ABSTRACT

BEKEWE, PEREJITEI E. Defoliation Management Effects on Productivity, Persistence, and Nutritive Value of ‘Performer’ Switchgrass. (Under the direction of Dr. Miguel S. Castillo).

‘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 USA. Forages with greater digestibility have potential to positively impact animal responses. Information on defoliation management strategies for ‘Performer’ is needed to develop recommendations that ensure persistence, productivity, and nutritious forage. Studies were conducted with the objectives of determining the effect of the factorial combination (4 x 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) on productivity, canopy characteristics, persistence and nutritive value of ‘Performer’ switchgrass. Productivity was estimated as total herbage mass production. Canopy characteristics were determined by leaf:stem ratio, tiller counts, canopy height, and light interception. Persistence was determined by estimating frequency and cover of weed infestation. Nutritive value measurements included crude protein (CP), digestibility (IVTD), neutral detergent fiber (NDF), and acid detergent fiber (ADF).The experiment was conducted at the Central Crops Research Station, Clayton, NC. Treatments were allocated in a complete randomized block design replicated four times. Total herbage mass produced ranged from 3.8 to 12.1 Mg ha^{-1} and it was greater in treatments with infrequent defoliation at lower stubble heights. The leaf:stem ratio ranged from 0.4 to 2.7, and in contrast to herbage mass response, leaf:stem ratio was greater for frequent defoliations at higher stubble heights. Canopy height was lowest for 3-wk DF at 10-cm DH (~36 cm) while greatest for 9-wk treatments (~91 cm). Light Interception (< 50%) and tiller counts (< 150 m^{-2}) were lowest for 3-wk DF with 10-cm

DH. Weed infestation was mainly due to crabgrass and it was greater (~70% cover and ~90% frequency) when defoliation occurred every 3 wk at 10-cm SH and remained below 15% for all other treatments. The IVTD ranged from 723 to 755 g kg^{-1} due to DH, being lowest and greatest for 10- and 40-cm SH, respectively; however, the IVTD range was greater due to DF, being lowest for 12-wk DF at 584 g kg^{-1} and greatest for 3-wk DF at 882 g kg^{-1}. Concentration of CP ranged from 83 to 99 g kg^{-1} for 9- and 12-wk DF and from 120 to 161 g kg^{-1} for 3- and 6-wk DF. The NDF ranged from 676 to 776 g kg^{-1} and ADF ranged from 342 to 426 g kg^{-1}. Based on one year data, and on the basis of total herbage mass, light interception, canopy height, tiller counts, and weed infestation, frequent defoliations such as every 3 wk should maintain a stubble height of at least 20 cm and for defoliation frequencies $\geq$ 6 wk stubble height as low as 10 cm are warranted to ensure stand persistence and prevent weed infestation. On the basis of IVTD, CP, NDF and ADF, greater nutritive value estimates (at least 795 and 120 g kg^{-1} for IVTD and CP, respectively, and max. 737 and 387 g kg^{-1} for NDF and ADF, respectively) were consistently achieved when DF $\leq$ 6 wk.

Defoliation Management Effects on Productivity, Persistence, and Nutritive Value of
'Performer' Switchgrass.

by
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A thesis submitted to the Graduate Faculty of
North Carolina State University
in partial fulfillment of the
requirements for the degree of
Master of Science

Crop Science

Raleigh, North Carolina

2017

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DEDICATION

To my family.

BIOGRAPHY

Perejitei Ebikirifagha, Bekewe was born and raised in Arogbo, Ondo State, Nigeria. Upon high school graduation in 2004, he attended EARTH University in Costa Rica, Central America. He graduated from EARTH University in 2015 with a Bachelor's Degree in Agricultural Science with emphasis in Agronomy. In January 2016, he moved to Raleigh, NC and began his graduate studies in the Crop Science Department at North Carolina State University under the advisement of Dr. Miguel S. Castillo. Perejitei plans to continue with graduate studies upon completion of his Master's degree at North Carolina State University.

ACKNOWLEDGMENTS

I would like to express my sincere gratitude and appreciation to Drs. Miguel Castillo, Matthew Poore, and Alan Franzluebbers for their support and mentorship. I would like to thank Raul Rivera, Juan Jose Romero, Diego Jose Contreras, Izamar Gonzales, and Stephanie Sosinski for their constant assistance with field and laboratory activities. Finally, I would like to thank the Natural Resources Conservation Service (NRCS) for providing financial support for this study.

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CHAPTER 1. LITERATURE REVIEW

Overview of the Research Problem

Continual soil coverage of desirable vegetation is one of the main factors that contributes to healthy pasture-based livestock systems and to soil health objectives. Native warm-season grasses, like switchgrass (*Panicum virgatum* L.), are widely adapted to our region and are resilient alternative forages. Switchgrass is a high-yielding grass species with potential to grow in marginal soils and for use as a bioenergy crop and forage for livestock. Defoliation management effects on persistence, productivity, and nutritive value of switchgrass are variable, and specifically for 'Performer' switchgrass have not been documented.

Clipping to 10 and 20 cm stubble height negatively affected dry matter (DM) yields of well-established (> 5 yr) switchgrass cultivars 'Alamo', 'Kanlow', and 'Cave-In-Rock' compared to 30 and 40-cm in the first 2 years of defoliation of a two-cutting per year system in Tennessee; nevertheless, in year 3 and 4, DM yields were actually greater when clipped at 10 and 20 cm (Ashworth et al., 2014). In addition, visual stand ratings after 4 years of defoliation indicated that there were cultivar differences in terms of persistence of the switchgrass (Ashworth et al., 2014). In Mississippi, yields of 'Alamo' decreased linearly when defoliation frequency increased from 1 to 6 times annually in plots that were defoliated at 5-cm stubble height (Seepaul et al., 2014). Identifying the range of management opportunities to utilize 'Performer' switchgrass while not compromising persistence will provide flexibility to farmers that may seek to put livestock to graze or to clip the forage for hay, silage, or bioenergy.

'Performer' switchgrass was released as a cultivar with potential for livestock grazing because of greater digestibility compared to 'Alamo' and 'Cave-In-Rock' (Burns et al., 2008). Switchgrasses with greater digestibility have the potential to increase animal performance and productivity (Anderson et al. 1988). Forage nutritive value and specifically digestibility, determine the upper limit of potential animal responses (i.e. average daily gain, milk production, and body condition) when forage quantity is not the limiting factor (Sollenberger and Vanzant, 2011). Therefore, forage nutritive value and persistence can be optimized by understanding the tradeoffs between forage quantity and nutritive value as a function of defoliation management. Data are needed for 'Performer' switchgrass to make recommendations that will not compromise long-term stand-survival and will result in increased animal responses. This project aims to evaluate plant responses to clipping as an initial step prior to grazing trials and animal responses.

Origin

Switchgrass is a perennial, C_4 photosynthetic pathway, warm-season grass native to North America. It is used for wildlife habitat, erosion control, or forage production (Sanderson and Wolf, 1995). Switchgrass has always been a part of the North American prairie community and thus served as forage for native herbivores and subsequently for cattle grazing on rangeland (Wolf and Fiske, 1995). It is a polymorphic species with two distinct ecotypes, lowland and upland (Porter, 1966; Brunken and Estes, 1975). Upland ecotypes are hexaploid and octoploid, whereas lowland ecotypes are commonly tetraploid (Stroupt et al., 2003). The ecotypes are cross-fertile when plants with the same ploidy level are intermated (Martinez et al. 2001). Ecotypes and cytotypes of switchgrass of switchgrass are classified as single species.

Distribution and Adaptation

Switchgrass is broadly adapted throughout the United States and is found in every state east of the Rocky Mountains (Hitchcock and Chase, 1950). Like many perennial C_4 grasses, switchgrass is highly tolerant to abiotic stresses such as drought, temperature extremes, and salinity. For that reason, it is being recommended for biomass production on marginally productive cropland where it would have minimal land use competition with commercial food crops (Simmons et al., 2008).

Lowland types are found on flood plains and other areas subject to inundation while upland types occur in upland areas that are not subject to flooding. Lowland types are taller, more coarse, generally more rust (*Puccinia spp*.) resistant, have a more bunch-type growth and may be more rapid growing than upland types. Common upland cultivars are “Shawnee” and ‘Summer”, whereas common lowland cultivars are “Alamo” and “Kanlow”. The ecotypes (upland and lowland) were initially distinguished by phenotypes but now can be separated by cytotypes and gene cluster, using numerous generic markers (Cortese et al., 2010; Casler, 2012; and Vogel, 2004). Both ecotypes are largely self-incompatible and plants are cross pollinated by wind (Vogel, 2004).

Switchgrasses are photoperiod sensitive and flowering is induced by short days (Benedict, 1941). The photoperiod response is also associated with winter survival. As a general rule, switchgrass germplasm should not be moved more than one USDA Plant

Hardiness Zone (Cathey, 1990) north of its area of origin because of the possibility of stand losses from winter injury. Switchgrass has become increasingly important as forage in the central and eastern United States because they are productive during the hot summer months when cool-season grasses are relatively unproductive (Moser and Vogel, 1995).

Taxonomy and Morphology

Switchgrass is a highly polymorphic species with considerable morphological and physiological variation. Much of this variation can be explained by ecotype, the main taxonomic subdivision named largely for phenotypic differentiation based on habitat (Casler, 2012). Switchgrass plant height ranges from 0.5- to 3-m tall. Most genotypes are said to be caespitose in appearance with short rhizomes. The inflorescence is a diffuse panicle 15- to 55-cm long with spikelets 3- to 5-mm long toward the end of long branches (Hitchcock, 1951; Gould, 1975). Leaves have rounded sheaths and firm flat blades that can vary from 10- to 60-cm in length. The genotype and environment in which switchgrass grows also determine the number of leaves (Redfearn et al., 1997). The ligule is a fringed membrane 1.5- to 3.5-mm long and consists mostly of hairs. Switchgrass modes of reproduction are by seeds, tillers, and rhizomes. Switchgrass has the Panicoid type of seedling root (Newman and Moser, 1988; Tischler and Voigt, 1993).

Breeding and Selection

‘Performer’ switchgrass (*Panicum virgatum* L.) was cooperatively developed as a cultivar by the USDA-Agricultural Research Service and the North Carolina Agricultural Research Service, North Carolina State University, Raleigh, NC and released on 1 Nov.,

2006. Incorporation and preservation of the unique switchgrass germplasm adapted to the southern U.S. is important in the development of a new cultivar with improved nutritive value and, hence, forage quality (i.e., intake and digestion) (Burns et al., 2008).

Performer switchgrass was developed from three cycles of selection occurring under natural environmental conditions. The original source population (cycle 0) consisted of a selected group of 161 lowland switchgrass plants, representing 11 different germplasm sources. Cycle 1 was represented by the 660 half-sib progeny derived from 33 selected cycle 0 plants. The progeny were evaluated for dry matter yield, *in vitro* dry matter digestibility (IVDMD) and N concentration (Talbert et al., 1983; Godshalk et al., 1986). Cycle 2 consisted of open-pollinated progeny from six synthetics derived from cycle 1. The six synthetics of the 33 plants selected from cycle1, family size of the progeny ranged from 20 to 100 members per half-sib family. The 33 cycle 2 families (progeny) were evaluated in a randomized complete block design with four replicates at the Central Crop Research Station at Clayton, NC during 1985 and 1986 (Godshalk et al., 1988a, 1988b). The plants were ranked for IVDMD over initial growth and regrowth, and the top eight plants were selected to constitute cycle 3. The eight selected plants were transplanted into an isolated cross block, with 16 replicates per plant. They were allowed to open-pollinate and the seed was harvested and bulked evenly by weight to constitute Breeder seed of the cultivar Performer (Burns et al., 2008).

Performer switchgrass was selected for its improved IVDMD, with consideration to digestible nutrients per hectare when grown in replicated experiments, which included the commercial cultivars ‘Alamo’ and ‘Cave-in-Rock’. These cultivars represented a widely used lowland type and an upland type, respectively (Burns et al., 2008). Performer is an eight-clone synthetic that provides significantly improved digestibility versus that of Cave-in Rock and Alamo. The area of adaptation is primarily the southern U.S. (Burns et al., 2008).

Potential of Switchgrass as a Forage

Despite its recent popularity as biofuel feedstock, switchgrass traditionally has been used for forage (Keshwani and Cheng, 2009). In the last 50 years, switchgrass has been adopted as a cultivated forage crop to fill summer production gaps left by cool-season forages in the central plains and eastern United States (Parrish and Fike, 2005). Producers in the temperate humid region of the United States often use warm-season grasses, such as switchgrass, to provide forage for livestock during the summer when cool-season grasses are dormant (Moore et al., 2004). In terms of animal responses, beef cattle weight gains reported from switchgrass grazing trials range from 0.5 to 1.1 kg animal^{-1} d^{-1} (Vogel, 2004). Burns and Fisher (2013) reported individual animal daily gains of 0.91 kg and total pasture productivity ~830 kg ha^{-1} of weight gains with a stocking rate of 6.7 steers ha^{-1} from April to September in North Carolina.

Switchgrass nutritive value declines rapidly as the plant matures and should be hayed or grazed before the R0 (boot) stage (Moore et al., 1991; Burns et al., 1997). Switchgrass reaches the R0 stage in early summer when most cool-season grasses are still producing sufficient forage. This early maturation makes switchgrass undesirable for producers who need forage later in the season when growth of cold-season grasses declines (Hudson et al., 2010). However, early-June defoliation of switchgrass prolongs the number of days it is in a vegetative stage, which could improve forage nutritive value in July and August (George and

Obermann, 1989). Switchgrass can provide valuable forage for livestock during the summer and complement cool-season forages (Vogel, 2004).

Effects of Management on Plant and Animal Responses

Maughan (2011) reported a meta-analysis of 106 sites from 45 studies covering the two third of the United States and southeastern Canada. Switchgrass biomass yield across all regions of the study, including both lowland and upland ecotypes, average 6.6 ± 3.0 Mg ha^{-1} during the establishment year, increased to 9.1 ± 5.5 Mg ha^{-1} in the second year, and reached a maximum of 10.9 ± 5.2 Mg ha^{-1} in the third year. During the post-establishment years, biomass yield for lowland and upland ecotypes was 11.1 ± 6.1 and 6.7 ± 3.2 Mg ha^{-1}, respectively.

Establishment

Recommended seeding rates are 200 to 400 pure live seeds (PLS) m^{-2} (Vogel, 1987); there are approximately 390,000 seed per pound. Establishment-year stands with 20 or more plants m^{-2} will produce harvestable forage the year of establishment if weeds are controlled and can be in full production the year after establishment (Vogel, 1987; Vogel and Masters, 2001). Establishment-year stands of 10 plants m^{-2} are adequate but will require one or more year to achieve full production yields. Stands of less than 10 plants m^{-2} may need to be over seeded or reseeded. Minimum germination temperature for switchgrass is 10°C (Hsu et al., 1985a). Temperature gradient table studies with several switchgrass cultivars and seedlots demonstrated that near maximum germination was obtained from 19 to 36°C and optimal germination was between 27 and 30°C (Dierberger, 1991). Optimum germination temperatures for switchgrass may be lower than those for seedling development (Panciera and Jung, 1984). Seedling growth of switchgrass at 20°C is much slower than at 25 or 30°C (Hsu et al., 1985b). Although seedlings develop slowly, planting in early spring may be advantageous even though the soil is cold if the seed lot being used has dormant seed. The cold soil may aid in breaking dormancy. Best stands in Iowa were obtained when planted at early to mid-spring (Vassey et al., 1985). In northeastern USA, a planting window of 3 wk before and 3 wk after the recommended maize planting date has been suggested (Panciera and Jung, 1984).

Seedling development has three phases: germination, emergence, and adventitious root development (Newman and Moser, 1988). Seed germination is initiated by the radicle protrusion and the coleoptile emergence from the seed coat. Once the coleoptile emerges, it is pushed to the soil surface by elongation of the sub coleoptile internode, typical of the panicoid seedling development (Newman and Moser, 1988). When the coleoptile reaches the soil surface, the sub coleoptile internode elongation stops, adventitious roots form, and water uptake and photosynthesis begin for plant growth. This is why proper seedling depth is critical for successful switchgrass establishment.

Planting seed too deeply often leads to seeding failures with switchgrass and other small seeded warm-season grasses (Masters et al., 2004, Vogel, 2004). Switchgrass seed should be planted about 1 to 2 cm deep so the seedbed needs to be firm to prevent a drill from placing the seed too deeply. Seeds planted deeper than 1 cm or 2 cm can result in poor establishment because seedling energy reserves are used for sub coleoptile elongation and adventitious root development is delayed (Newman and Moser, 1988). No-till seeding into crop residues or chemically killed sods is often very effective (Samson and Moser, 1982). Corrective applications of phosphorus (P) or potassium (K) should be made before seeding but nitrogen (N) applications are generally not made until the grass is established because it will stimulate excessive weed growth during the seeding year. Switchgrass growth during the establishment year varies depending on region, weather, soil fertility, and competition with weeds (Mitchell and Schmer, 2012), but generally it is feasible to produce and harvest 50 % of the cultivar's yield potential after a killing frost. The first full growing season after seedling, it is very feasible to produce and harvest 75 % - 100 % of the cultivar's yield potential (Mitchell and Schmer, 2012; Vogel et al., 2011; Mitchell, 2012).

Physiological seed dormancy of some cultivars and seedlots of switchgrass can result in seeding failure. The normal germination test carried out according to Association of Official Seed Analysts (AOSA) procedures (AOSA, 1988) includes a period of cold stratification where seed are allowed to imbibe water and are chilled at 4°C for 2 to 4 wk to break dormancy. Seed stored for three or more years at room temperature may result in poor stands due to decreased vigor (Vogel, 2002). Switchgrass seed can be stratified by wet chilling to break dormancy but drying the seed can cause some of the seed to revert to a dormant condition (Zhang-Xing et al., 2001). Extended stratification (>42 days) significantly reduced the percentage of switchgrass seed that reverted to a dormant condition after drying (Zhang-Xing et al., 2001). It must be emphasized that switchgrass seed should have high germination (>75%) and should not be older than 3 years to ensure successful establishment. Old seed can have good laboratory germination but may have poor seedling vigor and fail to produce acceptable stands under field conditions.

Variation exists among and within cultivars for seed size. Smart and Moser (1999) graded switchgrass seed into lots differing in seed weight and evaluated the seed lots in field plantings. Seedlings from the heavy seed had greater germination, earlier shoot and adventitious root growth than seedlings from light seed but growth and development were similar 8 to 10 wk after emergence.

Weed competition is one of the major reasons for stand failure of switchgrass. Seedlings do not develop rapidly until conditions are warm which is the same time that many annual weeds develop. Most dicot weeds can be controlled with 2, 4-D (2, 4-dichlorophenoxyacteic acid) (Anonymous, 2002). Generally, 2, 4-D should be applied after switchgrass seedlings have approximately four to five leaves. Atrazine [6-chloro-N-ethyl-N' -(1-methylethyl)-1, 3, 5-triazine-2, 4-diamine] has been used to improve establishment of switchgrass by controlling broadleaf weeds and C_3 weedy grasses (Martin et al., 1982; Bahler et al., 1984). Switchgrass can metabolize atrazine (Weimer et al., 1988). Acceptable stands of switchgrass could be established at a reduced seeding rate of 107 pure live seed m^{-2} when weed interference was reduced following atrazine application at time of planting (Vogel, 1987). Imazethapyr {2-[4,5-dihydro-4-methyl-4-(1-methylethyl)-5-oxo-1H-imidazol-2- yl]-5-ethyl-3-pyridine carboxylic acid}, applied at 70 g active ingredient (a.i.) ha^{-1} before the grass seedlings emerged, provided excellent weed control and enabled excellent stands of switchgrass to be obtained within 1 year of planting (Masters et aI., 1996). Metasulfuron (methyl 2-[[[[(4-methoxy-6-methyl-1, 3, 5-trizin-2-yl)-amino]carbonyl]-amino]sulfonyl] benzoate) and clopyralid (3, 6-dichloro-2-pyridinecarboxylic acid) plus 2, 4-D can be used for weed control in established pastures (Anonymous, 2002).

New growth with post-establishment years starts in early spring, with new tillers being initiated from auxiliary buds on the crown and/rhizomes (Heidemann and Van riper, 1967; Sims et al., 1971; Beaty et al., 1978). Moore et al. (1991) presented the phonologic development of switchgrass by maturity stages: emergence, vegetative/leaf development stem elongation, reproductive/floral development, and seed development and ripening. Although the duration of each stage is dependent on genetics, both photoperiod and temperature play a critical role on vegetative growth and reproductive development (Sanderson and Wolf, 1995 and Mitchell et al., 1997; Mitchell et al., 2001). Mitchell et al. (1997) and Castro et al. (2011) indicated that photoperiod is the primary determinant of switchgrass reproductive development, but temperature or heat units can significantly modify reproductive development.

Fertilization

Switchgrass can tolerate low fertility conditions but it responds to fertilizer (Rehm et al., 1976; Jung et al., 1988). It responds to N fertilization with significant increases in forage and biomass yield (McMurphy et al., 1975; Rehm et al., 1976, 1977; Perry and Baltensperger, 1979; Hall et al., 1982; Rehm, 1984; Madakadze et al., 1999a; Sanderson et al., 1999; Vogel et al., 2002a). Recommended N fertilization rates vary with location and are primarily dependent upon precipitation, cultivar, and harvest management. In the eastern Great Plains and the Midwest, recommended annual rates of N vary from 90 to 110 kg ha^{-1} when switchgrass is managed for hay or pasture while further west where there is less precipitation, rates of 45 to 70 kg ha^{-1} are used. When switchgrass is managed for optimal biomass production in the Midwest, approximately 10 to 12 kg N ha^{-1} need to be applied for each Mg ha^{-1} of biomass yield (Vogel et al., 2002a). At fertility rates above this level, nitrates accumulated in the soil profile. Nitrogen is a critical nutrient for production of biomass and typically the most limiting factor to plants productivity (Lemus et al., 2008b); therefore efficient utilization is critical.

In a multi-location study throughout the upper southeastern United States, Lemus et al. (2009) found that a single-cut system without adding any N would be a more sustainable management practice compared with a split application of N (100 kg N ha^{-1}) in a two-cut system. Muir et al. (2001) reported Alamo switchgrass yielded highest at N rates up to 224 kg ha^{-1}. Vogel et al. (2002) tested N application rates up to 300 kg ha^{-1} for the Cave-in-Rock (a southern upland cultivar). They reported maximum yield at 120 kg N ha^{-1}. Guretzky et al. (2011) tested N up to 225 kg ha^{-1} at three harvest seasons (July, Oct., and Dec.) and reported positive response of switchgrass biomass production to N fertilization. Switchgrass may respond to P fertilization if the availability of P in the soil is low (Rehm, 1984; Rehm et al., 1976). Switchgrass should be fertilized in late spring when initiating growth. Early spring fertilization will stimulate invasion by C_3 grasses and forbs (Rehm et al., 1976). Nitrogen fertilization increases the forage protein concentration (Perry and Baltensperger, 1979; Rehm, 1984; Rehm et al., 1977; Vogel et al., 2002a) and IVDMD of switchgrass (Perry and Baltsenberger, 1979; George et al., 1990).

On a strongly acid soil (pH ~4), low P, unfertilized switchgrass and big bluestem (*Andropogon gerardii* Vitman) produced 50% as much forage as that receiving a low level of nutrients (Jung et al., 1988). When P declined from 35 to 5 mg kg^{-1}, switchgrass yields declined 12% compared to C_3 grasses which declined 35% (Panciera and Jung, 1984). On acidic, low water-holding capacity soils, first cut switchgrass yields were two to three times greater, and four times greater than for tall fescue on sites with N and without N, respectively. Nitrogen-use efficiency was greater for switchgrass than for tall fescue (Staley et al., 1991). The timing of N application is critical in the maintenance of switchgrass stands. If N is applied too early in the spring or in the previous autumn, cool-season plants will use it because switchgrass is not active. The stimulated C_3 invaders will increase rapidly and use the soil moisture. Later, during the period of switchgrass growth, soil moisture will be depleted and the vigor of switchgrass plants will decline and stands will be invaded by additional C3 plants which can result in the conversion of a switchgrass pasture into a mixed species cool-season pasture.

Persistence under Clipping and Grazing

Grazing and clipping experiments in the northeastern United States and Canada have demonstrated differences among cultivars in forage production and persistence (Belesky and Fedders, 1995; Madakadze et al., 1999; Sanderson, 2008). Trials in Pennsylvania that evaluated ‘Cave-in-Rock’, ‘Shawnee’, and ‘Trailblazer’ switchgrasses under clipping and grazing showed few differences among cultivars in crude protein (CP), neutral detergent fiber (NDF), and *in vitro* NDF disappearance (NDFD); (Sanderson, 2008). Multiple cuttings of switchgrass within a season reduces total yield (Sanderson et al., 1999) and three or more cuttings have been reported to reduce stand longevity (Parrish and Fike, 2005) but no clipping height was specified. Delaying cutting after frost allows the plant to translocate nutrients from senescing stems and leaves to the underground portions of the plant. The nutrients are stored for the next season and enhance stand longevity (Parrish and Fike, 2005).

In temperate regions switchgrass pastures will be ready to graze in late spring, about the time the cool-season grasses have completed their spring growth. They are normally grazed when the grass is about 30-cm tall. The date will vary with location. Switchgrass should be grazed heavily to maximize beef production per unit of land (Burns et al. 1984; Barnhardt and Wedin 1984; Anderson et al, 1988). Under continuous stocking, sufficient animals should be kept on a unit of land to keep the switchgrass at about 30-cm tall. Beef cattle graze switchgrass from the top of the canopy giving pastures a clipped appearance. If sufficient animals are not available to maintain this pressure, part of the pasture should be fenced and harvested as hay. Under rotational stocking, cattle should be removed and the pastures allowed to regrow when the switchgrass has been grazed to a height of about 20 cm. A short period of grazing to partially defoliate switchgrass in late spring can shift a major portion of the yield to later in the summer and improve summer switchgrass quality (George and Obermann, 1989). Switchgrass stands can be damaged by overgrazing. Switchgrass needs recovery time prior to a frost to replenish stored carbohydrates in perennial tissue. Because of this, plants should be at least 10-cm tall after grazing during the summer and 20-cm tall in the fall after grazing ceases. Beef cattle gains in switchgrass grazing trials ranged from 0.5 to 1.1 kg animal^{-1} d^{-1}. In previous grazing experiments in the upper Piedmont of the United States, Burns et al.(1984) and Burns and Fisher (2000) continuously stocked switchgrass to maintain a canopy of about 13 cm and found that it remained vegetative throughout the growing season with leafy growth occurring from both apical meristems and basal buds. Burns et al. (1984) stated that, due to switchgrass bunchgrass morphology, the continuously defoliated switchgrass, as opposed to a spreading species such as bermudagrass, remained relatively upright in growth habit. Further, planted rows of switchgrass, although visible initially were no longer evident after several years of continuous stocking due to basal tilling (short rhizomes).

Nutritive Value

The nutritive value of warm-season grasses is initially moderate to high but declines rapidly with maturity (Perry and Baltensperger, 1979; Griffin and Jung, 1983; Mitchell et al., 1994a). When making management decision for perennial grasses, the morphological development is very important (Kalu and Fick, 1983; Moore and Moser, 1995). Plant maturity is the primary factor affecting the morphological development and forage nutritive value within a species (Kalu and Fick, 1983; Nelson and Moser, 1994). Nutritive value of switchgrass has been improved through plant breeding. ‘Trailblazer’ switchgrass was released in 1984 based on improved IVDMD of the whole plant (Vogel et al., 1991). Research in Nebraska demonstrated greater gain of beef steers grazing Trailblazer compared with other cultivars (Anderson et al., 1988). Shawnee, a cultivar released in 1995, has improved IVDMD compared with Cave-in-Rock, the parent population (Vogel et al., 1996). Cave-in-Rock, a cultivar developed from Illinois plant material, is considered a standard cultivar for the northeastern United States. The cultivar Performer, selected from lowland ecotypes, was released in 2007 based on improved forage quality compared with Cave-in-Rock and Alamo switchgrass (Burns et al., 2008). Digestibility and crude protein concentration of switchgrass during grazing trials have been reported at 677 g kg-1 and 103 g kg-1 respectively (Burns and Fisher, 2013). There are no reports of defoliation management effects on nutritive value of ‘Performer’ switchgrass.

Animal Responses

Mosali et al. (2013) reported average daily gains for light, moderate, and heavy stocking rates of 0.83, 1.04, and 1.05 kg. While the numbers reported by Mosali et al. (2013) are similar to previous reports in the literature, the ADG trend is contradictory to several reports in the literature where ADG increased at lower stocking rates (Bodine et al., 1998; Derner et al., 2008). Burns et al. (2011) reported ADG's of 1.11, 1.13, and 1.10 kg d^{-1}, respectively, when switchgrass was grazed at similar forage availabilities. Average daily gains in the Mosali et al. (2013) study were greater than reported by Anderson et al. (1988) who evaluated grazing effects of upland switchgrass cultivars.

Mosali et al. (2013) reported that on average, total gain for the light, moderate, and heavy stocking rate treatments were 167, 214, and 199 kg ha^{-1}, respectively. Utilization of moderate and heavy stocking rates produced an additional total gain of 48 and 32 kg ha^{-1}, respectively. Anderson et al. (1988) reported a greater total gain of 311 kg ha^{-1} across three varieties of switchgrass. The difference in gains reported by Anderson can partly be attributed to a heavier stocking rate (8.3 steers ha^{-1}) that was used to maximize animal gain rather than providing multiple products from a single system. It is important to note, that Krueger and Curtis (1979) used a put-and-take system to evaluate upland switchgrass cultivars. In their study, total gain was lower (147 kg ha^{-1}) than those achieved with continuous grazing managed to maximize system productivity per hectare. In North Carolina, Burns and Fisher (2013) reported ADG for switchgrass during summer trial as 0.70 kg d^{-1} and for the season-long growing period as 0.91 kg d^{-1}. Burns et al. (2013) also reported total gain per hectare for summer trial at stocking rate of 6.1 steers ha^{-1} as 373 kg ha^{-1}, and for the season-long growing period at stocking rate of 6.7 steers ha^{-1} as 839 kg ha^{-1}.

Summary and Expected Outcomes

Defoliation management is a critical factor that can affect presence/absence of desirable forage species that are ultimately needed to sustain healthy pasture-based livestock systems. 'Performer' switchgrass was released because of greater digestibility compared to the standard cultivars grown in the Southeast USA and therefore has potential to positively impact animal responses. Nevertheless, currently there is no information on the range of defoliation management that will optimize high nutritive value forage with persistence. The overall objective of this research was to evaluate the effect of a wide range of defoliation management strategies on production, persistence, and nutritive value of 'Performer' switchgrass. Two experiments were conducted; Chapter 2 presents the information related to productivity, canopy characteristics, and persistence. Chapter 3 presents the information on nutritive value. The data presented in this thesis corresponds to year one of the experiment (2016) because year two (2017) data are still under collection. The information generated from this study will provide a baseline for selection of defoliation management treatments to be evaluated under grazing and ultimately to measure animal responses.

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CHAPTER 2. Defoliation Effects on Productivity and Persistence of 'Performer' Switchgrass

ABSTRACT

'Performer' switchgrass (*Panicum virgatum* L.) was released because of its greater digestibility and potential to positively impact animal responses compared to standard cultivars grown in the Southeastern U.S. Information on defoliation management regimes for 'Performer' is needed to ensure persistence and productivity of nutritious forage. The objectives of this study were to determine the effect of the factorial combination (4 x 4) of defoliation height (10, 20, 30, and 40-cm; DH) and defoliation frequency (3, 6, 9, and 12-wk; DF) on productivity, canopy characteristics, and persistence of 'Performer' switchgrass. The experiment was conducted at the Central Crops Research Station, Clayton, NC. Treatments were allocated in a complete randomized block design replicated four times. For herbage production, there was no defoliation height effect for the more frequent defoliated treatments (4.4 and 6.4 Mg ha^{-1} for 3- and 6-wk DF); however, it increased from ~6.8 to ~12.1 Mg ha^{-1} for both 9 and 12-wk defoliation frequencies as defoliation height decreased from 40 to 10-cm. Leaf: stem was greater for 3-wk defoliation frequency treatments at higher defoliation height at ~2.5 and ~0.7 for both 9 and 12-wk defoliation frequencies. Canopy height before harvest ranged from ~36 to 91 cm. Frequent defoliation at lower defoliation height (i.e. 3-wk DF at 10-cm DH) resulted in lowest light interception (< 50%) and tiller count (< 150 m^{-2}), and greatest (~70%) weed infestation from crabgrass (*Digitaria spp*.) while weed infestation remained below 15% for all other treatments. 'Performer' switchgrass is a productive forage

and defoliation height of at least 20 cm for 3-wk defoliation frequency and 10 cm for defoliation frequency ≥ 6-wk ensures stand persistence and prevents weed infestation.

INTRODUCTION

Switchgrass is a C_4 perennial warm-season grass, native to the Great Plains and broadly adapted throughout the USA (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). In forage-livestock systems, switchgrass can particularly help to fill the gap in forage availability during the transition period from cool- to warm-season forage growth in the USA 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 349 kg of beef gain ha^{-1} by 1 June, before 'Coastal' bermudagrass [*Cynodon dactylon (*L.) Pers] is ready to graze (Burns et al., 1984).

Average daily gains for livestock grazing switchgrass range from 0.5 to 1.1 kg $animal^{-1}$ d^{-1} (Vogel, 2004). In North Carolina, steers grazing 'Alamo' switchgrass from mid-April to early September gained an average of 0.91 kg d^{-1} and weight gains ha^{-1} were up to 839 kg with a stocking rate of 6.1 steers ha^{-1} (Burns and Fisher, 2013). Cultivar 'Performer' of switchgrass was released because of greater digestibility and comparable dry matter yields to 'Alamo' and 'Cave-In-Rock' (Burns et al., 2008). Switchgrasses with greater digestibility have the potential to positively impact livestock production and to increase animal responses (Anderson et al. 1988). When forage quantity is not the limiting factor, forage nutritive value determines the upper limit of potential animal responses (Sollenberger and Vanzant, 2011). Therefore, animal responses could potentially be greater with 'Performer' switchgrass. Nevertheless, there is limited information on the effects of defoliation management on productivity of 'Performer' switchgrass under clipping or grazing. Information on defoliation management responses is critical to ensure persistence and production of nutritious forage.

Switchgrass cultivars respond differently to defoliation regimes. Ashworth, et al. (2014) conducted a visual assessment of vigor at the end of a 4-yr trial in Tennessee and reported less vigorous stands of lowland switchgrass cultivars 'Alamo' and 'Kanlow' compared to the upland type 'Cave-in-Rock' at clipping heights lower than 20 cm. Several studies have focused on the effects of defoliation management on productivity mainly; nevertheless, to a lesser extent defoliation trials with switchgrass have reported persistence and weed infestation. In Mississippi, Seepaul et al. (2014) reported that increasing defoliation frequency from one to six times per year consistently reduced yield of 'Alamo' switchgrass defoliated at 5-cm stubble height (Seepaul et al., 2014); in a similar trend in Texas, Sanderson et al. (1999) reported that 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.

Wide variation in switchgrass responses were reported by Fike et al. (2016) from a trial that included 24 year-location combinations and four switchgrass cultivars in the upper southeastern USA, indicating the need for development of site and cultivar specific management recommendations. Similarly, in Iowa, Lemus et al. (2002) reported wide variation in plant responses among years and several cultivars of switchgrass. Beaty and

Powell (1976) indicated that over-utilization of 'Pangburn' switchgrass at the start of the growing season decreased the number of tillers and resulted in weed problems. To date, there is limited information on defoliation management effects for 'Performer' switchgrass. Information on defoliation management effects on productivity and persistence of 'Performer' switchgrass is needed to ensure adequate utilization, either under clipping or grazing, and to prevent weed infestation that may compromise stand longevity. Identifying a range of management opportunities to utilize 'Performer' switchgrass will provide flexibility to farmers that seek to put livestock to graze or to clip the forage for hay or silage (Burns et al., 1993), or potentially using it for bioenergy. The objectives of this experiment were to determine the effects of defoliation frequency and defoliation height on 'Performer' switchgrass' productivity, canopy characteristics, and persistence. We aimed to evaluate wide range of plant responses to clipping treatments as a previous step for subsequent treatment selection for grazing- and animal-responses trials.

MATERIALS AND METHODS

Experimental Site and Plot Management

The experiment is under way for a second year (2017); therefore, data presented corresponds to year one (2016) only. The experimental area consisted of a 50 by 51.5-m plot of well-established (> 8 yr) 'Performer' switchgrass located at the Central Crop Research Station, Clayton, NC (35°40´ N, 78°29´ W). Original planting of switchgrass occurred in rows spaced 1.25-m apart, however, actual row spacing at initiation of this trial was much narrower as switchgrass bunches grew and spread over time from rhizomes at the base of the original plant. Plot management in the years previous to this trial consisted of annual maintenance soil fertilization as recommend by soil analysis and a single forage clipping to ~10-cm stubble height in late Sept. followed by residue-burning on Feb. In preparation for imposing treatments for this experiment, the accumulated biomass from the 2015 growing season was clipped and removed from the plots in the late Sept. 2015 and herbicide Remedy Ultra [triclopyr (3, 5, 6-trichloro-2-pyridinyloxyacetic acid, butoxyethyl ester); 2.13 kg a.i. ha^{-1}] was applied on 11 April 2016. The soil type was classified as Wedowee sandy loam (fine, kaolinitic, thermic Typic Kanhapludults). Initial soil characterization (0 to 15 cm deep) from samples taken on Feb. 2016 indicated pH of 6.0 and Mehlich 3 extractable P, K, Ca, and Mg concentrations (mg kg^{-1}) of, 205, 195, 733, and 218, respectively. Based on soil test recommendations, only N fertilizer was applied at the rate of 134 kg N ha^{-1} by broadcasting a granular formulation of Urea-Ammonium Sulfate blend (340 g N kg^{-1}) in a single application on mid-April of each year. Rainfall and temperature information are presented in Fig. 2.1.

Treatments and Experimental Design

There were 16 treatments total resulting from the factorial combination of four defoliation frequencies and four defoliation heights. Defoliation frequency (DF) levels were: clipping every 3, 6, 9, and 12 wk; defoliation height (DH) levels were: 10, 20, 30, and 40 cm stubble height. Treatments were randomly allocated to experimental units arranged in a randomized complete block design replicated four times. Experimental unit size was 5-m wide by 5-m long and consisted of four rows of switchgrass.

Response Variables

Total Herbage Mass

Total herbage mass was measured by harvesting a 3- by 2.5-m quadrat using hedge trimmers. The clipped forage was weighed fresh in the field and a sub-sample was dried in a forced-air oven at 60°C to constant weight for determination of dry matter concentration and yield. Total herbage mass was calculated by summing the herbage mass across harvest events within a year. The numbers of clipping events in 2016 were 8, 4, 2, and 2 for frequencies of defoliation every 3, 6, 9, and 12 wk, respectively. Day zero was fixed on 18 April 2016. The first harvest event of the season occurred when canopy height was ~40 cm tall on 9 May 2016 and a total of 16 plots were harvested (3-wk treatments only). The last harvesting event occurred on 15 Oct. 2016.

Leaf:stem Ratio and Tiller Count

Two tillers were randomly selected and clipped to the corresponding DH treatment before each harvesting event and were hand-separated while fresh into green leaf (blade + sheath) and stem components. The components were dried separately until constant weight and weights were recorded. Leaf:stem ratio was calculated by dividing the dry weight of the leaves by the weight of the stem component. Tiller counts occurred two weeks after each harvest event and were performed by counting the number of live tillers (i.e. green tillers) within two 0.25-m^2 quadrats randomly located within each plot. The average of the two quadrats provided an estimate of tiller counts per experimental unit.

Canopy Height

Canopy height was measured in the week prior to each harvest event. Plant height was defined as the distance from the soil level to average height of the canopy and it was determined by taking five measurements per plot using a ruler. The average of the five measurements provided an estimate of canopy height per experimental unit.

Light Interception

Canopy light interception was measured before and immediately after each harvest event. Light interception was characterized using a SunScan Canopy Analysis System (Dynamax Inc., Houston, TX) to measure transmitted photosynthetically active radiation (PAR) and incident PAR. The system consisted of two sensors, a 1-m long quantum sensor that was placed perpendicular to the rows at ground level to determine transmitted PAR and an unshaded beam fraction sensor that was placed outside the plots to measure incident PAR. Measurements were taken between 1200 and 1500 h Eastern Daylight Time. Canopy light interception was determined at four locations within each plot. The average of the four observations per experimental unit provided an estimate of light interception. Light interception was calculated as:

$$Light\ interception(\%) = \left(1 - \frac{transmitted\ PAR}{incident\ PAR}\right) * 100$$

Weed Canopy Cover and Frequency

Canopy cover and frequency of weeds, weeds defined in this experiment as plants other than switchgrass, were estimated on 6 Aug. 2016 using a 1-m^2 quadrat placed at two locations within the plot. The quadrat was divided in 25 20- by 20-cm (five rows of five) smaller squares and cover was determined visually (0 to 100 % scale with 0 corresponding to no weeds and 100 % corresponding to full weed cover) in each square and averaged to obtain weed canopy cover per quadrat. The average of the two quadrats provided an estimate of weed canopy cover per experimental unit. Frequency was determined on the same dates and using same quadrat-locations that were used to estimate cover. Presence or absence of weeds at each of the 25 squares per quadrat and the two quadrats per experimental unit (total of 50 squares) was recorded so that frequency was calculated as the percentage of total squares where weeds were present.

Statistical Analysis

Data were analyzed using PROC GLIMMIX of SAS (SAS Institute, 2010). Treatments were fixed effects. Block was considered random effect. In the case of two-way interactions, simple effects were analyzed using the SLICE procedure of SAS and mean separation was based on the SLICEDIFF option of LSMEANS. Orthogonal polynomial contrasts (linear, quadratic, and cubic) were used to determine the effect of defoliation height by using the LSMESTIMATE procedure. Plots of model residuals were used to check normality. Treatment effects were considered significant if $P \leq 0.05$.

RESULTS AND DISCUSSION

Total Herbage Mass

Annual herbage mass ranged from 3.8 to 12.1 Mg ha^{-1}. Greatest total herbage mass was obtained with less frequent defoliation at lower defoliation heights (Fig. 2.2), however, the intensity of this trend varied among treatments. There was an interaction effect for DF by

DH ($P < 0.001$). The interaction effect occurred because there was an effect of DH for both 9- and 12-wk DF but not for 3- and 6-wk DF treatments (Fig. 2.2). Total herbage mass was ~3.8 and 6.4 Mg ha^{-1} for defoliation frequency every 3 and 6 wk, respectively. Total herbage mass increased with linear effect for 9-wk DF, both linear and quadratic effects for 12-wk defoliation frequency from ~6.9 to ~12.0 Mg ha^{-1} as defoliation height decreased from 40 to 10 cm stubble height (Fig. 2.2). At 9 wk DF, herbage mass from the 30-cm DH was not different than from the 40-cm DH; however, at 12-wk DF, 30-cm DH was greater than 40-cm DH and not different than 10 and 20-cm DH.

Total herbage mass values similar to the 9 and 12-wk defoliation frequency treatments at lower stubble heights (Fig. 2.2) have been reported for 'Performer' switchgrass in North Carolina. Burns et al. (2008) reported total herbage mass of 12.1 Mg ha^{-1} for a 3-clippings per year system and Burns et al., (2010) reported 14.9 Mg ha^{-1} for total herbage mass averaged over four years in a 2-clippings per year system. There limited data available on performance of 'Performer' switchgrass in other regions. Lower total herbage mass due to multiple cuttings within a season have been reported for 'Alamo' switchgrass (Sanderson et al., 1999; Seepaul et al., 2014) with the magnitude of the reduction dependent on the number of clippings. In Mississippi, herbage mass of switchgrass decreased linearly from ~12 to ~5 Mg ha^{-1} when defoliation frequency increased from 1 to 6 clippings per year (Seepaul et al., 2014). Burns et al. (2008) reported that the digestibility of 'Performer' was at least four percent points greater than cultivars 'Alamo' and 'Cave in Rock'. Therefore, in spite of potential lower yields with multiple cuttings and because of the greater digestibility of 'Performer', multiple cutting systems have the potential to allow the farmer greater flexibility in deciding whether to use the harvested material as forage to feed livestock or feedstock for bioenergy conversion.

Leaf:Stem Ratio

The leaf to stem ratio ranged from 0.4 to 2.7. There was a DF by DH interaction effect (P = 0.01). The interaction effect occurred because leaf to stem ratio differences due to DH were present for 3- and 12-wk DF treatments only. For 3-wk DF, leaf to stem ratio decreased from ~2.5 for both 30 and 40-cm DH to ~1.7 for both 10- and 20-cm DH; for 12-wk DF, leaf to stem ratio decreased from ~1.1 for both 40- and 30-cm DH to ~0.5 for both 10- and 20-cm DH (Fig. 2.3). Leaf to stem ratio was intermediate at ~1.0 for 6 and 9 wk DF. In general, greater leaf:stem ratio occurred for younger plants and frequent defoliation regimes (i.e. 3-wk DF vs. 12-wk DF; Fig. 2.3). 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 in June and 38% by Aug. In Iowa, Lemus et al. (2002) reported leaf to stem ratios of 0.5 for 'Alamo' and 'Kanlow' cultivars, respectively, from a single clipping to 7.5 cm stubble height by the end of growing season. Leaf:stem ratios > in our study occurred consistently for treatments 3- and 6-wk DF irrespective of DH (Fig. 2.3). The leaf component has greater nutritive value (e.g. higher crude protein and digestibility combined with lower lignin and neutral detergent fiber) than stems in switchgrass (Burns et al., 2011; Griffin and Jung, 1982). Redfearn et al. (1997) suggested that if the switchgrass canopy is to be managed for grazing, leaf yield would be more important than total forage yield. Therefore, designing a defoliation management plan for 'Performer' that encourages greater proportion of leaves while not compromising stand persistence may result in total herbage mass with a more favorable nutritional profile to support production goals of grazing livestock.

Tiller Count

The number of tillers per m^2 ranged from 128 to 282. There was an interaction effect of DH by DF ($P < 0.001$). The interaction effect occurred because there were DH effects in all DF treatments except for 6 wk DF (Fig. 2.4). For treatment 10-cm DH, tiller counts were lowest (less than 150) at 3-wk DF and highest (greater than 250) at 9-wk DF, while for all other DF by DH treatment combinations the tiller count ranged from 155 to 235. Tiller count increased with linear and quadratic effects as stubble height increased from 10 to 40 cm at 3-wk DF; however, this pattern was completely reversed at 9-wk DF (linear and quadratic effects) and 12-wk DF (linear and cubic effects), and there was no DH effect at 6-wk DF. Using defoliation stubble heights of 15 cm in year 1 and changed to 20 cm in year 2, 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. We found a similar trend coinciding with that reported by Beaty and Powell (1976) but only for the 10-cm DH treatment. 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. Less variation in tiller counts and a consistent trend for lower number of tillers with less frequent defoliation occurred for the 30- and 40-cm DH treatments in our study; nevertheless, tiller numbers similar to those of the 30- and 40-cm DH treatments were also achievable with lower stubble heights but are dependent on frequency of defoliation (Fig. 2.4).

Canopy Height

Canopy height at harvest time ranged from 36 cm to 93 cm. There was an interaction effect of DF by DH ($P < 0.001$). The interaction occurred because there were DH effects for 3- and 6-wk DF treatments but not for 9- and 12-wk DF (Fig. 2.5). Canopy height increased (linear effect) from 36 to 61 cm, 48 to 71 cm, and 69 to 74 cm for 3, 6, and 9-wk DF, respectively, as DH increased from 10 to 40 cm stubble height. Canopy height was ~91.0 cm for 12-wk DF. Beaty and Powell (1976) reported that switchgrass clipped to 15 cm stubble height each time it reached a height of 91 cm yielded twice as much than when clipped at a height of 61 cm. The previously cited authors also reported that intense and frequent defoliation reduced tiller height and total yield. We found similar results in our study with treatments with greater canopy height concurrent for treatments with greater total herbage mass production. Seepaul et al., (2014) also reported lower canopy height and lower total herbage mass concurrent for treatments under more frequent defoliation for ‘Alamo’ switchgrass clipped to 5-cm stubble height.

Light Interception

Canopy light interception after harvest was affected by DH and DF. Light interception after harvest ranged from 41 to 48 % as a function of DF; however, the range was greater (from 23 to 64 %) as a function of DH with greater light interception for higher stubble heights (Fig. 2.6). Light interception before each clipping event ranged from 47 to 84 % and followed a similar pattern than canopy height, i.e. DH had a greater impact at more frequent defoliation events. There was an interaction effect of DF by DH ($P < 0.001$) for light interception before harvest. The interaction effect occurred because DH effect was significant for DF treatments 3, 6, and 9 wk but not in 12-wk (Fig. 2.6). Light intercepted increased from 47 to 72 %, 57 to 79 %, and 70 to 79 % for 3, 6, and 9-wk DF, respectively, as stubble height increased from 10 to 40 cm and it remained about 80 % for 12-wk DF. The majority of DF by DH treatment combinations (13 out of 16) achieved light interception values greater than 60 % before harvest. Light interception values lower than 60 % occurred only for 3-wk DF at 10-and 20-cm stubble height and 6-wk DF at 10-cm stubble height. Under frequent and lower stubble height defoliation, the leaf area of forage plants may not be capable of supporting the plant's growth needs, and regrowth is dependent upon mobilization of stored reserves (Booysen and Nelson, 1975; Harris, 1978). Understanding thresholds for light interception can help in defining defoliation strategies that to not only target greater yields, but also to optimize nutritive value of the forage while preventing competition from weeds. Crabgrass (*Digitaria spp*.) was the predominant weed observed in this experiment and it was most prevalent in the 10-cm DH 3-wk DF treatment (Fig. 2.7) which coincided with lowest light interception value.

Weed Canopy Cover and Frequency

Canopy cover and frequency of weeds followed a similar pattern (Fig. 2.7). Canopy cover is a measurement explaining the amount of ground area covered by weeds and frequency describes the distribution of the weeds. There was an interaction effect of DF by DF for canopy cover ($P < 0.001$) and it occurred because there were DH effects for 3- and 6-wk DF but not for 9- and 12-wk DF treatments. Weed canopy cover increased from ~10 to 68 % when DH decreased from 40 to 10 cm stubble height at 3-wk DF treatment. Weed canopy cover was below 15 % for all treatment combinations except for 3-wk DF at 10-cm DH (67

%). For 6-wk DF, although there was cubic effect of DH, weed canopy cover remained below 15 %.

There was an interaction effect of DH by DF for weed frequency ($P < 0.001$). Difference in weed frequency due to DH were present in 3- and 6-wk DF treatments only and not in 9- and 12-wk DF. Weed frequency for all treatment combinations were below 30 % with the exception of treatment 3-wk DH 10-cm DH for which weed frequency was 95 %. Weed infestation was mainly due to crabgrass (*Digitaria spp*.) and was greater (70 % cover and 95 % frequency) when defoliation occurred every 3 wk to 10-cm DH and remained below 15 % cover and 30 % frequency for all other treatments. Although, crabgrass is considered as one of the most desirable warm season annual forage species for livestock grazing systems. Madakadze et al. (1999) reported heavy weed infestation that resulted in discontinued experimental treatment for swards of switchgrass cultivars ‘Cave in Rock’, ‘Sunburst’, and ‘Pathfinder’ when clipped every 2 wk to 15-cm stubble height; no weed pressure was reported when frequency of defoliation was 4 wk. Parrish and Fike (2005) reported that three or more cuttings reduce stand longevity; although no clipping height was specified. Our findings indicate that there is a wide range of defoliation options for ‘Performer’ switchgrass at which weed infestation can be prevented. The study is being conducted for a second year to evaluate the consistency of this trend.

SUMMARY AND CONCLUSIONS

Defoliation management treatments imposed to ‘Performer’ switchgrass resulted in a wide range of plant responses. Total herbage mass produced ranged from 3.8 to 12.1 Mg ha^{-1} and it was greater in treatments with less frequent defoliation at lower stubble heights.

The leaf:stem ratio ranged from 0.4 to 2.7, and in contrast to herbage mass response, leaf:stem ratio was greater for frequent defoliations at higher stubble heights. Leaf:stem ratio was ~1 for 6- and 9-wk DF irrespective of DH and for 3-wk DF it decreased from ~2.5 for both 30 and 40-cm DH to ~1.7 for both 10- and 20-cm DH. Canopy height and light interception followed a similarly positive trend. The data indicate that there is wide range for the combination of DF and DH at which light interception values greater than 60 % can be achieved. Light interception lower than 60 % occurred for treatments 3-wk DF at 10-and 20-cm stubble height and 6-wk DF at 10-cm stubble height. Weed infestation was mainly due to crabgrass and it was greater (~70% cover and ~90% frequency) when defoliation occurred every 3 wk at 10-cm SH and remained below 15% for all other treatments. Four or more clippings resulted in lower herbage mass production. Defoliation frequencies every 3 wk to 10-cm stubble height reduced stand longevity with occurrence of high weed infestation. In conclusion, ‘Performer’ switchgrass is a productive forage and on the basis of total herbage mass, light interception, canopy height, and weed infestation, frequent defoliations such as every 3 wk should maintain a stubble height of at least 20 cm and defoliation frequencies ≥ 6 wk to 10 cm stubble height are warranted to ensure stand persistence and prevent weed infestation as they were observed during the year one of defoliation.

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FIGURES

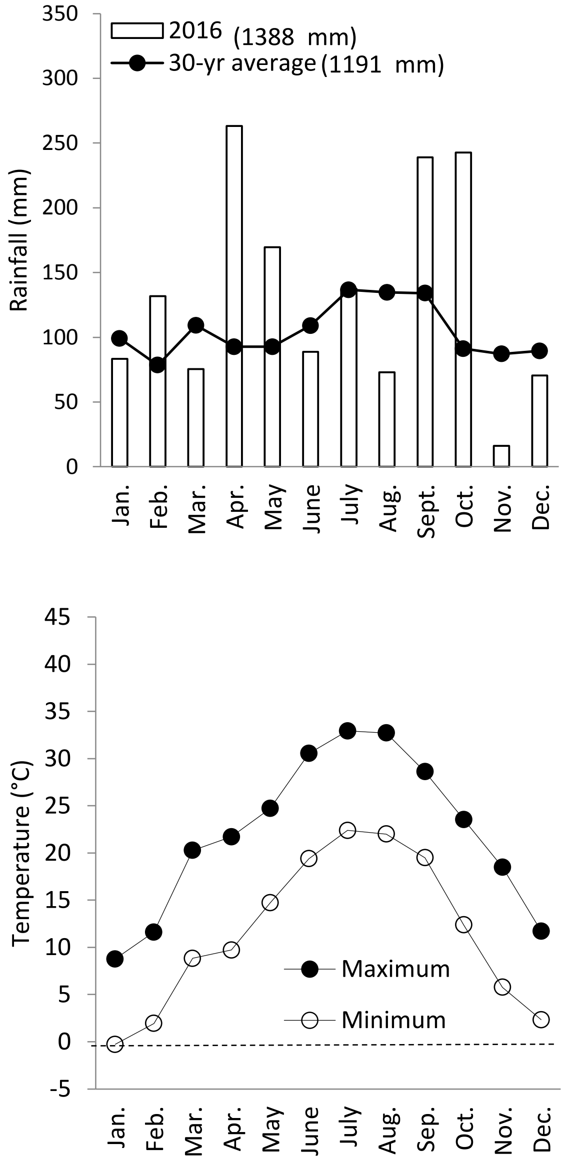

Figure 2.1. Monthly rainfall (for 2016 and 30-yr average) and temperatures (max. and min. for 2016) at the Central Crops Research Station, Clayton, NC.

Total Herbage Mass

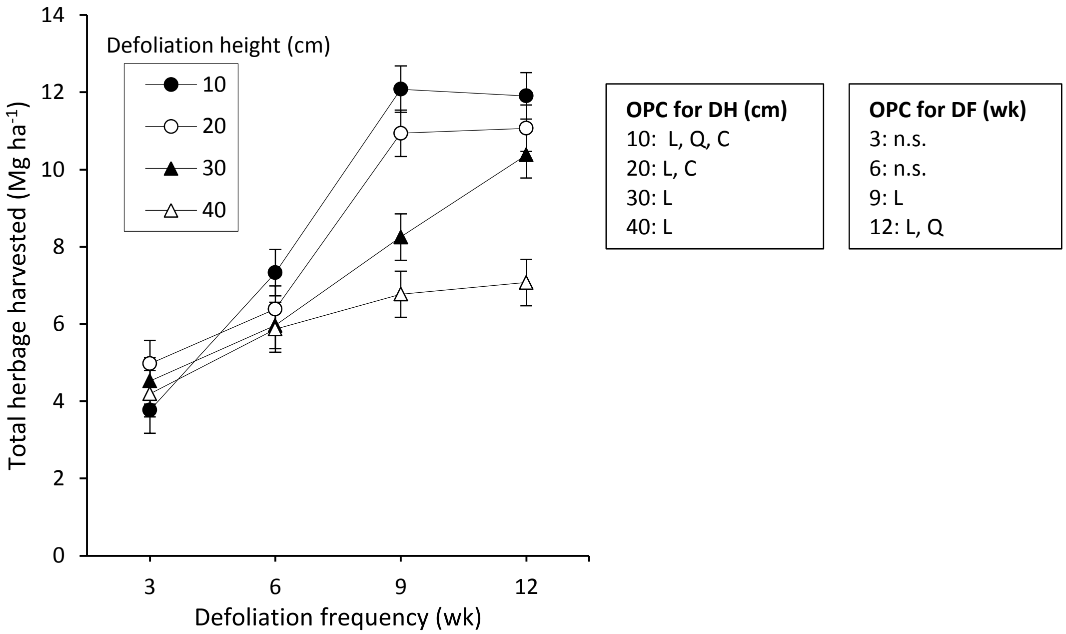

Figure 2.2. Total herbage harvested of 'Performer' switchgrass (*Panicum virgatum* L.) grown in Clayton, NC during the May – Oct. 2016 growing season as a function of defoliation frequency (clipped every 3, 6, 9, and 12 wk) and defoliation height (10, 20, 30, and 40 cm stubble height). Letters, L = linear, Q = quadratic, and C = cubic represent significant ($P < 0.05$) orthogonal polynomial contrasts (OPC) for defoliation height (DH), and defoliation frequency (DF). Error bars represent treatment means ± 1 standard error. Least significant difference (L.S.D) = 1.72 at $P = 0.05$.

Leaf:Stem Ratio

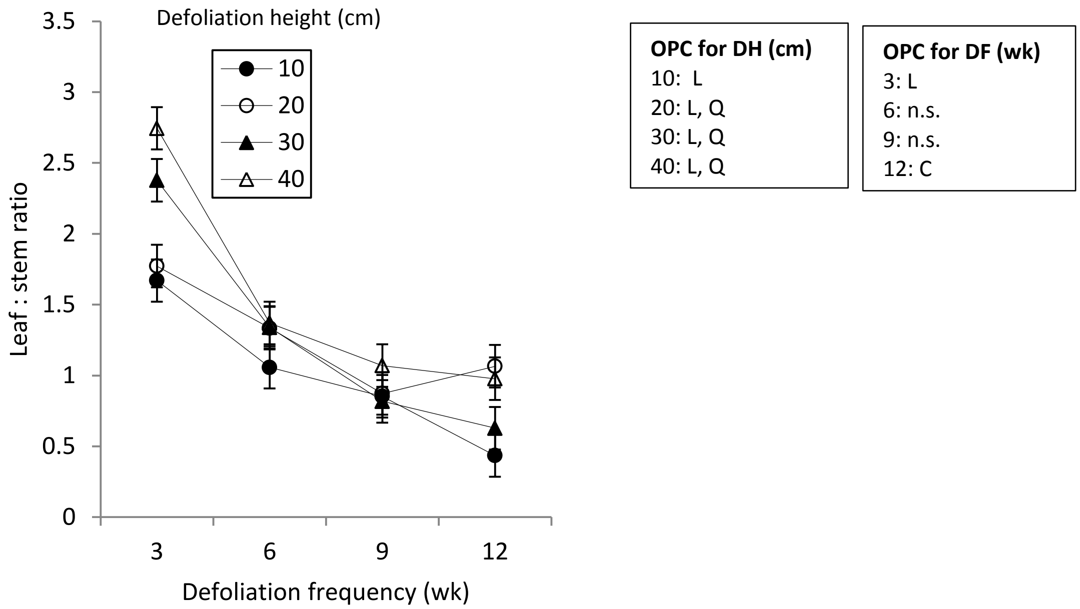

Figure 2.3. Leaf stem ratio of 'Performer' switchgrass (*Panicum virgatum* L.) grown in Clayton, NC during the May – Oct. 2016 growing season as a function of defoliation frequency (clipped every 3, 6, 9, and 12 wk) and defoliation height (10, 20, 30, and 40 cm stubble height). Letters, L = linear, Q = quadratic, and C = cubic represent significant ($P < 0.05$) orthogonal polynomial contrasts (OPC) for defoliation height (DH), and defoliation frequency (DF). Error bars represent treatment means ± 1 standard error. Least significant difference (L.S.D) = 0.44 at $P = 0.05$.

Tiller Counts

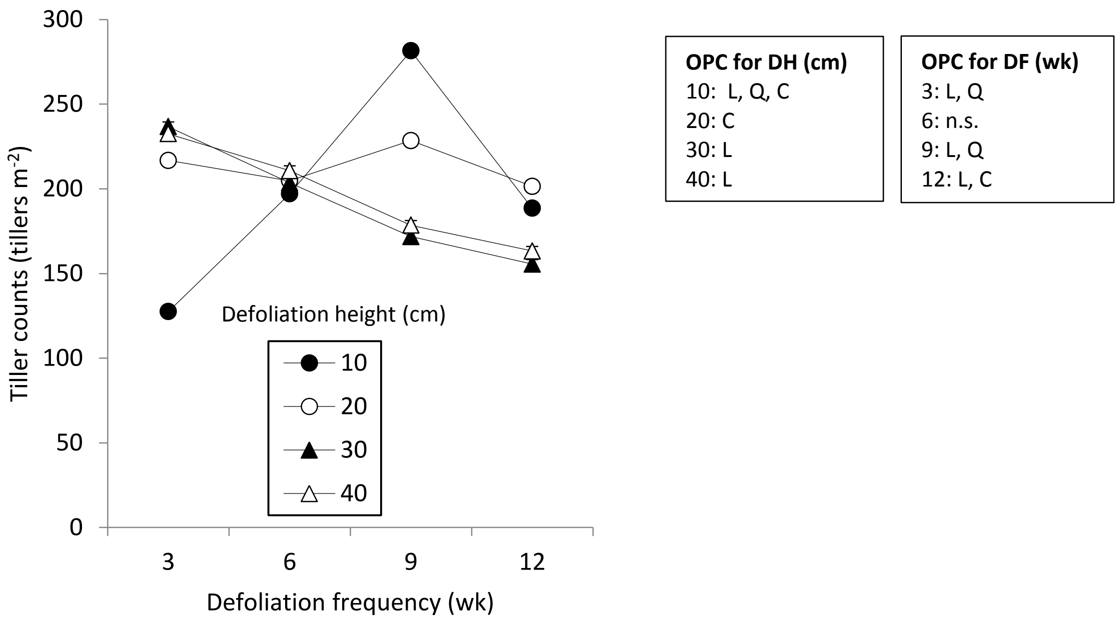

Figure 2.4. Number of tillers of 'Performer' switchgrass (*Panicum virgatum* L.) grown in Clayton, NC during the May – Oct. 2016 growing season as a function of defoliation frequency (clipped every 3, 6, 9, and 12 wk) and defoliation height (10, 20, 30, and 40 cm stubble height). Tillers counts occurred every 2 wks after a defoliation event. Letters, L = linear, Q = quadratic, and C = cubic represent significant (P < 0.05) orthogonal polynomial contrasts (OPC) for defoliation height (DH), and defoliation frequency (DF). Error bars represent treatment means ± 1 standard error. Least significant difference (L.S.D) = 7.15 at P = 0.05.

Canopy Height

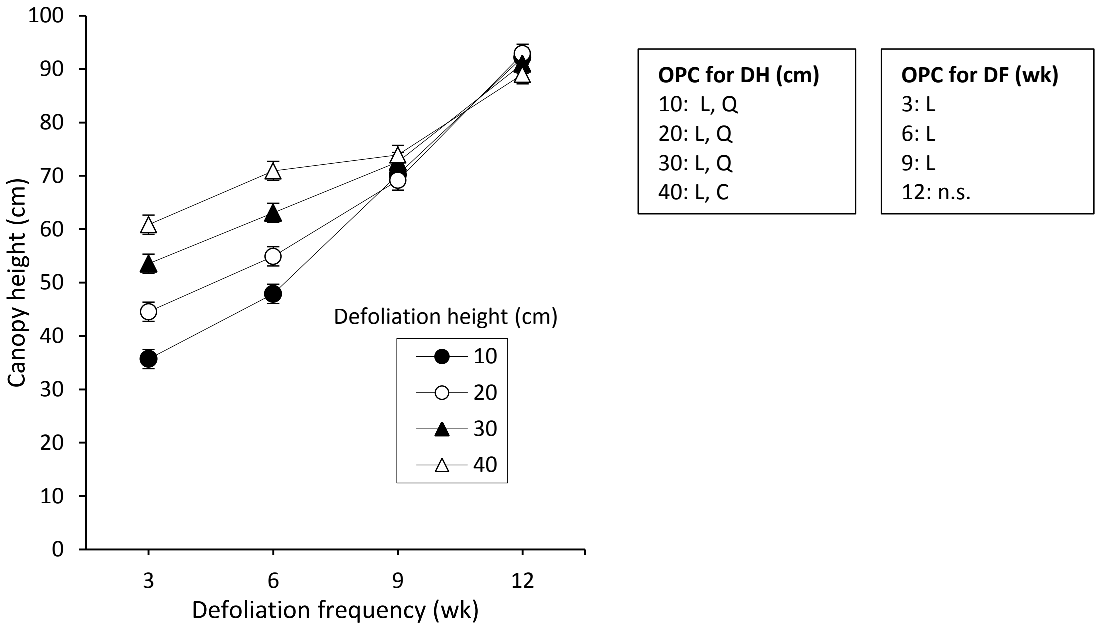

Figure 2.5. Canopy height of 'Performer' switchgrass (*Panicum virgatum* L.) grown in Clayton, NC during the May – Oct. 2016 growing season as a function of defoliation frequency (clipped every 3, 6, 9, and 12 wk) and defoliation height (10, 20, 30, and 40 cm stubble height). Letters, L = linear, Q = quadratic, and C = cubic represent significant ($P < 0.05$) orthogonal polynomial contrasts (OPC) for defoliation height (DH), and defoliation frequency (DF). Error bars represent treatment means ± 1 standard error. Least significant difference (L.S.D) = 4.35 at $P = 0.05$.

Light Interception

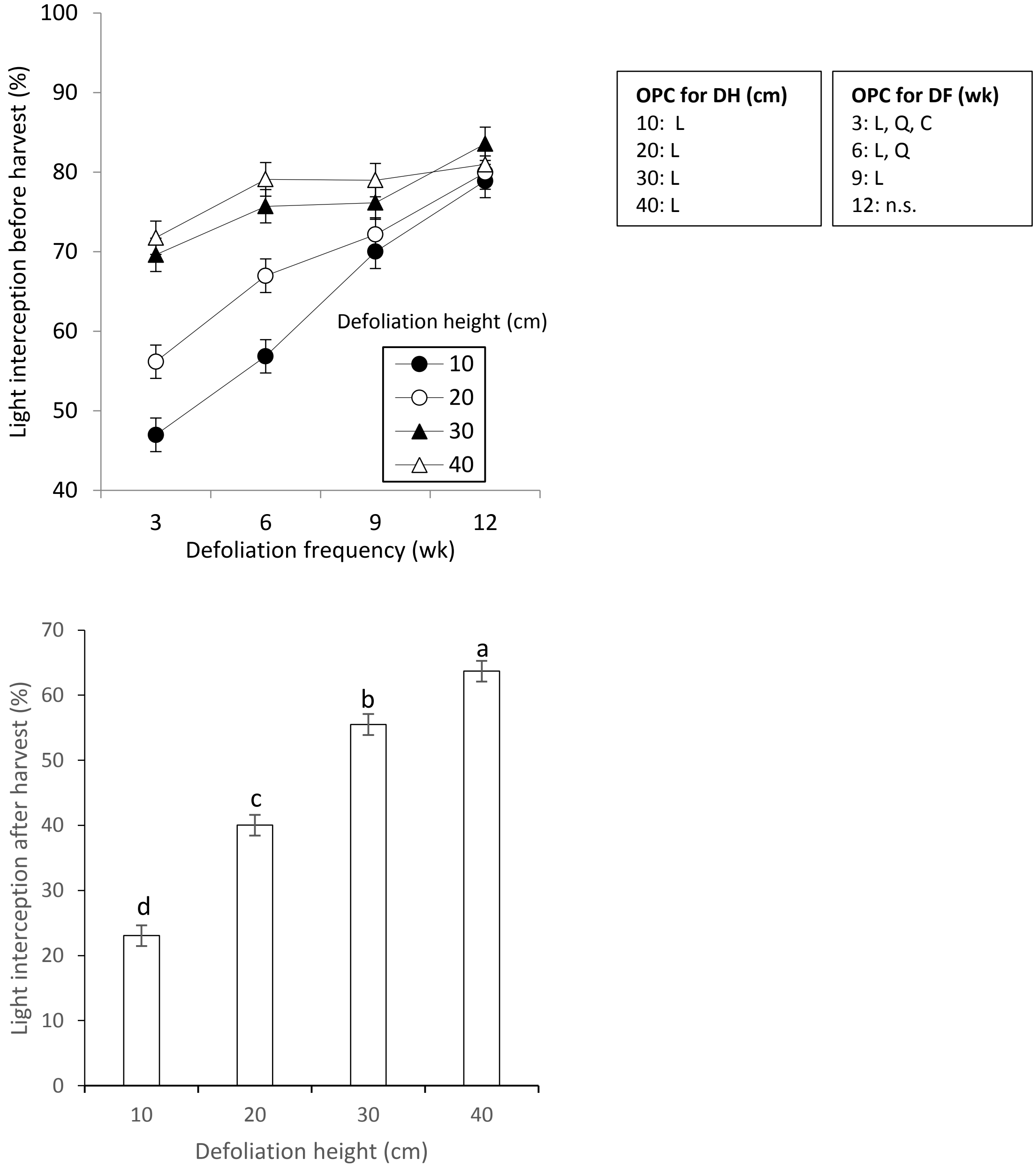

Figure 2.6. Light interception (before and after harvest) of ‘Performer’ switchgrass (*Panicum virgatum* L.) grown in Clayton, NC during the May – Oct. 2016 growing season as a function of defoliation frequency (clipped every 3, 6, 9, and 12 wk) and defoliation height (10, 20, 30, and 40 cm stubble height). Light interception was measured in the week leading to each defoliation event and immediately after. Letters, L = linear, Q = quadratic, and C = cubic represent significant ($P < 0.05$) orthogonal polynomial contrasts (OPC) for defoliation height (DH), and defoliation frequency (DF). Error bars represent treatment means ± 1 standard error. Least significant difference (L.S.D) for Light interception before and after harvest (4.75, and 9.0) respectively at $P = 0.05$.

Weed Canopy Cover and Frequency

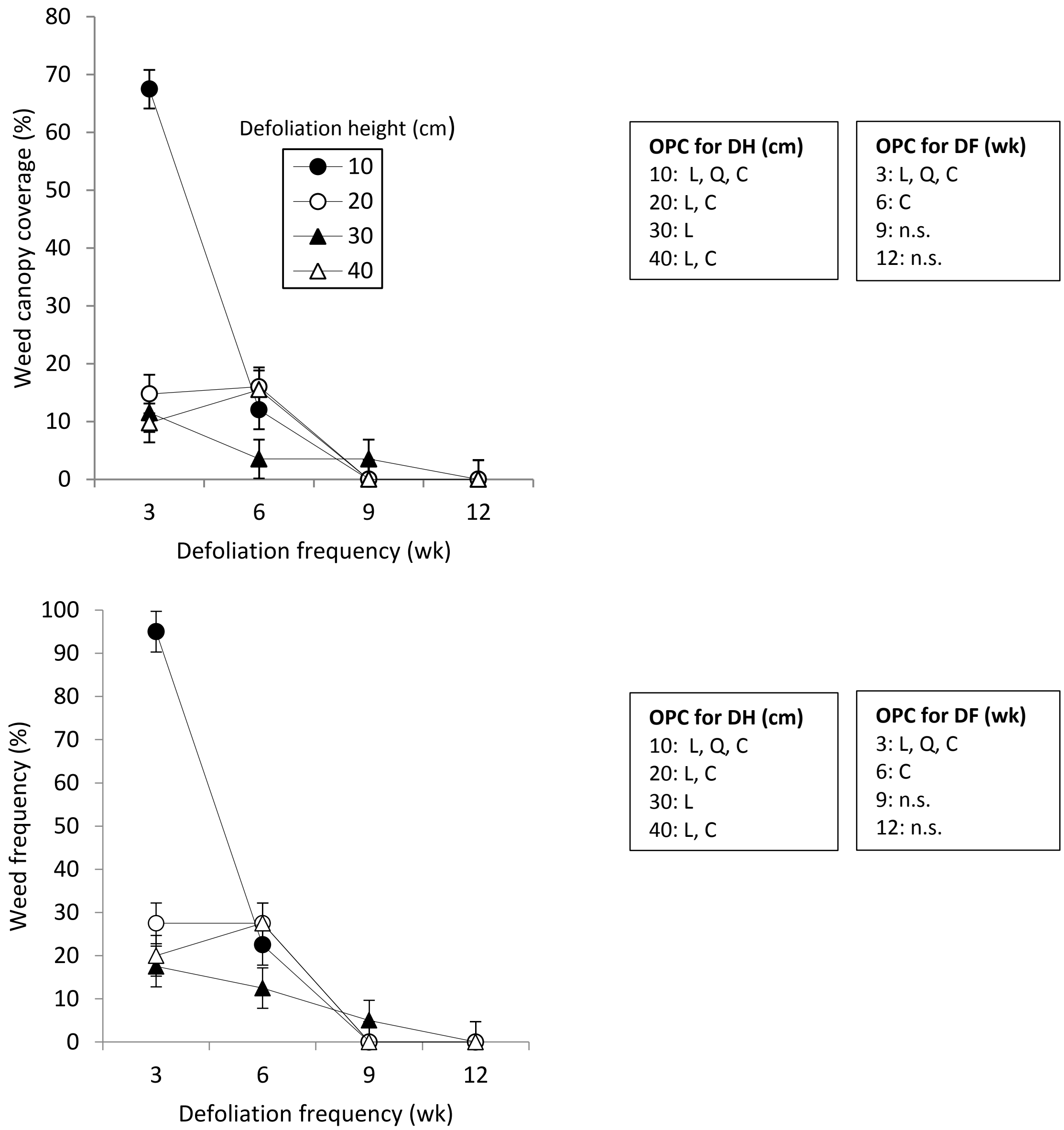

Figure 2.7. Weed canopy cover and frequency of occurrence in ‘Performer’ switchgrass (*Panicum virgatum* L.) grown in Clayton, NC during the May – Oct. 2016 growing season as a function of defoliation frequency (clipped every 3, 6, 9, and 12 wk) and defoliation height (10, 20, 30, and 40 cm stubble height). Cover and frequency were measured once during mid-season (approx. early Aug.). Letters, L = linear, Q = quadratic, and C = cubic represent significant ($P < 0.05$) orthogonal polynomial contrasts (OPC) for defoliation height (DH), and defoliation frequency (DF). Error bars represent treatment means ± 1 standard error. Least significant difference (L.S.D) for weed canopy cover, and frequency (8.88 and 12.41) respectively at $P = 0.05$.

CHAPTER 3. Defoliation Effects on Nutritive Value of Clipped 'Performer' Switchgrass

ABSTRACT

Forages with greater digestibility have potential to positively impact animal responses. 'Performer' switchgrass (*Panicum virgatum* L.) was released because of its greater digestibility compared to standard cultivars grown in the Southeastern USA. Information on defoliation regimes is critical to optimize production of nutritious forage. The objectives of this study were to determine the effect of the factorial combination (4 x 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) on crude protein (CP), digestibility (IVTD), neutral detergent fiber (NDF), and acid detergent fiber (ADF) on 'Performer' switchgrass. The experiment was conducted at the Central Crops Research Station, Clayton, NC. The IVTD ranged from 723 to 755 g kg^{-1} due to DH, being lowest at 10 cm DH and greatest at 40-cm DH; however, the IVTD range was greater due to DF, being lowest for 12-wk DF at 584 g kg^{-1} and greatest for 3-wk DF at 882 g kg^{-1}. The CP ranged from 83 to 99 g kg^{-1} for 9- and 12-wk DF and from 120 to 161 g kg^{-1} for 3- and 6-wk DF. The NDF ranged from 676 to 776 g kg^{-1} and ADF ranged from 342 to 426 g kg^{-1} being lowest for 3-wk DF at 10-cm DH and greatest for 12-wk DF at 10 cm DH. Frequent defoliation strategies such as every 3- and 6-wk DF, and the first harvest of the 9- and 12-wk DF, resulted in general greater nutritive value and could potentially impact animal responses positively; the second harvest for 9- and 12-wk, which are of lower nutritive value, may be used for biomass as an alternative utilization option.

INTRODUCTION

Switchgrass is a warm-season grass that can provide forage during the periods when cool-season grasses are unproductive (Anderson et al., 1989), and in North Carolina specifically, its utilization can start as early as mid-April or early May before ‘Coastal’ bermudagrass [*Cynodon dactylon* (L.) Pers] is ready to graze (Burns et al., 1984). Nevertheless, similar to other warm-season grasses, the nutritive value of switchgrass is initially moderate to high but declines rapidly as the plant matures (Burns et al., 1997; Griffin and Jung, 1983; Perry and Baltensperger, 1979). Burns et al. (1997) reported a decline in dry matter intake of ‘Kanlow’ switchgrass from 1.3 to 0.7 percent of body weight as steers were feed forage with 14-d old intervals starting June 9 concomitant with an increase in NDF concentration (~690 to 790 g kg^{-1}), and decreases of CP (~106 to 37 g kg^{-1}) and digestibility (~577 to 307 g kg^{-1}). Subsequently, it has been recommended that in order to ensure higher nutritive value, switchgrass be hayed or grazed before reaching the R0 (boot) stage (Moore et al., 1991; Burns et al., 1997; Richner et al., 2014). Early-June defoliation of switchgrass prolongs the number of days it is in a vegetative stage, which could improve forage nutritive value in July and August (George and Obermann, 1989) while seeking a compromise between forage yield, quality, and plant persistence (Moser and Vogel, 1994).

Plant breeding efforts have resulted in the development and successful release of cultivars with improved nutritive value, e.g., cultivars ‘Trailblazer’ (Vogel et al., 1991), ‘Shawnee’ (Vogel et al., 1996), and ‘Performer’ (Burns et al., 2008) were all released based on greater digestibility. Switchgrass cultivars with greater digestibility have the potential to positively impact livestock production and to increase animal responses (Anderson et al.

1988). When forage quantity is not the limiting factor, forage nutritive value determines the upper limit of potential animal responses (Sollenberger and Vanzant, 2011). In Nebraska, Anderson et al. (1988) reported greater individual animal average daily gains and gains per hectare for beef steers grazing 'Trailblazer' compared to 'Pathfinder' and another unnamed low digestibility switchgrass entry. Nevertheless, Sanderson (2008) indicated that 'Cave-in-Rock' and 'Shawnee' cultivars are superior (on the basis of less disease and lodging) to 'Trailblazer' for hay or grazing in northeastern USA. Cultivar 'Performer' of switchgrass is an eight-clone synthetic selected from lowland ecotypes, released for its improved digestibility (at least four percent points greater) compared to 'Alamo' and 'Cave-in-Rock', and with primary area of adaptation being the southern USA. (Burns et al., 2008). In North Carolina, Burns and Fisher (2013) reported average daily gain values of 0.91 kg and weight gains up 839 kg ha^{-1} yr^{-1} at a stocking rate of 6.1 steers $ha^{-1}$for steers grazing 'Alamo' switchgrass of approximately 677 g kg^{-1} digestibility and 103 g kg^{-1} crude protein concentrations. Therefore, on the basis of greater nutritive value, animal responses could potentially be greater if grazing 'Performer' switchgrass compared to 'Alamo'.

Information on defoliation management effects is critical to develop strategies that optimize the balance between forage quantity and nutritive value without compromising forage persistence. To date, there is limited information on the effect of defoliation management on productivity, persistence, and nutritive value of 'Performer' switchgrass. Therefore, the objectives of this experiment were to determine the effects of defoliation frequency and defoliation height on 'Performer' switchgrass' crude protein (CP), *in vitro* true digestibility (IVTD), neutral detergent fiber (NDF) and acid detergent fiber (ADF).

MATERIALS AND METHODS

Experimental Site, Plot Management, and Sample Collection

The experiment is under way for a second year (2017); therefore, data presented corresponds to year one (2016) only. The experimental area consisted of a 50 by 51.5-m plot of well-established (> 8 yr) ‘Performer’ switchgrass located at the Central Crop Research Station, Clayton, NC (35°40´ N, 78°29´ W). Original planting of switchgrass occurred in rows spaced 1.25-m apart, however, actual row spacing at initiation of this trial was much narrower as switchgrass bunches grew and spread overtime from rhizomes at the base of the original plant. Plot management in the years previous to this trial consisted of annual maintenance soil fertilization as recommend by soil analysis and a single forage clipping to ~10-cm stubble height in late Sept. followed by residue-burning on Feb. In preparation for imposing treatments in early spring of 2016, the accumulated biomass from the 2015 growing season was clipped and removed from the plots in the late Sept. 2015 and herbicide Remedy Ultra [triclopyr (3, 5, 6-trichloro-2-pyridinyloxyacetic acid, butoxyethyl ester); 2.13 kg a.i. ha^{-1}] was applied on 11 April 2016. The soil type was classified as Wedowee sandy loam (Fine, kaolinitic, thermic Typic Kanhapludults). Initial soil characterization (0 to 15 cm deep) from samples taken on Feb. 2016 indicated pH of 6.0 and Mehlich 3 extractable P, K, Ca, and Mg concentrations (mg kg^{-1}) of, 205, 195, 733, and 218, respectively. Based on soil test recommendations, only N fertilizer was applied at the rate of 134 kg N ha^{-1} by broadcasting a granular formulation of Urea-Ammonium Sulfate blend (340 g N kg^{-1}) in a single application on mid-April of each year.

Samples were collected by harvesting a 3- by 2.5-m quadrat along the two-center rows using hedge trimmers. A sub-sample (0.5 – 1.0 kg) from the clipped forage was dried in a forced-air oven at 60°C to constant weight and ground in a Christy Norris laboratory mill (Christy Turner Ltd., Suffolk, UK) to pass through a 1-mm screen in preparation for further analysis. The numbers of clipping events in 2016 were 8, 4, 2, and 2 for frequencies of defoliation every 3, 6, 9, and 12 wk, respectively. Day zero was fixed on 18 April 2016. The first harvest event of the season occurred when canopy height was ~40 cm tall on 9 May 2016 and a total of 16 plots were harvested (3-wk treatments only). The last harvesting event occurred on 15 Oct. 2016.

Treatments and Experimental Design

There were 16 treatments total resulting from the factorial combination of four defoliation frequencies and four defoliation heights. Defoliation frequency (DF) levels were: clipping every 3, 6, 9, and 12 wk, and defoliation height (DH) levels were: 10, 20, 30, and 40 cm stubble height. Treatments were randomly allocated to experimental units arranged in a randomized complete block design replicated four times. Experimental unit size was 5-m wide by 5-m long and consisted of four switchgrass rows.

Response Variables

Crude protein, IVTD, NDF, and ADF concentrations were determined using near-infrared spectroscopy. Calibration equations were developed correlating NIR spectra to CP, IVTD, NDF, and ADF measured using wet chemistry. Samples were scanned using a 5000 NIRS equipment (Foss North America, Inc., Eden Prairie, MN) and reflectance was determined in 2 nm wavelength-increments (from 1100 to 2500 nm). Wet chemistry analyses for CP, IVTD, NDF, and ADF were performed at Dairy One Laboratory (Ithaca, NY) (Dairy One, 2015). In summary for wet chemistry analyses, CP was calculated by multiplying the concentration of total N (determined by dry combustion) by 6.25; IVTD was determined through a 48-h *in vitro* digestion procedure, and NDF and ADF were determined using an Ankom fiber analyzer.

Eighty-two samples, which correspond to 34% of the total number of samples in the dataset, were randomly selected for wet chemistry analysis and used for model selection, calibration, and validation using a NIR pipeline (unpublished) in R. Mathematical pretreatments applied to the spectra were Savitzky-Golay smoothed spectra (using seven points; SG-7) for CP, detrend for IVTD, and standard normal variate followed by SG-7 for both NDF and ADF. Partial least square equations were then developed and cross-validation was performed using 'leave-one-out'. Number of factors in the model, coefficient of determination (R^2), and root mean square errors of prediction (RMSEP) were: 8 factors, 96.9% R^2, and 0.75 RMSEP for CP; 10 factors, 97.9% R^2 and 2.14 RMSEP for IVTD; 8 factors, 91.6% R^2, and 1.31 RMSEP for NDF; and 4 factors, 95.0% R^2, and 1.15 for ADF. These equations were then used to predict the nutritive value of the remaining samples.

Statistical Analysis

Data were analyzed using PROC GLIMMIX of SAS (SAS Institute, 2010). Treatments were fixed effects. Block was considered a random effect. In the case of two-way interactions, simple effects were analyzed using the SLICE procedure of SAS and mean separation was based on the SLICEDIFF option of LSMEANS. Orthogonal polynomial contrasts (linear, quadratic, and cubic) were used to determine the effect of defoliation height using the LSMESTIMATE procedure. Plots of model residuals were used to check normality. Treatment effects were considered significant if $P \leq 0.05$.

RESULTS AND DISCUSSION

Crude Protein (CP)

Crude protein (CP) ranged from 83 to 161 g kg^{-1}. There was an interaction effect of DF by DH ($P < 0.001$). The interaction effect occurred because DH effect was significant at 3- and 12-wk DF only (Fig. 3.1). For 3-wk DF, CP decreased with linear effect from 161 g kg^{-1} at 10 cm DH to 138 g kg^{-1} at 40 cm DH. For 12-wk DF, the trend was reversed, and CP concentration increased linearly from 84 g kg^{-1} at 10 cm DH to 99 g kg^{-1} at 40 cm DH. Concentration of CP was intermediate with 125 and 85 g kg^{-1} for 6- and 9-wk DF treatments, respectively.

Following a three-clippings per year schedule for switchgrass in North Carolina, Burns et at. (2008) reported CP concentration of 72 g kg^{-1} for ‘Performer’, ‘Alamo’, and ‘Cave-in-Rock’. The CP concentration of 72 g kg^{-1} reported by Burns et al. (2008) is similar to our 9- and 12-wk DF treatments (Fig. 3.1) which were defoliated two times during the growing season. The longer the regrowth period, the more mature the forage, and the lower the nutritive value; this response has been extensively documented in the literature for switchgrass. In North Carolina, Burns et al. (1997) reported CP decreased from ~106 to 37 g kg^{-1} for ‘Kanlow’ switchgrass as harvest was delayed from June 9 to August 4. Similarly, in Mississippi Seepaul et al (2017) reported N concentration of ‘Alamo’ switchgrass decreased by almost threefold (from 165 to 53 g kg^{-1}) when defoliation frequency decreased from 6 to 1 clippings per year. In Illinois, Twidwell et al. (1988) reported CP decreased from ~170 to 100 g kg^{-1} for cultivars 'Pathfinder', 'Cave-In-Rock', and 'Trailblazer' when harvest was delayed from 0 to 28 days after appearance of the flag leaf. 'Performer' CP concentration values in our study also followed the same general pattern of CP decreasing with more mature forage reported for other cultivars of switchgrass. The lowest CP concentration from treatments 9- and 12-wk DF, corresponding to two clippings per year, were ≥ 80 g kg^{-1}.

***In vitro* True Digestibility (IVTD)**

There were main effects of DH and DF ($P < 0.001$ for both factors) on IVTD. The extent of treatment impacts on IVTD was greater for DF (ranging from 584 to 883 g kg^{-1}) compared to DH (ranging from 723 to 755 g kg^{-1}) (Fig. 3.2). Greater IVTD values were achieved with frequent defoliations and also with clipping to greater stubble heights. In North Carolina, Burns et al. (2008) reported IVTD of 565 g kg^{-1} for 'Performer' switchgrass defoliated in a three-clipping per year system (harvest occurred in May, July and Oct.) and this value coincides with the 12-wk DF in our study where switchgrass was defoliated two times per year (mid-July and early-October).

Richner et al. (2014) at Columbia and Mt. Vernon, MO reported that late summer regrowth of switchgrass tended to be more lignified and less digestible compared to harvest at the R0 stage. Similarly, in Missouri Anderson and Matches (1983) reported that IVTD of 'Pathfinder' switchgrass declined rapidly as plants matured to the heading stage and suggested that grazing should begin prior to the boot stage. Lignin in the cell wall inhibits digestion of forage in the rumen (Jung and Allen, 1995). In agreement with the findings of

Richner et al. (2014), Burns (2011) reported greater lignin concentration concomitant with lower IVTD, for switchgrass regrowth (grown from June to August) compared to initial growth (until late June). Moore and Jung (2001) noted that the enzymes that synthesize lignin are more active as temperature increases. Van Soest et al. (1978) reported that plants grown in greater temperature tend to be more lignified. In our experiment, 'Performer' switchgrass clipped every 3- and 6-wk DF had greater IVTD compared to 9- and 12-wk DF (Fig. 3.2). This pattern is consistent with previous reports in the literature and reflects the longer regrowth period resulting in aging plants that grew at higher temperatures and lower precipitation during the mid-part of the summer (Fig. 2.1 in chapter 2).

Neutral Detergent Fiber (NDF)

The NDF concentration ranged from 676 to 776 g kg^{-1}. In general, lower NDF values occurred with less mature forage under frequent defoliation; however, NDF concentration at each DF treatment varied depending on DH. There was an interaction effect for DF by DH ($P < 0.001$). The interaction effect occurred because there were DH effects on NDF concentration for all DF treatments except for 9-wk DF (752 g kg^{-1}) (Fig. 3.3). The NDF concentration increased from 676 to 719 g kg^{-1} at 3-wk DF (linear and quadratic effects) and from 721 to 737 g kg^{-1} at 6-wk DF (linear effect) as DH height increased from 10 to 40 cm stubble height; nevertheless, this trend was reversed for more mature forage and at 12-wk DF treatment the NDF concentration decreased linearly from 772 g kg^{-1} at 10-cm stubble height to 755 g kg^{-1} at 40 cm stubble height (Fig. 3.3).

Greater NDF concentrations occurs with more mature forage and our results agree with several previous reports in the literature for switchgrass. In Texas, Sanderson et al.

(1999) reported that the NDF concentration of the last clipping event at the end of the growing season for ‘Alamo’ switchgrass was lower (688 g kg^{-1}) when clipped 4 times per year compared to 740 g kg^{-1} for a single clipping per year. In addition, the same authors reported that NDF concentration increased from 705 to 729 g kg^{-1} as the last harvest of the season was delayed from Sept. to Nov. Consistent with previous reports, these responses can be explained due to plant aging and transitioning from vegetative to reproductive stages, as forage quality of switchgrass typically decreases with maturity (Burns et al., 1997; Griffin and Jung, 1983; Sanderson and Wolf, 1995; Mitchell et al., 2001; Twidwell et al., 1998) and also due to lower leaf:stem ratio (Fig. 2.3 Chapter 2) and greater NDF concentration in the stem component than leaf (Hans-Joachim and Vogel, 1992). Griffin et al. (1980) and Van Soest (1965) suggested that when the levels of NDF exceed 50 to 60%, this may result in limited herbage intake. Anderson and Matches (1983) recommended that clipping or grazing ‘Pathfinder’ switchgrass at juvenile stage may increase voluntary intake since matured ‘Pathfinder’ switchgrass always contained over 65% NDF, and occasionally over 80% NDF, and intake by livestock grazing may be limited by distension. This may be applicable to our study with the higher DF treatments (Fig. 3.3).

Acid Detergent Fiber (ADF)

The ADF concentration ranged from 342 to 426 g kg^{-1} and in general followed the same response pattern as NDF. There was an interaction effect for DF by DH ($P < 0.001$). The interaction effect occurred because there were DH effects for 3-wk and 12-wk treatments only (Fig. 3.4). Concentration of ADF at 3-wk DF increased linearly from 341 to 361 g kg^{-1} as DH decreased from 40 to 10-cm stubble height; however this trend was reversed for 9-

and12-wk DF and ADF concentration ranged from 399 g kg^{-1} at higher stubble heights to 426 g kg^{-1} at lower stubble heights. (Fig. 3.4). In South Dakota, Mulkey et al. (2008) reported harvest timing as the primary factor affecting ADF concentration, and reported that ADF concentration between anthesis (late July to early Aug.) and killing frost (early Oct.) increased from ~363 to 409 g kg^{-1} (averaged across two locations) for switchgrass, big bluestem (*Andropogon gerardii*) and indiangrass (*Sorghastrum nutans*) mixtures. Lee et al. (2007) reported a similar response in South Dakota with greater ADF concentration due to longer switchgrass regrowth period. Switchgrass leaf:stem ratio decreases as plants mature resulting in further increases in concentration of ADF (Griffin and Jung, 1983). Previous findings about ADF concentration as a function of more mature plants are similar to our findings in this experiment with 'Performer' switchgrass. In general, greater ADF concentrations were found for more mature plants concurrent with lower leaf:stem ratio (Fig. 2.3 in chapter 2).

SUMMARY AND CONCLUSIONS

The concentrations of CP, IVTD, NDF, and ADF of 'Performer' switchgrass varied due to frequency and height of defoliation. Crude protein concentration ranged from 83 to 161 g kg^{-1} and remained above 100 g kg^{-1} only for 3- and 6-wk DF treatments. There was an interaction effect of DH by DF for CP, and there was greater CP at lower stubble heights at 3-wk DF but a reverse trend occurred at 6-wk DF. The *in vitro* true digestibility (IVTD) ranged from 723 to 755 g kg^{-1} due to defoliation height, being lowest and greatest for 10- and 40-cm DH, respectively; however, the IVTD range was greater due to DF being lowest for 12-wk DF at 584 g kg^{-1} and greatest for 3-wk DF at 883 g kg^{-1}. The NDF and ADF concentrations followed the same general pattern with lower concentrations at less mature forage (i.e. shorter regrowth period). The NDF concentration ranged from 676 to 776 g kg^{-1} and ADF concentration ranged from 342 to 426 g kg^{-1}. The CP and IVTD increased with frequent defoliation while decreased with infrequent defoliation. The reversed was the case for ADF and NDF as both increased with infrequent defoliation and decreased with frequent defoliation. In conclusion, ‘Performer’ switchgrass is a productive forage and high nutritive value is dependent on management with greater impact from frequency of defoliation. Frequent defoliation strategies such as every 3- and 6-wk DF, and the first harvest of the 9- and 12-wk DF resulted in greater nutritive values (i.e. higher CP and IVTD with lower NDF and ADF) and will positively impact animal responses while the second harvest for 9- and 12-wk DF may be used as hay or for biomass due to greater NDF and ADF concentrations.

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FIGURES

Crude Protein

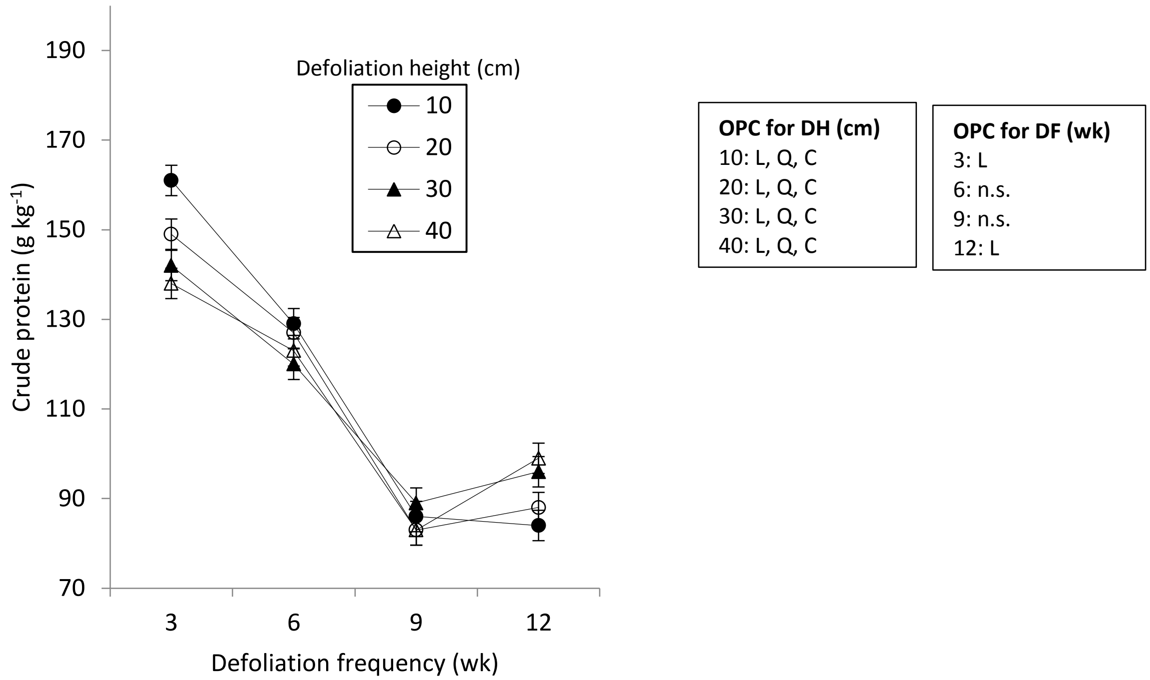

Figure 3.1. Crude protein (CP) concentration of 'Performer' switchgrass (*Panicum virgatum* L.) grown in Clayton, NC during the May – Oct. 2016 growing season as a function of defoliation frequency (clipped every 3, 6, 9, and 12 wk) and defoliation height (10, 20, 30, and 40 cm stubble height). Letters, L = linear, Q = quadratic, and C = cubic represent significant ($P < 0.05$) orthogonal polynomial contrasts (OPC) for defoliation height (DH), and defoliation frequency (DF). Error bars represent treatment means ± 1 standard error. Least significant difference (L.S.D) = 8.4 at $P = 0.05$.

In vitro true digestibility (IVTD)

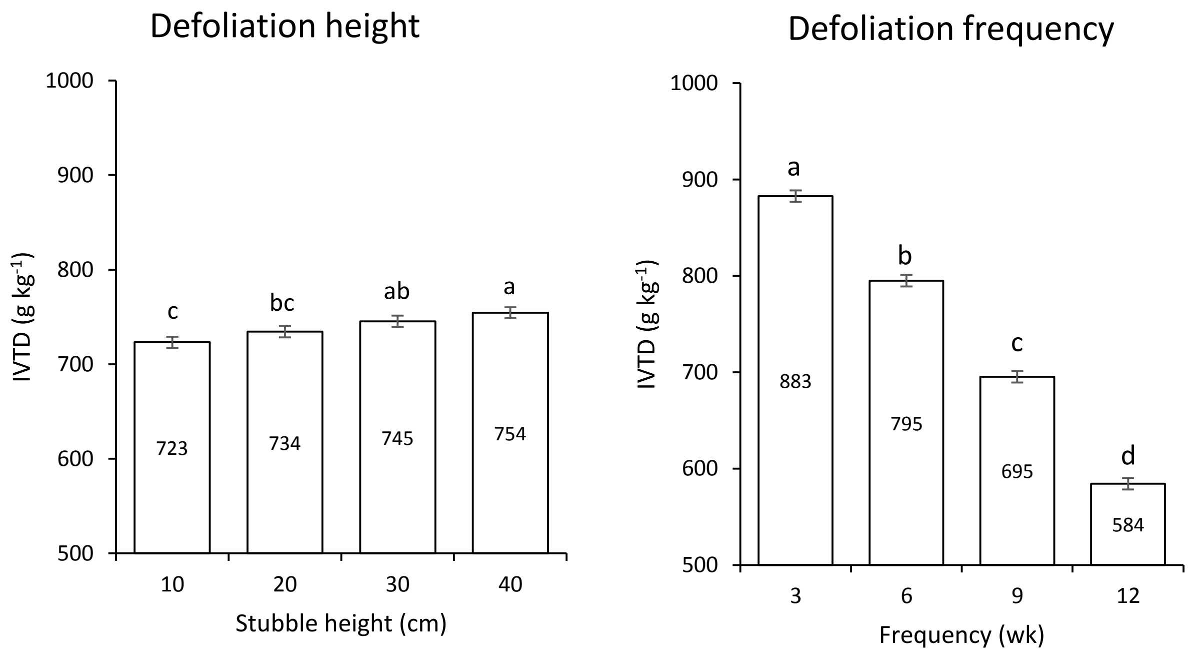

Figure 3.2. *In vitro* true digestibility (IVTD) of 'Performer' switchgrass (*Panicum virgatum* L.) grown in Clayton, NC during the May – Oct. 2016 as a function of defoliation frequency and defoliation height. Bars with different letters denote statistical difference ($P < 0.05$). Error bars represent treatment means ± 1 standard error.

Neutral detergent fiber (NDF)

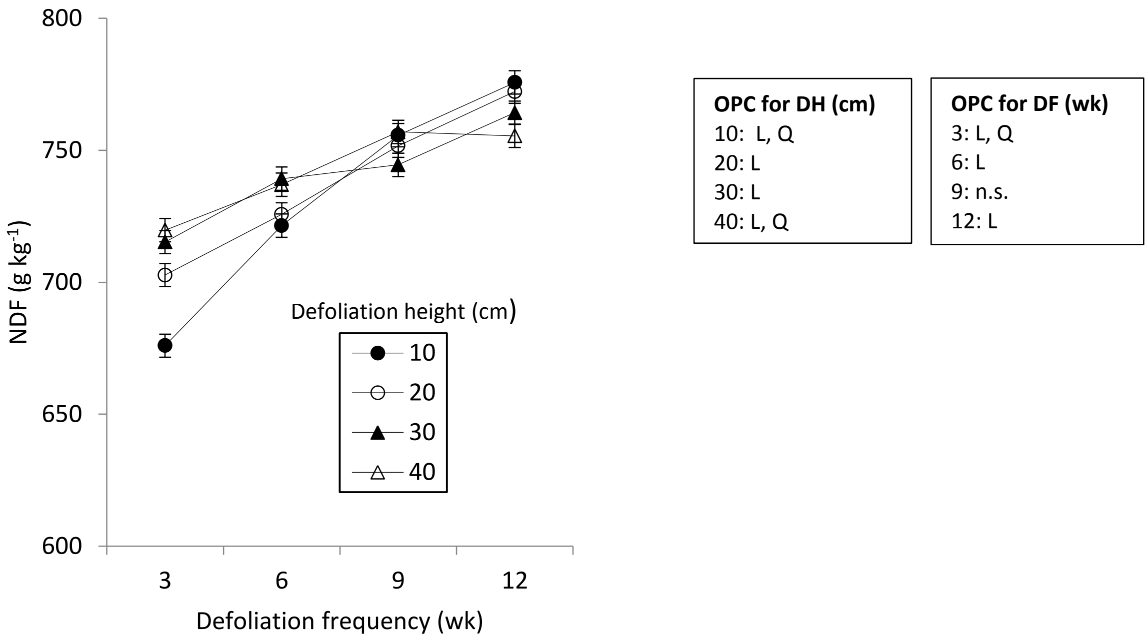

Figure 3.3. Neutral detergent fiber (NDF) of 'Performer' switchgrass (*Panicum virgatum* L.) grown in Clayton, NC during the May – Oct. 2016 growing season as a function of defoliation frequency (clipped every 3, 6, 9, and 12 wk) and defoliation height (10, 20, 30, and 40 cm stubble height). Letters, L = linear, Q = quadratic, and C = cubic represent significant (P < 0.05) orthogonal polynomial contrasts (OPC) for defoliation height (DH), and defoliation frequency (DF). Error bars represent treatment means ± 1 standard error. Least significant difference (L.S.D) = 11.98 at P = 0.05.

Acid detergent fiber (ADF)

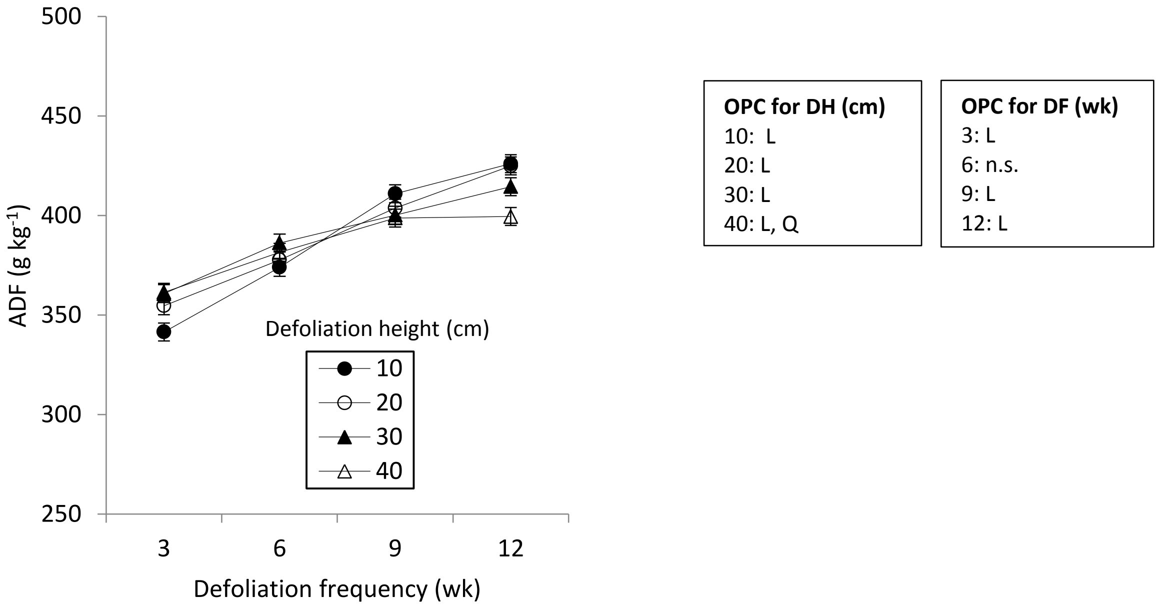

Figure 3.4. Acid detergent fiber (ADF) of 'Performer' switchgrass (*Panicum virgatum* L.) grown in Clayton, NC during the May – Oct. 2016 growing season as a function of defoliation frequency (clipped every 3, 6, 9, and 12 wk) and defoliation height (10, 20, 30, and 40 cm stubble height). Letters, L = linear, Q = quadratic, and C = cubic represent significant ($P < 0.05$) orthogonal polynomial contrasts (OPC) for defoliation height (DH), and defoliation frequency (DF). Error bars represent treatment means ± 1 standard error. Least significant difference (L.S.D) = 12.57 at $P = 0.05$.