	dead material, g kg^{-1}					dead material, g kg^{-1}			
July	0.0a	3.8a	5.5a	238.3b	July	139.0b	152.5b	131.0a	152.5a
August	479.3a	59.8a	78.5a	439.0a	August	676.7a	469.5a	87.0a	229.3a
P	0.0533	0.2755	0.2252	0.08905	*P*	0.0042	0.0015	0.1169	0.1636
	stem+sheath, g kg^{-1}					stem+sheath, g kg^{-1}			
July	0.0a	525.0a	533.3a	682.3a	July	234.3a	236.8a	248.5a	404.0a
August	0.0a	127.3b	489.3a	488.5b	August	13.3b	25.5b	172.0a	324.8b
P	1.0000	0.0020	0.5717	0.0176	*P*	0.0112	0.0001	0.4174	0.2842

† Means within a column without a common letter differ ($P < 0.05$).

Table 8. Morphology of bermudagrass monthly initiations by maturity during the 2013 and 2015 growing seasons at Plateau AgResearch and Education Center, Crossville, TN.

2013 Bermudagrass					2015 Bermudagrass				
	Weeks post monthly initiation					Weeks post monthly initiation			
Month	2	4	6	8	Month	2	4	6	8
	green-lamina, g kg^{-1}					green-lamina, g kg^{-1}			
June	854.8a†	634.5a	361.0b	308.8a	June	605.1a	570.1a	405.7a	357.8ab
July	309.3b	587.5a	805.0a	289.3a	July	465.6b	499.9a	480.2a	417.2a
August	117.5c	254.0b	311.5b	173.3a	August	77.2c	210.3b	347.8a	221.6b
P	<0.0001	0.0036	0.0021	0.5932	*P*	<0.0001	0.0056	0.1232	0.0129
	dead material, g kg^{-1}					dead material, g kg^{-1}			
June	85.0b	37.3b	121.0b	191.3b	June	531.0b	202.0c	63.8b	165.9b
July	196.8ab	207.3b	56.5b	107.5b	July	58.4b	199.1b	172.6b	255.6ab
August	371.3a	606.0a	5013a	755.5a	August	553.5a	656.4a	479.8a	382.3a
P	0.0385	0.0061	0.0009	0.0018	*P*	<0.0001	<0.0001	<0.0001	0.0378
	stem+sheath, g kg^{-1}					stem+sheath, g kg^{-1}			
June	60.3b	328.5a	518.0a	500.0a	June	341.8a	409.8a	530.5a	476.4a
July	494.0a	205.3a	138.5b	603.3a	July	476.0a	301.0a	347.3b	327.3a
August	511.3a	140.0a	187.3b	71.3b	August	369.4a	133.4b	172.4c	396.8a
P	0.0095	0.2878	0.0068	0.0071	*P*	0.1342	0.0033	0.0004	0.3567

† Means within a column without a common letter differ ($P < 0.05$).

Table 9. Morphology of crabgrass monthly initiations by maturity during the 2014 and 2015 growing seasons at Plateau AgResearch and Education Center, Crossville, TN.

2014 Crabgrass					2015 Crabgrass			
	Weeks post monthly initiation					Weeks post monthly initiation		
Month	2	4	6	8	Month	2	4	6
	green-lamina, g kg^{-1}					green-lamina, g kg^{-1}		
July	77.3b†	393.5a	185.8a	71.00a	July	480.0a	492.5a	585.0a
August	438.0a	52.0b	172.3a	35.25a	August	142.5b	420.0a	247.5b
P	0.0007	<0.0001	0.7974	0.2274	*P*	0.0009	0.3224	<0.0001
	dead material, g kg^{-1}					dead material, g kg^{-1}		
July	778.3a	156.8a	127.8a	123.0a	July	397.5b	435.0a	292.5a
August	317.8b	308.8a	303.3a	523.0a	August	825.0a	522.5b	327.5a
P	0.0051	0.4447	0.4135	0.0790	*P*	0.0021	0.3675	0.6718
	stem+sheath, g kg^{-1}					stem+sheath, g kg^{-1}		
July	244.3a	449.8a	686.8a	805.8a	July	122.5a	70.0a	127.5b
August	144.0a	639.3a	797.3a	441.8a	August	32.5a	50.0a	422.5a
P	0.2037	0.4135	0.1734	0.0770	*P*	0.1716	0.6852	0.0051

† Means within a column without a common letter differ ($P < 0.05$).

Although in 2014 and 2015 there were significant correlations for crabgrass, none occurred in both years.

DISCUSSION

Barker et al. (2010) studied how the patterns of pasture growth varied with time of year and showed that the initial growth in the season makes it difficult to test the effect of high HM for C_3 grasses. Similarly in our study, the HM of the first initiation date of most species (with the exception of bermudagrass in 2015 and crabgrass in both years) could not be accurately estimated due to a very high accumulation rate in the beginning of the growing season. Rainfall was greater than average during 2014 and 2015 (Fig. 1). The timing of the rainfall could have contributed to differences in HM accumulation between years (Henderson and Robinson, 1982).

Differences in CP, ADF, NDF, and NDFD were found among all cutting strategies for all species tested, with the exception of crabgrass in 2015, which showed no differences among monthly initiations for NDF and NDFD (Tables 2–5). Some of the stability in NDF and NDFD values can be explained by the continuing development of new, less mature tillers throughout the season and this limited change in fiber composition over a 4 to 6 wk period of time can be encouraging (Ogden et al., 2004). In all species, the observed ranges of CP, ADF, NDF, and NDFD were comparable to those recorded in other experiments (Teutsch et al., 2005; Starks et al., 2006; Burns and Fisher, 2008; Reich, 2008; Temu et al., 2014). In most cases, nutritive value was lower with late season initiations than with early initiations. These findings correspond to the patterns observed in C_3 grasses where nutritive value is highest in young herbage regrowth and declines with maturity (Karn et al., 2006; Nave et al., 2014) and to the findings of Belesky et al. (1991), which reported that CP in bermudagrass steadily decreased with maturity. Bosworth et al. (1980) confirmed the same pattern for crabgrass. However, in this study there were some exceptions.

It was expected that nutritive value would differ among monthly initiations of each species, with earlier initiations producing herbage with higher nutritive value than later initiations when the samples were compared at the same biological age. In multiple cases, there were no differences among monthly initiations, most commonly at 8 wk postinitiation (Tables 2–5), which would suggest at 8 wk postcutting, herbage has low nutritive value whether monthly initiation occurred earlier or later in the growing season. However, these relationships varied within species from 2 to 8 wk postinitiation.

Rainfall from August to October in 2014 was higher than in 2013 and the amount of precipitation for the first month following initiation in 2014 was greater for August than for June. This likely improved the nutritive value of the herbage regrowth for August initiations of switchgrass (Fig. 1), which is supported by the lack of differences in morphological composition during this time (Table 6) (Buxton and Fales, 1994). For sorghum–sudangrass the high amount of stem+sheath present in July initiation samples (Table 7) could have lowered nutritive value (Table 3) (Griffin and Jung, 1983).

Fluctuations of CP and NDF found in bermudagrass (Table 4) could be attributed to the greater than average rainfall that occurred during the growing seasons (Fig. 1), especially during July of 2013 and 2015. Excess moisture can reduce whole-plant lignin concentration (Moore and Jung, 2001). Forage plants growing under conditions of excess moisture stunted plant development, resulting in lower concentration of lignin and other fiber components (Buscaglia et al., 1994).

For crabgrass, most changes occurred at 2 and 4 wk postinitiation in both 2014 and 2015. These results suggest that the first month should be prioritized while managing crabgrass to maximize nutritive value, which tends to decrease, staying low for the remaining of the season (Table 5) and to minimize the proportion of dead material and stem+sheath as the growing season progresses (Table 9). The magnitude of changes in nutritive value of crabgrass can be limited over an extended 6-wk sampling interval, thereby indicating that considerable flexibility may exist with respect to management and utilization (Ogden et al., 2004).

In mature crabgrass plots, stem+sheath was steady due to the formation of reproductive seed heads. To reduce stem+sheath proportion and increase green-lamina proportion, frequent clipping of seed heads or close grazing may be necessary (Youngner and McKell, 1972). Not only does clipping of the seed heads reduce stem+sheath proportion, but it will also stimulate additional production of vegetative tissues. As grasses mature, they grow reproductive tillers with more proportions of cellulose and lignin (Wilson and Hatfield, 1997), while CP decreases (Buxton and Redfearn, 1997). Similar management has been recommended for bermudagrass (Burns et al., 1984).

Switchgrass, sorghum–sudangrass, and bermudagrass showed a strong relationship between CP and morphological components, especially green-lamina. Also, switchgrass and sorghum–sudangrass showed a strong relationship between CP and HM. Very little changes in proportions of dead material and stem+sheath have occurred throughout the season and between management strategies. These results led us to believe that HM is a more reliable predictor of CP than NDFD, which is the inverse of similar analysis of C_3 grasses performed by Nave et al. (2013). With adequate moisture, C_4 grasses will have delayed maturity, reduced lignification, and greater regrowth rates than when moisture is inadequate (Buxton and Fales, 1994). The greater than average rainfall and near average seasonal temperatures from 2013 to 2015 supported active growth for much of the growing season, which likely minimized changes in the fiber content of these C_4 grasses. However, precipitation alone may not cause increase in CP (Angell et al., 1990).

Based on the regression analysis of the relationships between forage nutritive value and HM, CP can be predicted from HM for all species early in the growing season, with the exception of crabgrass (Fig. 4–7). These regression equations can use HM to predict NDFD for June and July initiations of switchgrass and July initiations of sorghum–sudangrass (Fig. 4 and 5). For bemudagrass and crabgrass, NDFD was predictable by HM in at least 1 yr (Fig. 6 and 7). Regression equations describing the relationship between nutritive value and HM can be a good tool to producers once that HM can be easily and quickly measured in the field (Nave et al., 2013). Future study of these variables should occur for bermudagrass and crabgrass to confirm these relationships.

SUMMARY AND CONCLUSIONS

Crude protein and NDFD are important factors for producers to consider when selecting feed for their livestock, with high CP and NDFD being desirable. Therefore, practical ways of estimating CP and NDFD in the field are essential for determining the best time to harvest or graze forage. Through this study we were able to develop recommendations for the four species studied for application in the southeastern United States.

After studying the effects of cutting strategies on CP and NDFD, we determined that HM was influential on these variables for all species tested, with the exception of crabgrass, and that time of defoliation is most influential for bermudagrass. June and July cuttings are preferred to August cuttings for bermudagrass and differences between initiations become less apparent as the stands mature. In addition, CP can be predicted by HM when bermudagrass cutting initiation occurs in June or July. Forage of high nutritive value can be maintained in switchgrass using either June, July, or August initiation cuttings, although CP and NDFD fluctuate among initiations as they mature, both can be predicted from HM for June and July initiation cuttings and therefore, June or July initiations are recommended. For sorghum–sudangrass, July initiations are recommended because both CP and NDFD can be predicted from HM for July initiations, although CP and NDFD varied between July and August initiations with maturity. For crabgrass, differences in nutritive value were not consistently apparent in this experiment and neither CP nor NDFD were consistently predicted from HM, which suggests that these relationships should continue to be investigated in the future.

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