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Defoliation Management Affects Productivity, Leaf/Stem Ratio, and Tiller Counts of 'Performer' Switchgrass

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ABSTRACT

'Performer' switchgrass (*Panicum virgatum* L.) was released in 2006 by the USDA-NCSU forage program because of its greater digestibility compared to standard cultivars grown in the southeastern United States. Forages with greater digestibility have potential to positively impact animal responses, however, defoliation management can influence its productivity and persistence. The objectives were to determine the effect of the factorial combination of four defoliation heights (DH) (clipped to 10, 20, 30, and 40-cm) and four defoliation frequencies (DF) (clipped every 3, 6, 9, and 12 wk) on productivity, leaf/stem ratio, and tiller counts. The experiment was conducted in 2016 and 2017 at the Central Crops Research Station, Clayton, NC. The 16 treatments were allocated in a complete randomized block design replicated four times. In 2016, total dry matter (DM) yield ranged from 4.2 to 13.1 Mg ha^{-1} being greatest for the 9- and 12-wk DF at 10- and 20-cm DH and lowest for all DH at 3-wk defoliation frequency. In 2017, the DM yield range was wider ranging from 0.5 to 14.0 Mg ha^{-1} with lower tiller counts for the 10- and 20-cm DH, 3-wk DF treatments. Leaf/stem ratio was greater for the more frequently defoliated treatments in both years. 'Performer' switchgrass is a productive forage and on the basis of total DM harvested, leaf/stem ratio, and tiller counts, frequent defoliations such as every 3 wk to 40-cm stubble height, ≥6 wk to 20-cm stubble height, and ≥ 9 wk to 10 cm stubble height, are warranted to ensure stand persistence.

Core Ideas

- Defoliation management resulted in a wide range of plant responses that varied by year, with deleterious responses more evident in the second year.
- Greater leaf/stem ratios occurred with more frequent defoliation treatments.
- Frequent defoliations such as every 3 wk should maintain a stubble height of at least 40 cm, defoliation frequencies ≥6 wk to 20-cm stubble height, and ≥9 wk to 10 cm stubble height are warranted to ensure stand persistence.

Switchgrass is a C_4 perennial warm-season grass, native to the Great Plains and broadly adapted throughout the United States (Hitchcock and Chase, 1950), with potential to be used for wildlife habitat, erosion control, forage production, and as a bioenergy feedstock (Keshwani and Cheng, 2009; Moore et al., 2004, Sanderson and Wolf, 1995). For forage–livestock systems, switchgrass can particularly help to fill the gap in forage availability during the transition period from cool- to warm-season temperatures in the US transition region (Beaty and Powell, 1976; Parrish and Fike, 2005). In North Carolina specifically, switchgrass' spring growth is not as severely damaged by late winter cold or late spring frost and it can be utilized by mid-April or early-May producing an average of 322 kg of beef gain ha^{-1} by 1 June, before 'Coastal' bermudagrass [*Cynodon dactylon (*L.) Pers] is ready to graze (Burns et al., 1984).

Defoliation management determines presence and/or absence of the desired forage species affecting its productivity and persistence. Wide variation in switchgrass responses have been reported due to environment, management, and genotype (Fike et al., 2006; Lemus et al., 2002). In Mississippi, increasing defoliation frequency from one to six times per year for switchgrass cv. 'Alamo' clipped at 5-cm stubble height, consistently resulted in a linear decrease for annual DM yield, and at the end of 4 yr of defoliation the lowest DM yield were recorded when defoliation frequency occurred every 6 wk (Seepaul et al., 2014). A similar trend was reported by Sanderson et al. (1999) in Texas, where total seasonal yield of 'Alamo' switchgrass decreased by more than 50% when harvest frequency increased from one to four cuts per year with switchgrass defoliated at 15-cm stubble height. Beaty and Powell (1976) indicated that over-utilization of cv. 'Pangburn' switchgrass at the start of the growing season decreased the number of tillers and resulted in weed infestation. Using cv. 'Pathfinder' of switchgrass, Anderson et al. (1989) indicated that lengthy regrowth periods following severe defoliation, that allows apical meristems or leaf area, or both, to remain, are likely to enhance stand maintenance and plant vigor of switchgrass. However, the negative impact of frequent defoliation on productivity and persistence of switchgrass may be mitigated by higher stubble heights and may interact with cultivars. Clipping heights at 20-cm stubble or lower reduced grass stands for lowland switchgrass cultivars 'Alamo' and

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Abbreviations: DM, dry matter; DF, defoliation frequency; DH, defoliation height; NCDA&CS, North Carolina Department of Agriculture and Consumer Services.

'Kanlow' but not for the upland-type 'Cave-in-Rock' (Ashworth et al., 2014). To date, there is limited information on defoliation management effects for cv. 'Performer' switchgrass.

'Performer' switchgrass was selected because of its greater digestibility tested versus cultivars 'Alamo' and 'Cave-in-Rock' (Burns et al., 2008). Information on defoliation management effects on productivity and persistence of 'Performer' switchgrass is needed to ensure adequate utilization either under clipping or grazing. In addition, identifying a range of management opportunities to utilize 'Performer' switchgrass will provide flexibility to farmers that seek to put livestock to graze or that seek to clip the forage for hay or silage (Burns et al., 1993), or potentially use it as a feedstock for bioenergy. The objectives of this experiment were to determine the effects of combining defoliation frequency and defoliation height on 'Performer' switchgrass' DM yield, leaf/stem ratio, and tiller counts.

MATERIALS AND METHODS

Experimental Site, Plot Management, and Weather

The experiment was conducted in 2016 and 2017 at the Central Crop Research Station, Clayton, NC (35°40′ N; 78°29′ W) using a well-established (>8 yr) 'Performer' switchgrass sward. Plot management in the years prior to this trial consisted of annual fertilization for maintenance of switchgrass as recommended by the North Carolina Soil Testing Laboratory (NC Department of Agriculture and Consumer Services [NCDA&CS]; Hardy et al., 2014) and a single clipping to ~10-cm stubble height in late September followed by residue-burning in February. The accumulated biomass from the 2015 growing season was clipped and removed from the plots in late September 2015 and herbicide triclopyr {2-[(3, 5, 6-trichloro-2-pyridinyl)oxy] acetic acid, butoxyethyl ester; 2.13 kg a.i. ha^{-1}; Remedy Ultra} was applied on early April 2016. The soil type was classified as Wedowee sandy loam (fine, kaolinitic, thermic Typic Kanhapludults). Initial characterization of the surface soil (0 to 15 cm deep) from samples collected in February 2016 indicated soil pH of 6.0 and Mehlich-3 extractable P and K concentrations (mg kg^{-1}) of 205 (very high) and 195 (high), respectively. A new set of soil samples were also collected in February 2017. Soil samples were tested by routine procedures at the NCDA&CS (Hardy et al., 2014). 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 in both years followed the recommendations for growing switchgrass of the NCDA&CS. Fertilizer amendments were broadcasted-applied in a single application on mid-April in both years. In 2016, N was applied at a rate of 141 kg ha^{-1} using a granular formulation of urea–ammonium sulfate blend (340 g N kg^{-1}). In 2017, granular formulations of ammonium sulfate (210 g N kg^{-1}) and ammonium nitrate (340 g N kg^{-1}) were mixed to provide a final fertilization rate of 176 kg N ha^{-1}. Monthly rainfall during 2016, 2017, and the 30-yr average, and average monthly maximum and minimum temperatures are provided in (Fig. 1). The last freeze event in spring occurred on 3 Mar. 2016 and 23 Mar. 2017, and the first freeze event at the end of the growing season occurred on 13 Nov. 2016 and 4 Nov. 2017. The experiment was conducted under rain-fed conditions.

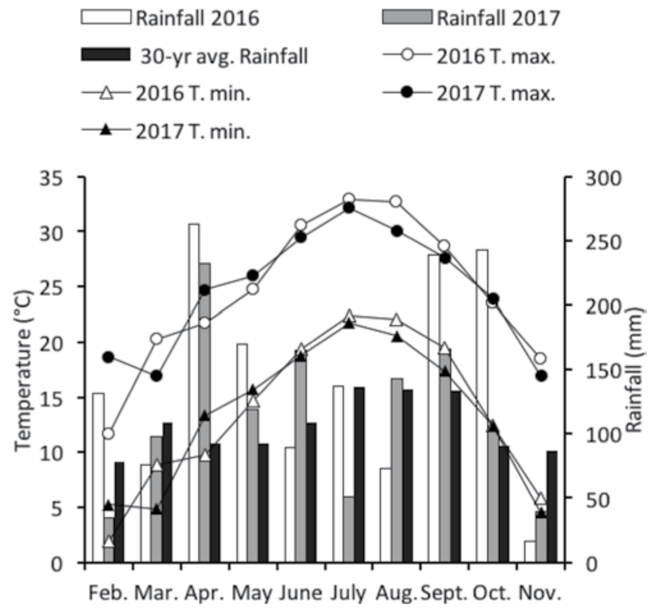

Fig. 1. Monthly rainfall (2016, 2017, and 30-yr average) and temperatures (average max. and min. for 2016 and 2017) at the Central Crops Research Station, Clayton, NC.

Treatments and Experimental Design

The experimental variables for this study were defoliation frequency (DF) and defoliation height (DH). There were 16 treatments total resulting from the factorial combination of four levels of defoliation frequency (clipped every 3, 6, 9, and 12 wk) and four levels of defoliation height (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 year 2016 and were imposed on the same corresponding experimental units in 2017. Experimental unit size was 5-m wide × 5-m long and contained four originally planted-rows, although rows were no longer evident due to basal tillering (short rhizomes), that covered the entirety of the plot. Alleys between experimental units were 1-m wide.

Response Variables

Total Dry Matter Yield

Total DM yield was measured by harvesting tillers within a centered 7.5-m^2 area (3-m long × 2.5-m wide) in each experimental unit that contained the two center rows of the original planting-pattern. Hedge trimmers were used to clip switchgrass tillers. The clipped forage (including all green and brown tissues attached to the stems) was collected and weighed fresh in the field; a subsample of the clipped forage (between 0.5 to 1 kg) was also weighed fresh in the field and dried in a forced-air oven at 60°C to constant weight to determine DM concentration and DM harvested. Total DM yield was calculated by summing the herbage mass across clipping events within a year. The numbers of clipping events were 8, 4, 2, and 2 for frequencies of defoliation every 3, 6, 9, and 12 wk, respectively. The first harvesting event of the season, for the 3-wk defoliation frequency, occurred when canopy height was ~40-cm tall in each year and it occurred on 9 May 2016 and 18 May 2017; consequently, day zero was fixed to 18 Apr. 2016 and 27 Apr. 2017. The last harvesting events occurred on 19 and 15 Oct. in 2016 and 2017, respectively.

Table 1. Coefficient estimates for the fitted regression model: Estimated response = $b_0 + b_1$DF + b_2DF^2 + b_3DH + b_4DH^2 + b_5 (DF*DH)† or a reduced form of the model for responses reported.

Model‡	Coefficient estimate b_0	b_1	b_2	b_3	b_4	b_5	R^2	Figure
DMY-16	–0.777	1.79	-3.96×10^{-2}	6.01×10^{-2}	–	-2.1×10^{-2}	0.80	2
		0.001§	0.043	0.116	–	0.001		
DMY-17	–5.45	2.32	-4.88×10^{-2}	0.163	–	-2.48×10^{-2}	0.82	2
		0.001	0.042	0.001	–	0.001		
LSR-16	1.85	–0.104	–	–	–	–	0.63	–
		0.001	–	–	–	–		
LSR-17	1.77	–0.14	4.81×10^{-3}	–	–	–	0.80	–
		0.001	0.006	–	–	–		
TC-16	64.7	28.6	–1.07	4.16	–	–0.592	0.40	3
		0.001	0.022	0.001	–	0.001		
TC-17	–284.2	124.5	–5.75	7.73	–	–0.864	0.90	3
		0.001	0.001	0.001	–	0.001		

† DF = defoliation frequency; DH = defoliation height.

‡ DMY = total dry matter harvested (Mg ha^{-1}); LSR = leaf/stem ratio; TC = tiller counts (tillers m^{-2}). Trailing digits indicate the year of evaluation; 16 (2016) and 17 (2017).

§ For each model, values in the second row indicate significance level P ($|t| > t_{\alpha}$) = α.

Leaf/Stem Ratio

Two tillers were randomly selected and clipped to the corresponding defoliation height treatment before each harvesting event. The harvested tillers were hand-separated fresh into green leaf (blade + sheath) and green stem components. The brown tissue was discarded. When seed heads or immature panicles were observed, they were added to the leaf component. The components were dried separately in a forced-air oven at 60°C until constant weight and weights were recorded. Leaf/stem ratio was calculated by dividing the aggregate dry weight of the leaf by the aggregate weight of the stem components across harvests within a year.

Tiller Counts

Tiller counts were performed every 2 wk after each harvest event. Two 0.25-m^2 quadrats were randomly located within each plot and the number of live tillers (i.e., green tillers and tillers with new visible regrowth tissue) were counted. The average of the two quadrats provided an estimate of tiller counts per experimental unit. Consequently, the number of tiller count events corresponded to each harvest frequency. Tiller counts were calculated by averaging the counted tillers across clipping events within a year and divided by 0.25 to express the number of tillers per m^2.

Statistical Analysis

Statistical analysis results were considered significant if $P \leq 0.05$. An initial analysis of variance was performed using PROC MIXED in SAS (SAS Institute, Cary, NC) with DF, DH, year, and their interaction effects as fixed effects. Year was treated as repeated measured with covariance structure modeled using autoregressive order one based on smaller AIC values. Block was considered random. Because of significant interaction effects of year with DF and year with DH, data are reported by year. Within year, response surface regressions were performed using RSREG of SAS. The complete model used was a second-order polynomial of the form:

$$y=\beta_0+\beta_1\mathrm{DF}+\beta_2\mathrm{DF}^2+\beta_3\mathrm{DH}+\beta_4\mathrm{DH}^2+\beta_5(\mathrm{DF}\times\mathrm{DH})+\varepsilon$$

Where y is the response variable, β_0 is the intercept, β_1 and β_2 are the linear and quadratic coefficients for DF, respectively, β_3 and β_4 are the linear and quadratic coefficients for DH, respectively, β_5 is the interaction coefficient for DF and DH, and ε is the experimental error term. Lack of fit of the second order polynomial was tested simultaneously. The GLM procedure of SAS was used to test the significance of coefficient estimates in reduced models (Freund and Littell, 2000). Terms that were not significant in the full model were retained in the reduced model only when there was a presence of higher-order terms (e.g., not significant linear effects of DF and DH were included in the reduced model when there was a significant DF × DH interaction; similarly, a nonsignificant linear effect was included in the reduced model when there was a significant quadratic effect). Table 1 shows the effects (coefficient estimates) in the reduced model. Contour plot figures were fitted using the ggplot2 package (Wickham, 2009) in R software (R Core Team, 2016).

RESULTS AND DISCUSSION

Dry Matter Yield

Total DM yield ranged from 4.2 to 13.1 Mg ha^{-1} in 2016 (Table 1; Fig. 2). There was a defoliation height × defoliation frequency interaction effect that occurred because DM yield increased to a greater extent with decreasing defoliation heights for 9- and 12-wk defoliation frequency treatments compared to every 3- and 6-wk defoliation frequency treatments (Fig. 2). Greatest total DM harvested was obtained by clipping every 12 wk to 10-cm stubble height, followed by every 9-wk to 10-cm and every 12-wk to 20-cm stubble heights which were not different, and it was lowest for all stubble heights at 3-wk defoliation frequency.

In 2017, total DM yield range was wider compared to 2016, and it ranged from 0.5 to 14.0 Mg ha^{-1} (Table 1). The defoliation height by defoliation frequency interaction effect in 2017 was less pronounced for 9- and 12-wk defoliation frequencies, and more pronounced for 3-wk, compared to 2016 (Table 1; Fig. 2). Similar to 2016, greatest total DM yield values were obtained with treatments defoliated every 12-wk to 10-cm stubble height and

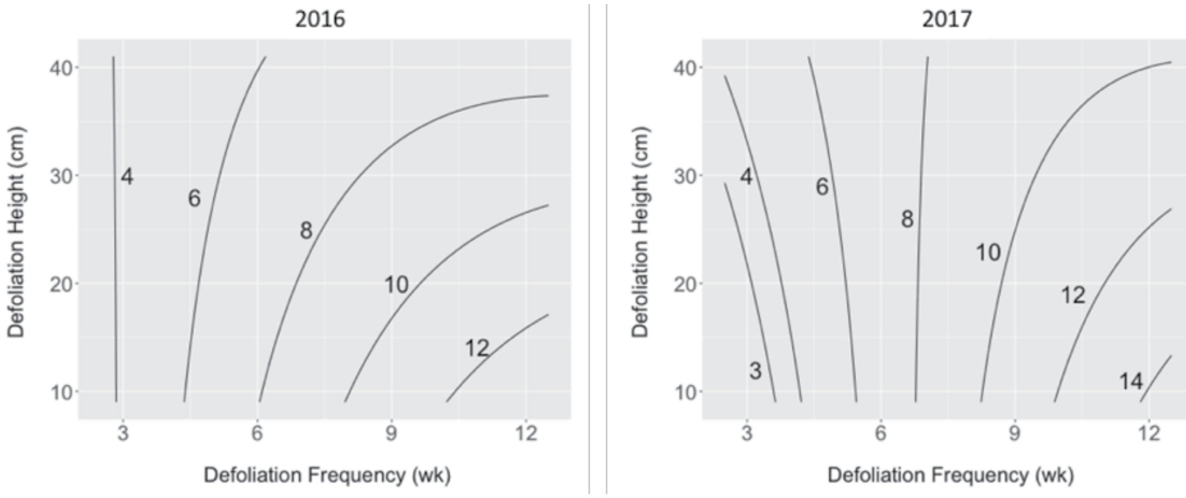

Fig. 2. Total dry matter yield (Mg ha^{-1}) in 2016 and 2017 of 'Performer' switchgrass as a function of defoliation frequency and defoliation height. Surface contours were generated using models in Table 1 (model DMH-16 for 2016 and model DMH-17 for 2017).

followed by 20-cm stubble height. In contrast to 2016, defoliation heights of 10- and 20-cm stubble height defoliated every 3 wk in 2017 resulted in the lowest DM yield values observed across the experiment, decreasing from approximately 4.2 Mg ha^{-1} in 2016 to less than 2.8 Mg ha^{-1} in 2017 (Table 1). Clipping every 3 wk to 10- and 20-cm stubble heights was a deleterious defoliation regime that resulted in discontinuation of treatments by mid-season of the second year (2017) due to loss of switchgrass plants and weed infestation by crabgrass (*Digitaria* sp.).

Productivity and persistence of 'Performer' switchgrass was affected not only by treatments, but also as a function of the duration (time) to which treatments were imposed, highlighting the basis for measuring treatment effects and plant responses over extended periods longer than a single growing season. Before treatments were imposed in 2016, the plots were defoliated once a year with maintenance fertilization for over an 8-yr period; consequently, it is likely that greater DM yield in 2016 for treatments 10- and 20-cm stubble height, 3-wk defoliation frequency occurred at the expense of previously stored organic reserves, e.g., total non-structural carbohydrates in the root and rhizome structures, as a function of the less intensive defoliation management regime prior to this experiment. However, in the second year of defoliation, potentially lower storage reserves carried-over from 2016 needed to sustain active regrowth (Anderson et al., 1989), in combination with lack of basal foliage (Beaty and Powell, 1976; Neiland and Curtis, 1956) for light interception and photosynthesis, resulted in greater weed infestation, limited regrowth of 'Performer' switchgrass, and ultimately, the discontinuation of the frequently-clipped and lower stubble height treatments in 2017. Treatments 10- and 20-cm stubble height, 3-wk defoliation frequency were clipped eight times in 2016 and only four times in 2017.

Total DM yield values for the 9- and 12-wk defoliation frequency in combination with 10- and 20-cm stubble heights in our study are similar to previous DM yield reports for 'Performer' switchgrass in North Carolina (Burns et al., 2008). Lower total herbage mass due to multiple cuttings within a season has been also reported for other cultivars of switchgrass such as 'Alamo' (Sanderson et al., 1999; Seepaul et al., 2014) with the magnitude of the reduction dependent on the number of clippings. Based on the change of total DM yield values observed in 2016 and in 2017, intense defoliation regimes as every 3-wk to 40-cm stubble height and every 6 wk to 20-cm stubble height maintain similar yields with no negative effects on productivity and persistence. Burns et al. (2008) reported that the digestibility of 'Performer' was at least four percent points greater than cultivars 'Alamo' and 'Cave in Rock' when defoliated up to three times per year, although DM yield was slightly lower for 'Performer'. Therefore, in spite of potential lower DM yield of 'Performer', and even lower yield with multiple cuttings such as in treatments defoliated every 3 and 6 wk, the greater digestibility of 'Performer' compared to 'Alamo' and 'Cave in Rock' in a multiple-cutting system has potential to allow the farmer greater flexibility for deciding whether to use the harvested herbage as forage to feed livestock or as a bioenergy feedstock.

Leaf/Stem Ratio

The leaf/stem ratio ranged from 0.6 to 1.5 in 2016 and it was impacted by defoliation frequency only (Table 1). The leaf/stem ratio decreased linearly from 1.5 for the 3-wk defoliation frequency treatment to 0.6 for the 12-wk defoliation frequency treatment. In 2017, there was a similar pattern with linear and quadratic effects of defoliation frequency ranging from 0.8 to 1.4 (Table 1). In general, greater leaf/stem ratio occurred for plants with shorter regrowth period (e.g., defoliated every 3 wk) or more frequent defoliation regimes. Switchgrass forage samples with greater leaf/stem ratios have been associated with greater overall digestibility due to greater digestibility of the leaf component (Burns et al., 2011).

Similar leaf/stem ratio pattern for 'Blackwell' switchgrass was reported by Griffin and Jung (1983) in Pennsylvania who reported that leaves accounted for 71% of plant dry weight by June (vegetative state) and 38% by August (reproductive state). In Iowa, Lemus et al. (2002) reported leaf/stem ratios ranging from 0.39 to 0.79 for 20 populations of switchgrass including 'Alamo' and 'Kanlow' cultivars from a single clipping to 7.5-cm stubble height by the end of growing season. The leaf component has greater nutritive value (i.e., higher crude protein and digestibility, combined with lower lignin and neutral detergent fiber concentrations) than stems in switchgrass. Burns and Fisher (2013)

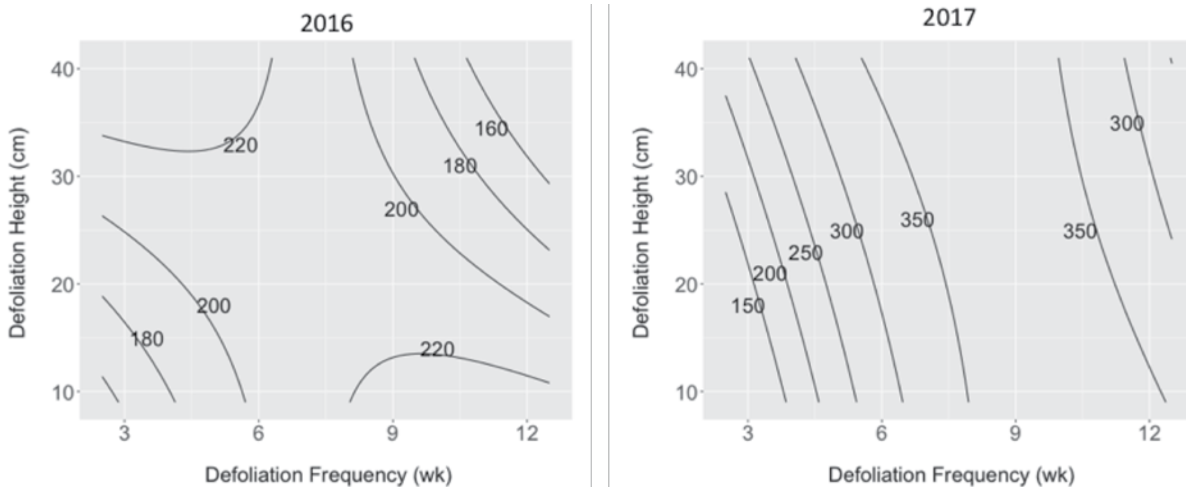

Fig. 3. Tiller counts (tillers m^{-2}) as a function of defoliation frequency and defoliation height in 2016 and 2017. Surface contours were generated using models in Table 1 (model TC-16 for 2016 and model TC-17 for 2017).

reported values of 792 and 643 g kg^{-1} for digestibility, 151 and 80 g kg^{-1} for crude protein, and 643 and 720 g kg^{-1} for neutral detergent fiber, for the leaf and stem components, respectively, for 'Alamo' switchgrass. A similar trend was also reported by Griffin and Jung (1983). Consequently, if the switchgrass canopy is to be managed for grazing, leaf yield would be more important than total forage yield (Redfearn et al., 1997). Designing a defoliation management plan for 'Performer' switchgrass that encourages greater proportion of leaves while not compromising stand persistence, e.g., with frequency of defoliation every 3 wk to 40-cm stubble height or every 6 wk to 20-cm stubble height, may result in acceptable total herbage mass with a more favorable nutritional profile to support livestock production.

Tiller Counts

In 2016, number of tillers per m^2 ranged from 136 to 236. There was a defoliation frequency by defoliation height interaction (Table 1; Fig. 3). As defoliation height increased from 10- to 40-cm stubble height, the number of tillers increased for both 3-wk and 6-wk defoliation frequencies; however, this trend was reversed for 9- and 12-wk defoliation frequency treatments, where tiller numbers decreased as defoliation height increased from 10- to 40-cm stubble height (Fig. 3). Lowest tiller numbers (less than 180 tillers m^{-2}) occurred in 2016 for extreme defoliation treatments, that is, the 10-cm stubble height 3-wk defoliation frequency treatment and for the 30- and 40-cm stubble heights and 12-wk defoliation frequency treatment. Lower tiller counts in the former treatment are most likely a function of the combined effect of slower plant regrowth from basal shoots, limited basal foliage remaining after defoliation to provide photosynthate, and removal of stem apices (Anderson et al., 1989; Neiland and Curtis, 1956); and for the latter treatment, lower tiller counts are a function of suppressed tillering at the onset of reproductive growth, as has been noted also in smooth brome (*Bromus inermis* Leyss.) (Eastin et al., 1964) and timothy (*Phleum pretense* L.) (Langer, 1956).

In 2017, the range in tiller numbers was wider compared to 2016, ranging from 88 to 370. There was a defoliation frequency by defoliation height interaction that occurred because the number of tillers increased more rapidly with increasing defoliation height from 10- to 40-cm stubble height at 3-wk defoliation frequency treatments compared to 9- and 12-wk defoliation frequency (Table 1; Fig. 3). Beaty and Powell (1976) reported lower tiller numbers at lower defoliation heights and suggested that infrequent defoliation increases number of tillers and herbage mass production. A similar trend, was reported for 'Kanlow' switchgrass (Burns et al., 2011). We found similar results compared to those reported by the previously cited authors for the 9- and 12-wk defoliation frequency 10- and 20-cm defoliation height treatments only. Sanderson et al. (1999) reported no difference in tiller density among four harvest frequencies (1 to 4 clipping per year) with 15-cm stubble height for 'Alamo' switchgrass. Increased tiller density in response to defoliation may be a positive indicator of plant vigor where physiological and morphological plant responses interact to restore carbohydrate shortage resulting from plant defoliation (Chapman and Lemaire, 1993). Frequent defoliation every 3-wk to 10- and 20-cm stubble height resulted in lower number of tillers and resulted in loss of stands by mid-season of 2017.

CONCLUSIONS

Defoliation management treatments imposed to 'Performer' switchgrass resulted in a wide range of plant responses that varied by year, with deleterious responses more evident in the second year. Long-term productivity of 'Performer' switchgrass stands will be favored by less frequent clipping events (9 and 12 wk) and lower defoliation heights (10- and 20-cm stubble heights). More frequent defoliation result in greater leaf/stem ratio and lower DM yields, but stubble height is more critical to ensure stand persistence and prevent weed infestation. Based on the change of total DM yield values observed between 2016 and 2017, defoliation as frequent as every 3 wk to 40-cm stubble height and every 6 wk to 20-cm stubble height maintained similar yields with no negative effects on productivity and persistence. Therefore, 'Performer' switchgrass is a productive forage and on the basis of total DM harvested, leaf/stem ratio, and tiller counts, frequent defoliations such as every 3 wk to 40-cm stubble height, ≥6 wk to 20-cm stubble height, and ≥9 wk to 10-cm stubble height, are warranted to ensure stand persistence.

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