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Defoliation management effects on nutritive value of ‘performer’ switchgrass

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Abstract

Forage species with greater nutritive value have the potential to positively affect animal responses. ‘Performer’ switchgrass (*Panicum virgatum* L.) was released because of greater digestibility and lower lignin concentrations as compared to ‘Alamo’ and ‘Cave-in-Rock.’ However, the relationship between nutritive value, canopy characteristics, and dry matter yield for this species has not yet been established. The goal of this study was to determine in vitro true digestibility (IVTD), crude protein (CP), neutral detergent fiber (NDF), and acid detergent fiber (ADF) as a function of a wide range of defoliation management strategies to aim optimize production of nutritious forage. Treatments were the factorial combination (4 × 4) of defoliation height (DH; clipped to 10, 20, 30, and 40 cm) and defoliation frequency (DF; clipped every 3, 6, 9, and 12 wk). The range of digestibility values was greater due to DF (from 590–779 g kg^{-1} when averaged across DH treatments) than DH treatments (from 675–692 g kg^{-1} when averaged across DF treatments). In general, frequent defoliation resulted in greater IVTD and CP but lower yields; however, there were interaction effects of DF × DH for all response variables. With the exception of NDF, all response variables had strong correlations with dry matter yield, canopy height, and leaf/stem ratio. Although there are tradeoffs when managing for productivity and nutritive value, there is a wide range of defoliation management options for ‘Performer’ switchgrass that provide flexibility in terms of harvesting schedules to optimize productivity and persistence of nutritious forage.

1 | INTRODUCTION

Switchgrass (*Panicum virgatum* L.) is a productive warm-season perennial native grass, commonly found in the southeastern United States, with ability to tolerate a wide range of climatic and edaphic conditions (Moore, White, Hintz, Patrick, & Brummer, 2004; Moser & Vogel, 1995; Parrish & Fike, 2005; Wullschleger, Davis, Borsuk, Gunderson, & Lynd, 2010). In North Carolina, utilization of switchgrass by grazing livestock can start as early as mid-April or early May, producing an average of 322 kg of beef gain ha^{-1} by 1 June and before ‘Coastal’ bermudagrass [*Cynodon dactylon* (L.) Pers] is ready to graze (Burns, Mochrie, & Timothy, 1984). Burns & Fisher (1980) reported daily weight gain values of 0.91 kg and weight gains up to 839 kg ha^{-1} yr^{-1} for steers (*Bos taurus*) grazing ‘Alamo’ switchgrass. In addition, switchgrass cultivars have potential to provide

Abbreviations: ADF, acid detergent fiber; CP, crude protein; DF, defoliation frequency; DH, defoliation height; IVTD, in vitro true digestibility; NDF, neutral detergent fiber; NIR, near infrared.

nutritious forage during the so called "summer slump" period for cool-season grasses in the US transition zone (Sanderson & Burns, 2010; Tracy, Maughan, Post, & Faulkner, 2010) and to complement and improve overall productivity of traditional tall fescue [*Lolium arundinaceum* (Schreb.) Darbysh.] and tall fescue–bermudagrass pasture-based livestock systems (Burns et al., 1984; United States Department of Agriculture [USDA], 2018).

Forage nutritive value determines the upper limit of potential animal responses when forage availability is not the limiting factor (Sollenberger & Vanzant, 2011). Switchgrass cultivars with greater digestibility have the potential to positively affect livestock production and increase animal responses such as weight gains (Anderson et al., 1988). However, the nutritive value of switchgrass declines rapidly as the plant matures (Burns, Pond, Fisher, & Luginbuhl, 1997; Griffin & Jung, 1983; Perry & Baltensperger, 1979). Cultivar 'Performer' of switchgrass was developed and released to provide greater digestibility and lower lignin concentrations compared to 'Alamo' and 'Cave-in-Rock' (Burns, Godshalk, & Timothy, 2008).

Information on the effects of defoliation management on forage mass and nutritive value are critical to define management strategies that ensure persistence of the forage and that positively affect animal responses. Ashworth, Keyser, Holcomb, and Harper (2013) reported that the effects of switchgrass defoliation management varies by cultivar. Clipping to ≤20-cm stubble height reduced stands of lowland switchgrass 'Alamo' and 'Kanlow' but not for the upland-type 'Cave-in-Rock' (Ashworth et al., 2013). Bekewe, Castillo, and Rivera (2018, 2019) reported that clipping to 10-cm stubble height resulted in lower dry matter yield and greater weed infestation of 'Performer' switchgrass when defoliation occurred every 3 wk, but not when compared to defoliating every 9 or 12 wk. The aforementioned results highlight the interaction effects frequency and intensity of defoliation on switchgrass responses. The effects of defoliation management on forage mass, tiller counts, leaf/stem ratio, canopy height, light interception, and weed infestation for 'Performer' switchgrass were previously reported by Bekewe et al. (2018, 2019); however, information on nutritive value as a function of a wide range of defoliation treatments is still limited. The objectives of this experiment were to: (i) determine the effects of defoliation frequency and defoliation height on in vitro true digestibility (IVTD), crude protein (CP), neutral detergent fiber (NDF), and acid detergent fiber (ADF) concentrations of 'Performer' switchgrass and (ii) identify defoliation management recommendations for utilization of 'Performer' switchgrass by establishing relationships between nutritive value estimates measured in this study and previously reported productivity and persistence measurements.

2 | MATERIALS AND METHODS

2.1 | Experimental site and plot management

The experiment was conducted for two consecutive years (2016 and 2017) at the Central Crop Research Station, Clayton, NC (35°40′ N, 78°29′ W). An area of 50- by 51-m plot of well-established (>8 yr) 'Performer' switchgrass was used for this experiment. A detailed description of plot management was provided by Bekewe et al. (2018); in summary for plot management in the years prior to this trial, the forage was allowed to accumulate (no clipping or grazing) during the summer, and it was followed by prescribed fire between January and March of every year. The soil type is classified as Wedowee sandy loam (fine, kaolinitic, thermic Typic Kanhapludults).

Initial soil characterization (0–15 cm deep) from samples taken on February 2016 indicated pH of 6.0 and Mehlich-3 extractable P and K concentrations (mg kg^{-1}) of 205 (very high) and 195 (high), respectively. Nutrient analysis on Mehlich-3 soil extracts were performed using inductively coupled plasma and soil pH was determined on a 1:1 soil/water volume ratio (Mehlich, 1984). Fertilization followed the recommendations for growing switchgrass of the North Carolina Department of Agriculture and Consumer Services (Hardy, Tucker, & Stokes, 2014), and fertilizer amendments were broadcasted in a single application on mid-April for both years. In 2016, N was applied at a rate of 141 kg N ha^{-1} using a granular formulation of urea-ammonium sulfate blend (340 g N kg^{-1}). In 2017, a granular formulation of ammonium sulfate (210 g N kg^{-1}) and ammonium nitrate (340 g N kg^{-1}) were applied at a rate of 176 kg N ha^{-1}. The last freeze event in spring occurred on 3 March 2016 and 23 March 2017, and the first freeze event occurred on 13 November 2016 and 4 November 2017 in fall, concluding the growing seasons. Monthly rainfall and average maximum and minimum temperatures are provided in Figure 1 (NC State University, 2019).

2.2 | Treatments, experimental design, and sample collection

The experimental variables for this study were defoliation frequency (DF) and defoliation height (DH). There were 16 treatments resulting from the factorial combination of four levels of DF (harvested every 3, 6, 9, and 12 wk) and four levels of DH (clipped to 10-, 20-, 30-, and 40-cm stubble height). The experimental design was a randomized complete block design replicated four times. Treatments were randomly allocated to each of the four complete blocks in 2016 and were imposed on the same corresponding

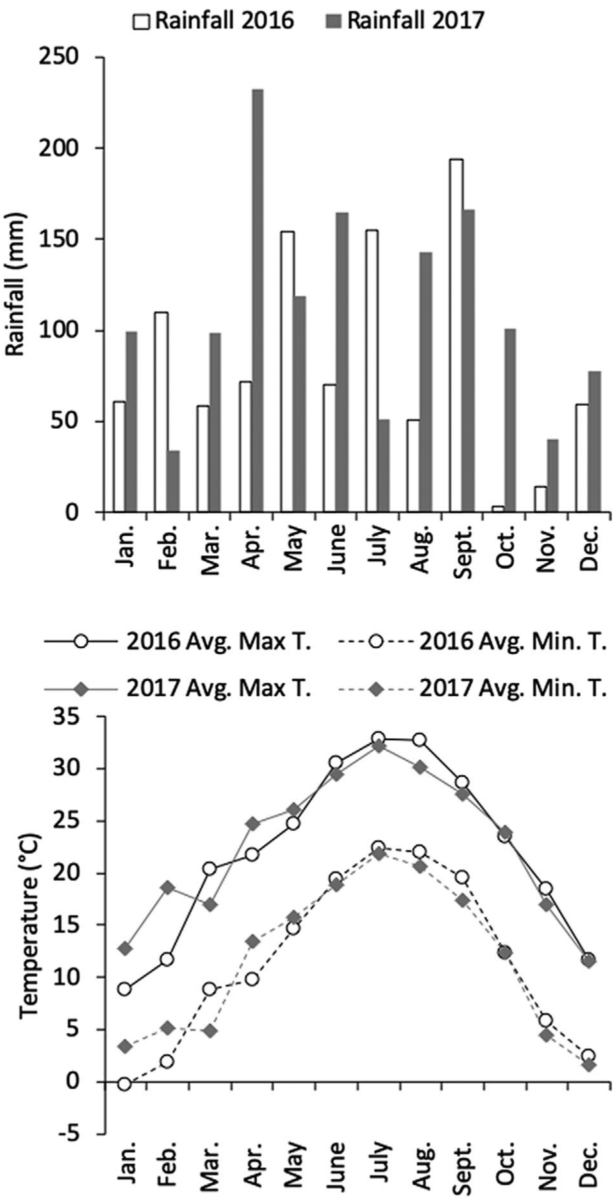

FIGURE 1 Cumulative monthly maximum and minimum rainfall and average temperatures (T) for years 2016 and 2017 at the Central Crops Research Station, Clayton, NC

experimental units in 2017. Experimental unit size was 25-m^2 (5-m wide by 5-m long) with 1-m wide alleys between experimental units.

Forage samples were collected from a centered 7.5 m^2 area (3-m long by 2.5-m wide) in each experimental unit that was harvested by hand using hedge trimmers. A subsample (between 0.5–1 kg) was collected from the clipped forage and was weighed fresh in the field, then dried in a forced-air oven at 60°C to constant weight to determine dry matter concentration, and ground in a Christy Norris laboratory mill (Christy Turner, Suffolk, UK) to pass through a 1-mm screen in preparation for laboratory analysis. The number of clipping events were 8, 4, 2, and 2 for defoliation frequency treatments every 3, 6, 9, and 12 wk, respectively. The first harvest events of the season occurred on 9 May 2016 and 18 May 2017. The last harvest events occurred on 19 October 2016 and 15 October 2017.

2.3 | Response variables and predictive modeling using near infrared spectra

Concentrations of IVTD, CP, NDF, and ADF were determined using near-infrared (NIR) spectroscopy by using equation-models developed for this experiment. Samples were scanned using a 5000 NIRS equipment (Foss North America, Eden Prairie, MN) and reflectance was determined in 2-nm wavelength-increments (from 1100–2500 nm). Wet chemistry analyses were performed at Dairy One Laboratory (Ithaca, NY) where CP was calculated by multiplying the concentration of total N (determined by dry combustion using a LECO628, St. Joseph, MI) by 6.25; IVTD was determined through a 48-h in vitro digestion procedure (Daisy II incubator), and NDF and ADF were determined using an Ankom fiber analyzer (Ankom, Macedon, NY; Dairy One, 2015).

We selected 120 samples, out of a total of 512 samples, for wet chemistry analysis. The selected samples were chosen using a stratified random sampling approach to ensure that at least one sample from each harvest-treatment combination was included and to represent the range of the sample population. The selected samples were used for model calibration, cross-validation, and prediction by adapting a data analysis pipeline created under the R environment that was originally developed for studying wood chemistry (Hodge, Acosta, Unda, Woodbridge, & Mansfield, 2018; R Core Team, 2016). In summary for the R-NIR pipeline, raw spectra were transformed to test a total of 14 mathematical pretreatments that included single and paired transformations. Mathematical pretreatments are applied to the raw spectra with the objective of removing the scattering of diffuse reflections associated with sample particle size and to improve the subsequent regression. Outliers were identified using local outlier factors (LOF) calculated for all observations in each of the 14 databases. Models were developed using partial least square regression (PLS). Performance of the models was evaluated using 'leave-one-out' (LOO) cross-validation. Information of fit statistics for the selected models is presented in Table 1. Desirable PLS-NIR models are those that (i) maximize the coefficient of determination (R^2_{CV}), (ii) minimize the standard error of cross-validation (SECV), and (iii) have a small number of latent variables (Hodge et al., 2018). These equations were then used to predict the nutritive value of the remaining samples.

TABLE 1 Fit statistics of calibration models for in vitro true digestibility (IVTD), crude protein (CP), neutral-detergent fiber (NDF), and acid-detergent fiber (ADF) for 'Performer' switchgrass developed with 120 samples

Constituent	Mathematical pretreatment (# factors)[a]	R^2_C	R^2_{CV}	SEC	SECV
				g kg^{-1}	
IVTD	DT (8)	.98	.98	17	21
CP	SG-7 (8)	.99	.97	4	7
NDF	SNV-SG7 (8)	.97	.87	7	14
ADF	SNV-SG7 (5)	.94	.93	10	12

[a]DT, Detrend; SG-7, Savitzky-Golay smoothed spectra using seven points; SNV, Standard normal variate.

2.4 | Statistical analysis

Treatments were considered significant if $P \leq .05$. Data were analyzed using PROC GLIMMIX of SAS (SAS Institute, 2010). Treatments were considered fixed effects; block and year were considered random effects in the model. When an interaction effect was declared, simple effects were analyzed using the SLICE procedure of SAS. Polynomial contrasts (linear, quadratic, and cubic) were used to determine the nature of the response to DH at each DF level. Polynomial contrasts were set up using the LSMESTIMATE procedure in SAS. Plots of model residuals were used to check for normality.

3 | RESULTS AND DISCUSSION

3.1 | In vitro true digestibility

The range of digestibility values was greater due DF (from 590–779 g kg^{-1} when averaged across DH treatments) than DH treatments (from 675–692 g kg^{-1} when averaged across DF treatments; Figure 2). Working with 'Performer' switchgrass, Bekewe et al. (2018, 2019) reported that frequently defoliated treatments, such as every 3 and 6 wk, resulted in greater leaf/stem ratio, lower dry matter yield, and lower canopy height at time of harvest than less frequent defoliated treatments such as every 9 and 12 wk. Based on the data reported by Bekewe et al. (2018, 2019) and the results of our study, there are strong correlations of IVTD with leaf/stem ratio (positive correlation), canopy height (negative correlation), and dry matter yield (negative correlation; Table 2). Lower digestibility for switchgrass harvested at greater maturity stages and with longer regrowth intervals has been previously reported for several cultivars of switchgrass (Burns, 2011; Burns et al., 1997; Griffin & Jung, 1983; Perry & Baltensperger, 1979; Richner, Kallenbach, & Roberts, 2014); however, to the best of our knowledge, this is the first time that the relationship between IVTD, canopy characteristics, and dry matter yield are reported for 'Performer' switchgrass.

There was an interaction effect of DF × DH treatments. The interaction effect occurred because defoliation height effect

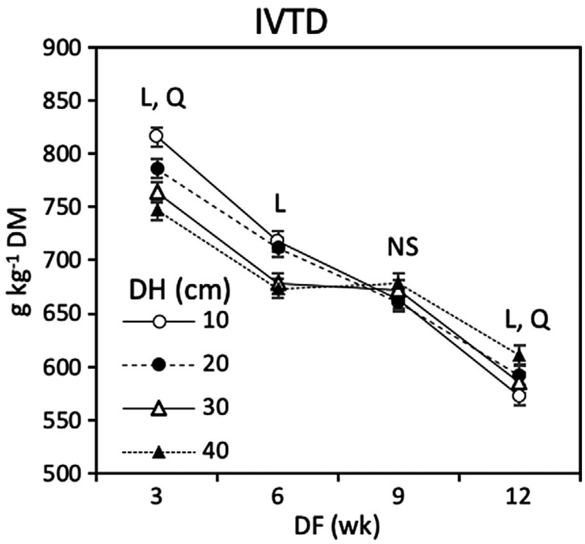

FIGURE 2 Digestibility (in vitro true digestibility, IVTD) as a function of defoliation frequency (DF) and defoliation height (DH). Data are means of 2 yr and four replicates (n = 8; standard error = 9.2). DM, dry matter; L, linear effect; Q, quadratic effect; NS, not significant for DH effects at each DF level

TABLE 2 Coefficients of linear correlation (r) between canopy height before harvest (CHBF), dry matter yield (DMY), leaf/stem ratio reported by Bekewe et al. (2018, 2019), in vitro true digestibility (IVTD), crude protein (CP), neutral-detergent fiber (NDF), and acid-detergent fiber (ADF) for 'Performer' switchgrass grown for 2 yr in North Carolina. Data used in this analysis were the average of 4 replicates and 2 yr (n = 16)

Item	IVTD	CP	NDF	ADF
	g kg^{-1}			
Range, [min–max]	[572–816]	[64–155]	[687–772]	[349–495]
CHBF, cm [35–97]	−.966***	−.678***	.420 NS[a]	.910***
DMY, Mg ha^{-1} [2.4–13.4]	−.898***	−.488*	.100 NS	.684**
Leaf/stem [0.7–1.5]	.846***	.498*	−.03 NS	−.725**

*Significant at the .05 probability level.
**Significant at the .01 probability level.
***Significant at the .001 probability level.
[a]NS, not significant.

was significant when switchgrass was harvested every 3, 6, and 12 wk, but not when harvested every 9 wk; in addition, the IVTD response pattern was reversed when defoliation occurred every 12 wk compared to 3 and 6 wk (Figure 2). Because of the DF × DH interaction effect on IVTD, the data were analyzed by DF treatments. As DH increased from 10- to 40-cm stubble height, IVTD decreased with linear and quadratic effects (from 815 to 747 g kg^{-1}) when harvested every 3 wk, and decreased with a linear effect (from 718 to 674 g kg^{-1}) when harvested every 6 wk (Figure 2). A similar response pattern, but with narrower response range in digestibility, was reported for 'Mott' elephantgrass (*Pennisetum purpureum* Schum.) by Chaparro and Sollenberger (1997). The aforementioned authors reported that leaf blade digestibility decreased with increasing clipping stubble height when cuttings were more frequent. In contrast, the effect of DH on IVTD was reversed when harvest occurred every 12 wk and IVTD increased with linear and quadratic effects (from 572 to 611 g kg^{-1}) as DH increased from 10- to 40-cm stubble height (Figure 2). Bekewe et al. (2018) reported that leaf/stem ratio was more than double when 'Performer' was defoliated every 3 wk (leaf/stem ratio of 1.5) compared to 12 wk (leaf/stem ratio of 0.6). Leaf/stem ratio is strongly and positively associated with total plant IVTD (Table 2). Working with 'Blackwell' switchgrass, Griffin and Jung (1983) reported that, as plants matured, digestibility of the stem component decreased by about 3.6 times compared to the leaf component. Therefore, clipping to greater stubble heights for 'Performer' switchgrass of 12 wk regrowth most likely resulted in a greater proportion of leaf component being harvested versus the stem component and consequently greater overall plant IVTD. There was no effect of DH treatments on IVTD when the harvest occurred every 9 wk (669 g kg^{-1}).

Defoliation regimes to ensure persistence and productivity of 'Perfomer' switchgrass should allow the plants to rest and recover until the canopy is at least 60-cm tall (or 70% light interception) before imposing a new defoliation event (Bekewe, Castillo, & Rivera, 2019). Intense defoliation regimes such as harvesting every 3 wk to 40-cm stubble height or every 6 wk to 20 cm stubble height are possible without compromising persistence of 'Performer' switchgrass (Bekewe et al., 2019), but such management will result in 50% or greater reduction of dry matter yield compared to harvesting every 9 and 12 wk (Bekewe et al., 2018). However, frequent defoliation of switchgrass will result in greater IVTD values as measured in our study.

3.2 | Crude protein

There was a DF × DH interaction effect for CP (Figure 3). The interaction effect occurred because DH effects on CP were significant when defoliation occurred every 3 and 12 wk, but there were no DH effects when defoliation occurred every 6 and 9 wk. In general, concentration of CP followed a more similar trend than IVTD; that is, CP was lower for the less frequent defoliated treatments which resulted in more mature plants at the time of harvest. Across treatments, CP concentration ranged from 73–144 g kg^{-1} (Figure 2). As DH increased from 10- to 40-cm stubble height, CP decreased linearly from 144 to 129 g kg^{-1} when defoliation occurred every 3 wk (Figure 3). There was an opposite response pattern when defoliation occurred every 12 wk where CP increased linearly from 73 to 84 g kg^{-1} as defoliation height increased from 10- to 40-cm stubble height (Figure 3). Concentration of CP was 114 and 90 g kg^{-1} when defoliation occurred every 6 and 9 wk, respectively.

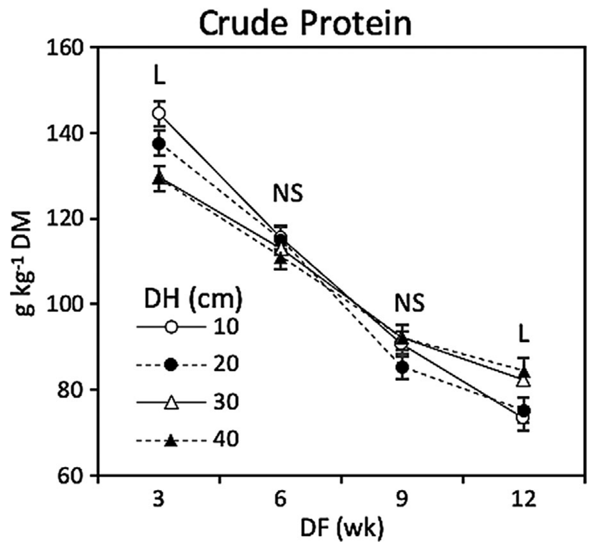

FIGURE 3 Crude protein as a function of defoliation frequency (DF) and defoliation height (DH). Data are means of 2 yr and four replicates (n = 8; standard error = 8.5). DM, dry matter; L, linear effect; Q, quadratic effect; NS, not significant for DH effects at each DF level

There are numerous reports in the literature that noted lower CP concentration values for switchgrass harvested at greater maturity stages (Griffin & Jung, 1983; Sanderson, Read, & Roderick, 1999; Twidwell, Johnson, Cherney, & Volenec, 1988). Working with 'Performer' switchgrass, Burns et al. (2008) reported average CP concentration of 72 g kg^{-1} for a three clipping per year schedule with harvests at the end of May, end of July, and early October. Working with 'Kanlow' switchgrass, Burns et al. (1997) reported that CP decreased from 106 to 37 g kg^{-1} as harvest was delayed from 9 June to 4 August. 'Performer' switchgrass harvested at the end of June in our experiment, which corresponds to treatment DF 9 wk, had CP concentration of 90 g kg^{-1}. Forage with CP concentration of 90 g kg^{-1} is suitable to meet the CP dietary needs of a nonpregnant nonlactating mature cow according to the National Research Council (1996). Dry matter yield and canopy height before harvest where negatively associated with CP values, while leaf/stem ratio was positively correlated, but all relationships had low linear correlation values (Table 2).

3.3 | Neutral detergent fiber and acid detergent fiber

The NDF and ADF concentrations followed a similar trend; and that is, greater concentrations occurred for the less frequently defoliated treatments (Figure 3). Multiple reports in the literature have described greater concentrations of NDF and ADF for switchgrass harvested at greater maturity stages and when harvest was delayed at the end of the growing season, such us after a freezing event (Burns et al., 1997, 2008; Griffin & Jung, 1983; Mitchell et al., 2001; Mulkey, Owens, & Lee, 2008; Sanderson et al., 1999; Twidwell et al., 1988). The range in concentration values for NDF (676–753 g kg^{-1}) and ADF (363–466 g kg^{-1}) in our study are within those values previously reported in the literature.

There was a DF × DH interaction effect for NDF concentration. The interaction effect occurred because there was a DH effect when defoliation occurred every 3 and 6 wk only, and not when defoliation occurred every 9 and 12 wk (Figure 4). Therefore, NDF data were analyzed by DF. As DH increased from 10- to 40-cm stubble height, NDF concentration increased with linear and quadratic effects from 676 to 717 g kg^{-1} when defoliation occurred every 3 wk and decreased with a linear effect from 740 to 718 g kg^{-1} when defoliation occurred 6 wk. Concentrations of NDF were 749 and 762 g kg^{-1} for treatments defoliated every 9 and 12 wk, respectively. There was a DF × DH interaction effect for ADF (Figure 4). The interaction effect occurred because there were DH effects when clipping occurred every 3 and 12 wk only, but not for 6 and 9 wk (Figure 4). As DH increased from 10- to 40-cm stubble height, the ADF concentration increased from 364 to 386 g kg^{-1} with a linear effect when defoliation occurred every 3 wk; contrary, ADF concentration decreased from 466 to 449 g kg^{-1} with linear and quadratic effects when defoliation occurred every 12 wk. The ADF concentrations were 408 and 427 g kg^{-1} when defoliation occurred every 6 and 9 wk, respectively. Griffin, Wangsness, and Jung (1980) and Van Soest (1965) suggested that when the levels of NDF exceed 500–600 g kg^{-1}, they may result in limited herbage intake. Burns and Fisher (2013) reported average daily gains of 0.91 kg d^{-1} for steers grazing 'Alamo' switchgrass with NDF and ADF concentrations of about 694 and 376 g kg^{-1}, respectively.

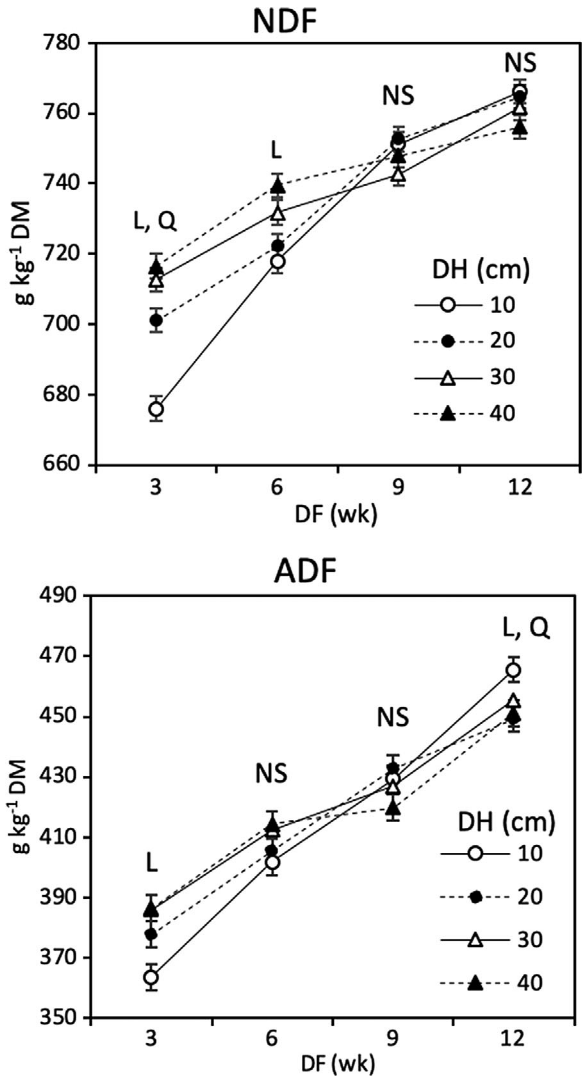

FIGURE 4 Neutral-detergent fiber (NDF) and acid-detergent fiber (ADF) as a function of defoliation frequency (DF) and defoliation height (DH). Data are means of 2 yr and four replicates (n = 8; standard error = 3.4 for NDF and standard error = 4.3 for ADF). DM, dry matter; L, linear effect; Q, quadratic effect; NS, not significant for DH effects at each DF level

4 | CONCLUSIONS AND IMPLICATIONS

During the 2-yr study, our results highlight the interaction effect of defoliation frequency and intensity on forage nutritive value of 'Performer' switchgrass. Based on the nutritive value data presented in this study, and productivity and persistence measurements previously, we conclude that intense defoliation regimes such as harvesting every 3 wk to ≥40-cm stubble height or every 6 wk to ≥20-cm stubble height are possible without compromising persistence of 'Performer' switchgrass, but such management will result in 50% or greater reduction of dry matter yield compared to harvesting every 9 and 12 wk. Frequent defoliation will also result in greater IVTD and CP values. Forage IVTD is reduced from 3 to 6 wk DF. As DH increased from 10- to 40-cm stubble height, IVTD decreased from 815 to 747 g kg^{-1} when harvested every 3 wk, and from 718 to 674 g kg^{-1} when harvested every 6 wk. Meanwhile, CP would fall in 3 wk. Concentration of IVTD was not affected by DH in 9 wk and CP, or in 6 and 9 wk of DF. Twelve weeks would result in a very low DF with lowest nutritive value but greatest dry matter yields. With the exception of NDF concentration, all the other response variables measured in this study correlated significantly with canopy height, dry matter yield, and leaf/stem ratio for 'Performer' switchgrass. Although there are tradeoffs when managing for productivity or nutritive value, there is a wide range of defoliation management options for 'Performer' switchgrass that provide flexibility in terms of harvesting schedules and to optimize productivity and persistence of nutritious forage.

CONFLICT OF INTEREST

The authors declare that there is no conflict of interest.

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