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Reducing Mowing Requirements in Home Lawn and Golf Course Turfgrass

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REDUCING MOWING REQUIREMENTS IN HOME LAWN AND GOLF COURSE TURFGRASS

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REDUCING MOWING REQUIREMENTS IN HOME LAWN AND GOLF COURSE TURFGRASS

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Turfgrass systems are routinely managed by frequent mowing to increase aesthetics and function. Mowing is resource intensive with a high labor and energy demand. Reducing the number of mowings events in a growing season will decrease the labor and energy but may reduce quality as well. Previous work has looked at reducing mowing by changing the frequency and by using a plant growth regulator (PGR). Limited information is available about how to reduce mowing while maintaining acceptable quality. We looked at two different management practices to reduce mowing and maintain quality. The first study evaluated seven different mowing frequencies at two mowing heights (7.6 cm and 5.1 cm). Dry clipping yield mass was measured and the total number of mowing events were recorded from the different treatments. Weekly visual quality ratings were recorded using the NTEP scale. Removing one-third of the leaf biomass at mowing minimized mowing requirements while it sustained turfgrass quality rating. Mowing more frequently increased further improved turfgrass quality. The second study examined lengthening the longevity of suppression from two PGRs by the inclusion of various surfactants with the application Clipping suppression was modeled with sine-wave regression to determine the suppression of both PGRs and for comparison of clipping yield suppression provided by the PGR applied alone. Visual quality declined in with the straight block co-polymer surfactant.

DEDICATION

This thesis is dedicated to my parents Steve and Angie Keck and the memory of my grandma Evie Kroeger. My parents have always supported and encouraged my academic pursuits. My grandma Evie taught me to always persevere through any difficulties in life. She was faced with polio as a child. She was in a terrible car accident during my first semester of my MSc. She never stopped persevering and always overcame life’s challenges.

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CHAPTER ONE: ICREASING TALL FESCUE LEAF REMOVAL RATE INCREASES VISUAL QUALITY WHILE REDUCING CLIPPING YIELD

ABSTRACT

Mowing is a cultural practice needed to maintain an attractive looking lawn. Mowing requires labor and increases the net C emission. Reducing mowing decreases labor and net carbon emission. Recommendations for mowing tall fescue (TF) [*Schedonorus arundinaceus*, (Schreb)] lawns are to removing33% of leaf blades with each mowing (LRM). No one has examined the effect of removing 25% LRM or 50% LRM. . The objectives of this study were to determine (i) how the different mowing frequency and height of cut (HOC) effected clipping yield, (ii) how the different mowing frequencies and HOC effected the number of mowing events during a year, (iii) the impact of HOC and mowing frequency on the visual quality of TF. The 5.1 cm HOC had 57 g m^{-2} of clipping yield than the 7.6 cm HOC. The lower HOC had more mowings than the higher HOC. Visual quality rating (based on color and density) increased as the number of mowings increased. Mowing at 25% LRM and 33% LRM had an acceptable quality with the fewest number of mowing. A homeowner should mow at a 33% LRM at a 7.6 cm height to reduce the number of mowings while maintaining an acceptable quality.

INTRODUCTION

One of the fundamental cultural practices in turfgrass management is the routine removal of leaf tissue via mowing. The advantages of mowing include the removal of the older leaves, maintained aesthetic value (visual rating), increased penetration of active radiation into the leaf canopy, and improved weed control (Lommen et al., 2018). Disadvantages of mowing include a temporary cessation of root growth, reduced carbohydrate production, new ports of entry for diseases, and temporarily increased water loss from leaf blade cut (Inguagiato, et al., 1999). Mowing practices are labor and energy-intensive (Wu, 2019). A logical goal is to schedule mowings would maximize the positive plant responses and minimize the negative plant responses.

For over a century, turfgrass managers and researchers have tried to determine an optimal mowing height and frequency to balance opposing turfgrass responses to mowing. Researchers have measured plant productivity such as root and shoot biomass and performance attributes including visual turfgrass quality in cool-season lawn species (Dickinson, 1931; Harrison, 1933; Felix, et. al, 1961; Law et. al, 2016). Dickinson (1930) recommended that turfgrass areas maintained as lawns be maintained 1.3 cm less than the ideal height of cut (HOC) and that grasses should be mowed when the turfgrass was 1.3 cm greater than that ideal HOC. Harrison (1933) determined the ideal HOC for different lawn species: Kentucky bluegrass [*Poa pratensis,* (L)], red fescue [*Festuca rubra,* (L)], and colonial bentgrass [*Agrostis capillaris,* (L)]. Harrison found at the lowest HOC (0.6 cm) vegetative biomass production decreased compared to turfgrass mowed at a higher HOC (7.6 cm). The shorter HOC reduced root growth as well (Harrison, 1933). Other mowing studies have there is a reduction in root mass when the turf sward is mowed more frequently (Madison, 1931; Harrison, 1933).

These research studies led to the creation of the "one-third rule" (will be referred to as 33% LRM). This recommendation was to mow when one-third of the turfgrass grass leaf height would be removed from the stand of any turf species. Wise (1961) recommended to, "never remove more grass than you leave" which would represent 50% leaf removal. Removing too much leaf tissue could result in scalping and dramatic reduction in visual turfgrass quality. These studies and statements have since been widely published in turfgrass management textbooks, extension documents, and other lawn and turf care information (Beard, 1973; Christians et al., 2016; Reicher, 2006; Turgeon, 1985; Waddington et al., 1992).

Fifty years later, Law et al., (2016) compared 33% LRM to a weekly mowing schedule for three cultivars of Kentucky bluegrass and (TF) cultivars in Indiana. Law et al., (2016) showed that the 33% LRM mowing reduced the number of mowings compared to weekly treatment. The reduction in LRM saved labor and reduced energy requirement by at least seven mowings. Both mowing frequencies produced acceptable visual turfgrass quality. The 33% LRM method was more efficient than weekly mowing because it allowed for different mowing intervals as growth rate changed during the growing season. The researchers did not measure cumulative biomass production which directly impacts nutrient requirements and carbohydrate partitioning.

While the 33% LRM interval outperformed weekly mowing, it has still not been evaluated against other leaf removal thresholds and at differing mowing heights in cool-season lawn species. This objectives of this research were to determine (i) how the different mowing frequency and height of cut (HOC) effected clipping yield, (ii) how the number of mowings varied between mowing frequencies, and (iii) HOC the impact of HOC and mowing frequency on the visual quality of TF.

MATERIALS AND METHODS

Site Description

A field experiment was conducted on a TF research plot located at the East Campus Turf Plots in Lincoln, NE (40°50'09.6"N 96°39'54.7"W) during 2017 and 2018. The plot areas were established in 2014 and were maintained as a lawns. The field soil type was a Kennebec urban fine silt (mesic Cumulic Hapludolls) with a pH of 6.4. Overhead irrigation supplemented precipitation to 80% of estimated evapotranspiration as calculated by an on-site weather station daily. Soil tests indicated that soil test P and K were sufficient, and urea (46-0-0) was applied in liquid form twice monthly at 9.8 kg N ha^{-1} from 1 Apr. to 15 Oct. during both years. No pesticides were applied to the study, and weeds were removed by hand.

Experimental design

The experiment was conducted in a randomized incomplete block design with split-strip plot treatment arrangement with three replications. Whole plots measured 1.8 x 2.4 m and included seven different mowing frequency treatments. Four of the mowing frequency treatments were based on calendar intervals (weekly, monthly, twice annually and annually; Table 1.1). All replicates in these calendar-based intervals were mowed at the same time, as scheduled. The other three mowing frequencies were based on LRM threshold percentage, which are described in more detail below. Whole plots were split into 0.9 x 2.4 subplots of either a low HOC (5.1 cm) or high HOC (7.6 cm).

For the LRM treatments, mowing occurred when the mean canopy height for an individual experimental unit exceeded a predetermined canopy height threshold.

Thresholds were a based on the amount of canopy height removed at each HOC. The LRM levels were 25%, 33%, and 50% of the canopy height. For the low HOC (5.1 cm), mowing were triggered treatments that had a mean canopy height greater than 6.8, 7.6, or 10.2 cm for the 25%, 33%, and 50% LRM treatments, respectively. The high HOC (7.6 cm) treatments were mowed when the mean canopy height were greater than 10.2, 11.4, or 15.2 cm for the 25%, 33%, and 50% LRM treatments, respectively.

Mean canopy height of each experimental unit was measured three days wk^{-1} using a modified disk method (Bransby et al., 1977; Law et al., 2016). A rectangular piece of corrugated plastic cardboard (24 x 31 cm; 47 g) was placed on the turfgrass stand. A ruler was placed through a small slot in the middle of the board to measure the height of the canopy above the soil surface. This measurement was replicated three to five times over each plot to establish a mean canopy height. Once the required LRM thresholds had been surpassed, mowing treatment occurred on that day.

Data Collection

Cumulative clipping dry matter yield was determined by collecting clippings for every mowing in both years. Clippings were collected by mowing each experimental unit with a John Deere JX75 (John Deere Co, Moline, IL) rotary mower that was amended to discharge cut clippings into a mesh bag. Prior to clipping collection, 0.6 m buffer alleys were mowed down each side of the experimental unit (3.8 cm HOC) to minimize variation from stopping and starting the mower and to prevent mowing into adjacent plots. The collected clippings were placed into a paper bag, dried for 48 h at 60C and weighed to determine clipping yield. Collections occurred between 24 Apr. to 2 Nov. 2017 and 20 May to 19 Oct. 2018.

Turfgrass visual quality was rated weekly in accordance with the National Turfgrass Evaluation Program (NTEP) guidelines for assessing turfgrass performance (Morris and Shearman, 2007). The visual quality rating was based on the aggregate assessment of color, stand density, and visual uniformity expected for a TF lawn. Visual quality was collected weekly using the National Turfgrass Evaluation Program (NTEP) 1-9 rating system, with a six or greater being acceptable (Krans and Morris, 2007).

Statistical Analysis

Cumulative annual yield was calculated as the summation of all the clipping yields collections within each experimental until at the end of 2017 and 2018. Monthly average turfgrass quality ratings were also calculated from the weekly ratings to account for variability within each month resulting from the different mowing frequencies. The resultant cumulative yields, number of mowings from the LRM treatments, and monthly average turfgrass quality ratings where then subject to ANOVA in JMP 15 (SAS Institute, Cary, NC). Means were separated when appropriate with Students LSD ($p<0.05$).

Unlike the calendar-based mowing intervals, the LRM threshold treatments were mowed as needed. All calendar based mowing of the same frequency treatment occurred on the same calendar day. The 25%, 33%, and 50% LRM treatment frequencies were mowed on different calendar days from each other. The variation in the date collected among the same frequency treatment allowed for statistical separation of the mowing requirement or the three treatments (25%, 33%, and 50% LRM).

Annual cumulative clipping dry matter yield and mean annual turfgrass quality rating were plotted as a function of the total number of mowings from all treatment combinations and subjected to quadratic regression. Values from 2017 and 2018 were combined in this analysis. The resultant quadratic models were solved to understand the number of mowings required to sustain acceptable turfgrass quality (y=6.0) and produce the desired growth rate range. The ideal mowing timing for TF in Lincoln, NE could then be determined as the number of mowings required to produce acceptable visual TF quality and produce the lowest cumulative dry matter.

RESULTS AND DISCUSCION

Cumulative Clipping Dry Matter Yield

Tall fescue cumulative annual clipping dry matter yield was influenced by year, HOC and mowing frequency (Table 1.2). No interactions occurred. When averaged across all treatments, 455 gm^2 clippings were produced in 2017 and 363 gm^2 2018. The TF broke winter dormancy earlier in 2017 than 2018, Thereby resulting in a longer growing season in 2017. The weather within the two growing seasons differed (Fig 1.1). The monthly temperatures and total precipitation was the months of June, August, September but, May and July of 2018 were drier compared to the same months in 2017 (Fig. 1.1). Kiniry et al. (2017) modeled the biomass accumulation of TF and showed the biomass yield increased with greater precipitation across a bimodal curve. This was likely the result of increased nitrogen mineralization that drives turfgrass clipping yield production. Orloff et al. (2016) found that the timing of irrigation can decrease biomass of TF. They found a 33% decrease in cumulative yield when irrigating ceased in early-season compared to watering all season long. In addition, a 25% yield reduction occurred when irrigation ceased during the middle of the season. In our study, the increased rain in May and July likely increased the yield in 2017 over these in 2018.

The cumulative clipping of 438 gm^{-2} at 5.1 cm HOC was greater than the 381 gm^{-2} yield at 7.6 cm HOC Brink et al. (2010) showed a similar growth response on stands of meadow fescue [*Festuca pratensis,* (Huds.)] TF, and orchardgrass [*Dactylis glomerata,* (L)] mowed at a 5 cm HOC and to 10 cm HOC. The turf mowed at 5.1 cm HOC in this study had a higher leaf density than turf maintained at 7.6 HOC. While tiller density was not measured in this study, other research has found a direct relation between HOC and stand density (Holt and Lancaster, 1968; Sheffer et al., 1978). The added number of tillers and leaves could have increased the clipping yield. Another possible reason for the difference between the HOC could be attributed to differences in leaf area index (LAI). Increasing HOC has been shown to increase turfgrass LAI (Schut and Ketelaars, 2003). It is likely that the 7.6 cm HOC TF is near a physiologically optimum leaf area index which could reduce clipping yield production. Schut and Ketelaars (2003) found that a leaf area index was inversely correlated to clipping yield production.

Mowing frequency was a source of variability for cumulative clipping yield. Generally, more frequently mowed treatments had at least 200 gm^{-2} of cumulative clipping production less than the infrequently mowed treatments (Table 1.3). The weekly mowing interval and the three LRM threshold treatments produced similar cumulative clipping yields, and all had less clipping yield than the once and twice annual mowed plots. The monthly mowing interval also produced less cumulative clipping yield than the once and twice annual mowing treatments, but it was greater than the 25% LRM treatment. Brink et at. (2010) reported the in the turf sward of TF, orchard grass, and meadow fescue mowed six times during a growing season (mowed every three weeks) produced less cumulative yield than the turf sward that was mowed only three times during growing season.

The trend of the cumulative yield decline with increased number of mowings may be explained by the inverse response of the herbivory effect (Strauss and Agrawal, 1999). The herbivory effect is a strategy in which a plant reduces the amount of vegetation being produce above ground to overcome the stress of or mowing. The more frequent a plant is the grazed, the less vegetation is produce. Schönbach et al., 2010 found that the above ground biomass of grass is reduced as cutting or grazing is increased in a system. The steppe vegetation included keng (*Cleistogenes squarrosa*, Trin.), Korean needlegrass (*Stipa grandis*, P.A. grandis), and false wheatgrass (*Leymus chinensis*, Trin.). Sheep grazed a steppe pasture at different intensities (Schönbach et al., 2010). The biomass of all the vegetation declined as the treatments changed from ungrazed to very-light grazed to light grazed, and light moderate grazed. If yields are decreased as mowings are increased, some frequencies may be mowed more than the required amount for maintenance. In our study, the less frequently mowed treatments had the highest cumulative yield. The treatment mowed more often had lower cumulative yield. This decrease in yield as mowing increases supports the idea that the intensity of the mowing frequency can vary the growth rate of the turf sward (Biran et al., 1981).

Clipping yield production was highly correlated to color, density, and overall health. Excessive turfgrass growth from N fertilizer application, soil N mineralization or favorable environmental conditions can alter carbon partitioning away from roots and other storage organs and increased demand for other essential nutrients (Kussow et al., 2012). Plant growth regulators are frequently applied to turfgrass to suppress clipping yield. Routine applications of these products are known to reduce N requirements, improve density, turfgrass quality and increase non-structural carbohydrate reserves (Ervin and Koski, 1998, 2001, Stier and Rogers, 2001, Han et al., 1998, 2004; Kreuser and Soldat, 2012). Frequent mowing may mirror application of these growth regulating products and improve turf quality and reduce nutrient requirements.

Mowing

There were 28 weekly mowings in 2017 and 20 in 2018. Monthly mowing accrued seven mowings in 2017 and six 2018. As stated above, the 2017 started earlier than the 2018 season because of warm and wet weather during 2017 spring.

Only HOC and mowing frequency influenced the number of required mowings. Year and all the possible interaction of HOC, mowing frequency and year were not different. This indicates the longer growing season did not increase the number of LRM threshold-based mowings that occurred with the calendar-based mowings.

The 5.1 cm HOC had 13.67 required mowings each year 13.67 than the 7.6 cm HOC turfgrass which had 10.5 mowings per season. This is expected because the lower HOC treatment increased cumulative clipping yield and mowing frequency. However, the shorter 25% LRM threshold had the most required mowings with17.9 mowing per season. The 33% LRM had the second most mowing with 12.7 mowings per season. The 50% LRM had the fewest required mowings with 5.6 mowings per season. (Table 1.3).

Leaf removal at mowing treatment would be mowed more frequently even though mowing frequency did not affect clipping yield. This suggests a minor inverse relationship between clipping yield and mowing frequency do not out-weigh the impact of a LMR thresholds. As a result, increasing mowing frequency from 33% to 25% LRM is not recommended to minimize mowings and improve plant health through a reduction in clipping yield.

Turfgrass Quality

Visual quality was influenced by year, month, HOC, and mowing frequency (Table 1.4), however interactions of HOC*Mowing Frequency and Year*Month*Mowing Frequency occurred. The HOC*Mowing Frequency interaction is mainly the result of statistically similar turfgrass quality within the once and twice annual mowing frequencies at both HOCs (Table. 1.5). This was expected because these plots are rarely or never mowed during the growing season and therefore, had a similar appearance. Whereas regular mowings had a higher visual turfgrass quality at the 5.1 cm HOC than the 7.6 HOC. This was due to poor surface uniformity, occasional scalping – especially on the 50% LRM threshold and monthly interval that had significant scalping from infrequent mowing. Mowing more frequent resulted in the greatest turfgrass quality ratings (Table 1.5).

The Year*Month*Mowing Frequency interaction occurred for several different reasons. The principle difference for this interaction resulted from the decline in turfgrass quality during 2017 for the once and twice annual mowing frequency treatments. The once and twice annual treatments had visible stand thinning and high seed head production by the end of the 2017 season. These visible defects continued early in 2018 and therefore did not decline as they did in the first season of the study (2017). The weekly interval and 25% LRM threshold treatments sustained the highest turfgrass visual quality rating in both years. The turfgrass quality of the 33% and 50% LRM threshold and the monthly treatment were similar to the weekly interval and 25% LRM thresholds in 2017 study but began to decline later in 2018. A decline in quality can be carried over from one growing season into next year’s growing season.

Optimizing Mowing Practices

Annual cumulative clipping yield means and yearly average turfgrass quality means from each of the fourteen treatments were plotted against the number of mowings for each treatment. A quadratic relationship ($P < 0.05$; R2 = 0.6) between the number of mowings and cumulative yearly yield can be describe by the equation:

$$\text{Cumulative clipping yield } y = 1.1x^2 - 40.5x + 627.5$$

The y value was the cumulative yield (g dwt m^{-2}) and the x value was the number of mowings. The quadratic regression was significant for both heights with cumulative biomass production declining to minimum of 253 g m^{-2} at 18.5 mowings each year. The average turf quality curve was opposite the cumulative clipping yield curve. A quadratic relationship ($P < 0.05$; $R^2 = 0.8$) between mowing and can be described by the equation:

$$\text{Cumulative clipping yield } y = -0.009(x)^2 + 0.4(x) + 3.7$$

The y value was the visual quality and the x value was the number of mowings. The average turf quality improved to a maximum value of 7.4 at 19.7 mowings each year.

These quadratic curve for the cumulative biomass and the quadratic curve for the quality can be used to calculate the *ideal* quantity of mowings required to sustain an annual turfgrass quality rating of at least 6.0 and minimize clipping yield production. The quadratic equation from the plot of average turf quality vs number of mowing was solved for a value of y=6.0. This value created the minimum value for the *ideal* mowing number range. The resultant was 7.6 mowings were required to maintain a turfgrass quality rating of 6.0 or more. The high end of the *ideal* number of mowings was set at the minimum value of the cumulative clipping yield vs number of mowings, per year. This analysis suggests that 8 to 19 mowings are *ideal* for maintenance of TF lawns in Lincoln, NE.

Table 1.6 summarizes the number of mowings for each of the fourteen HOC and mowing frequency treatments in 2017 and 2018. Applying the *ideal* mowings range to that table suggests that the 25% LRM and 33% LRM treatments produced *ideal* clipping production for all mowing heights and years except for the low HOW at 25% LRM in 2017 – 20.7 mowings that treatment combination that year. These data suggest that the 33% LRM is an *ideal* way to reduce mowing and clipping yield, but the 25% LRM will provide the best turfgrass quality and sustain minimal clipping yield production.

CONCLUSIONS

The results of this study highlight the importance of mowing frequency and height’s on visual quality, amount of cumulative clipping yield, and number of mowings. The number of times a lawn is required mowing and the overall quality will impact a homeowner decision on deciding when to mow their lawn Mowing frequency and HOC influenced the clipping yield and turfgrass quality of a TF lawn. Mowing at 5.1 cm increased clipping yield compared to 7.6 cm HOC and mowing more frequently reduced clipping yield production, while improving quality. The 33% LRM resulted in the fewest mowings required to suppress clipping yield which also sustained turfgrass quality. Mowing more frequently further enhanced turfgrass quality and minimized clipping yield. The growth inhibition that resulted from mowing to the 33% LRM or even 25% LRM improve turfgrass quality. Mowing on calendar-based intervals (i.e. weekly) was inefficient and led to more mowings and less clipping yield reduction. Increasing mowing to 50% LRM, monthly or longer increased growth rate which increase N and carbohydrate demand to sustain increased clipping yield production as suggested from Kussow et al. (2012). These intervals caused scalping and a general decline in turfgrass quality. This study indicates that a homeowner can reduce the number of mowing in TF lawns by mowing to a 33% LRM at a mowing threshold height of 7.6 cm.

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Table 1.1 Tall fescue collection dates and number of mowings for weekly, monthly, semi-annual, and year-end treatments during 2017 and 2018.

Frequency	2017		2018	
	Date(s)	Total mowings	Date(s)	Total mowings
Weekly	4/24, 5/1, 5/8, 5/15, 5/22, 5/30, 6/5, 6/13, 6/20, 6/26, 7/3, 7/10, 7/17, 7/24, 8/7, 8/14, 8/23, 8/29, 9/7, 9/11, 9/19, 9/28, 10/3, 10/7 10/12, 10/19, 10/26, 11/2	28	5/23, 5/30, 6/4, 6/11, 6/18, 6/28, 7/9, 7/16, 7/23, 7/30, 8/6, 8/13, 8/22, 8/27, 9/11, 9/18, 9/24, 10/3, 10/10, 10/19	20
Monthly	5/5, 6/5, 7/6, 8/4, 9/7, 10/12 ,11/2	7	6/1, 7/6, 8/1, 8/31, 10/3, 10/19	6
Semi-annual	7/11, 11/2	2	7/13, 10/19	2
Year end	11/2	1	10/19	1

Table 1.2 Degrees of freedom and probability levels for frequency of mowing, height of cut, and year on annual cumulative clipping yield and number of mowings of a tall fescue [*Schedonorus arundinaceus,* (Schreb)] lawn.

Source	Cumulative clipping yield		Number of mowings	
	df	p-value	df	p-value
Frequency of mowing (F)	6	<0.001*	2	<0.001*
Height of cut (HOC)	1	<0.005*	1	<0.001*
Year (Y)	1	<0.001*	1	0.090
F*HOC	6	0.168	2	0.072
F*Y	6	0.160	2	0.989
HOC*Y	1	0.715	1	0.190
F*HOC*Y	6	0.979	2	0.165

* Indicates a statistically significant effect.

Table 1.3. The impact of mowing frequency on the cumulative annual clipping yield production of a tall fescue [*Schedonorus arundinaceus*, (Schreb)] lawn.

Mowing frequency	Cumulative clipping yield
	g m^{-2}
Twice annually	646a
Once annually	580a
Monthly	363b
33% LRM[a]	350bc
50% LRM	333bc
Weekly	311bc
25% LRM	281c

[a] Leaf removal during mowing. This threshold was used to initiate a mowing on an individual experimental unit.

[b] Cumulative clipping yield not followed by a letter is different at P=0.05

Table 1.4. Degrees of freedom and probability for the frequency of mowing, height of cut, month, and year on turfgrass visual quality rating of a tall fescue [*Schedonorus arundinaceus,* (Schreb)] lawn.

Source	df	p-value
Frequency of mowing (F)	6	<0.001*
Height of cut (HOC)	1	<0.005*
Month (M)	5	<0.001*
Year (Y)	1	0.003*
M*Y	5	<0.001*
F*M	30	<0.001*
F*Y	6	<0.001*
F*M*Y	30	<0.001*
HOC*M	5	0.753
HOC*Y	1	0.081
HOC*M*Y	5	0.748
F*HOC	6	0.023*
F*HOC*M	30	0.999
F*HOC*Y	6	0.864
F*HOC*M*Y	30	0.973

Table 1.5. The interaction of mowing frequency and height of cut mowing on the visual quality rating of a tall fescue [*Schedonorus arundinaceus*, (Schreb)] lawn

Height of cut (cm)	Mowing frequency	Turf visual quality rating
		1-9 scale[a]
7.6	Weekly	6.8bc
	25% LRM[b]	7.2a
	33% LRM	6.2e
	50% LRM	5.9ef
	Monthly	5.8f
	Twice annually	3.9gh
	Once annually	3.7h
5.1	Weekly	7.2a
	25% LRM†	7.2a
	33% LRM	6.9b
	50% LRM	6.7bc
	Monthly	6.4d
	Twice annually	4.1g
	Once annually	4.0g

[a] Turfgrass visual quality rating of one represents dead, six represents minimally acceptable for a lawn, and nine represents perfect lawn quality.
[b] Leaf removal during mowing. This threshold was used to initiate a mowing on an individual experimental unit.
[c] Cumulative clipping yield not followed by a letter is different at P=0.05

Table 1.6. Number of mowings from the different mowing heights and frequencies in 2017 and 2018. The leaf removal during mowing treatments represent an average of the number of mowings from the individual experimental units within those treatments.

Year	Height of cut (cm)	Mowing frequency	Mowings
2017	7.6	Weekly	28
		25% LRM[a]	14.3†
		33% LRM	10†
		50% LRM	4.7
		Monthly	7
		Twice annually	2
		Once annually	1
	5.1	Weekly	28
		25% LRM	20.7
		33% LRM	14.3†
		50% LRM	5.7
		Monthly	7
		Twice annually	2
		Once annually	1
2018	7.6	Weekly	20
		25% LRM†	17.3†
		33% LRM	11.3†
		50% LRM	5.3
		Monthly	6
		Twice annually	2
		Once annually	1
	5.1	Weekly	28
		25% LRM†	19.3†
		33% LRM	15†
		50% LRM	7
		Monthly	6
		Twice annually	2
		Once annually	1

[a] Leaf removal during mowing. This threshold was used to initiate a mowing on an individual experimental unit.

† Signifies an ideal mowing height which produced acceptable turfgrass quality and minimal clipping yield production.

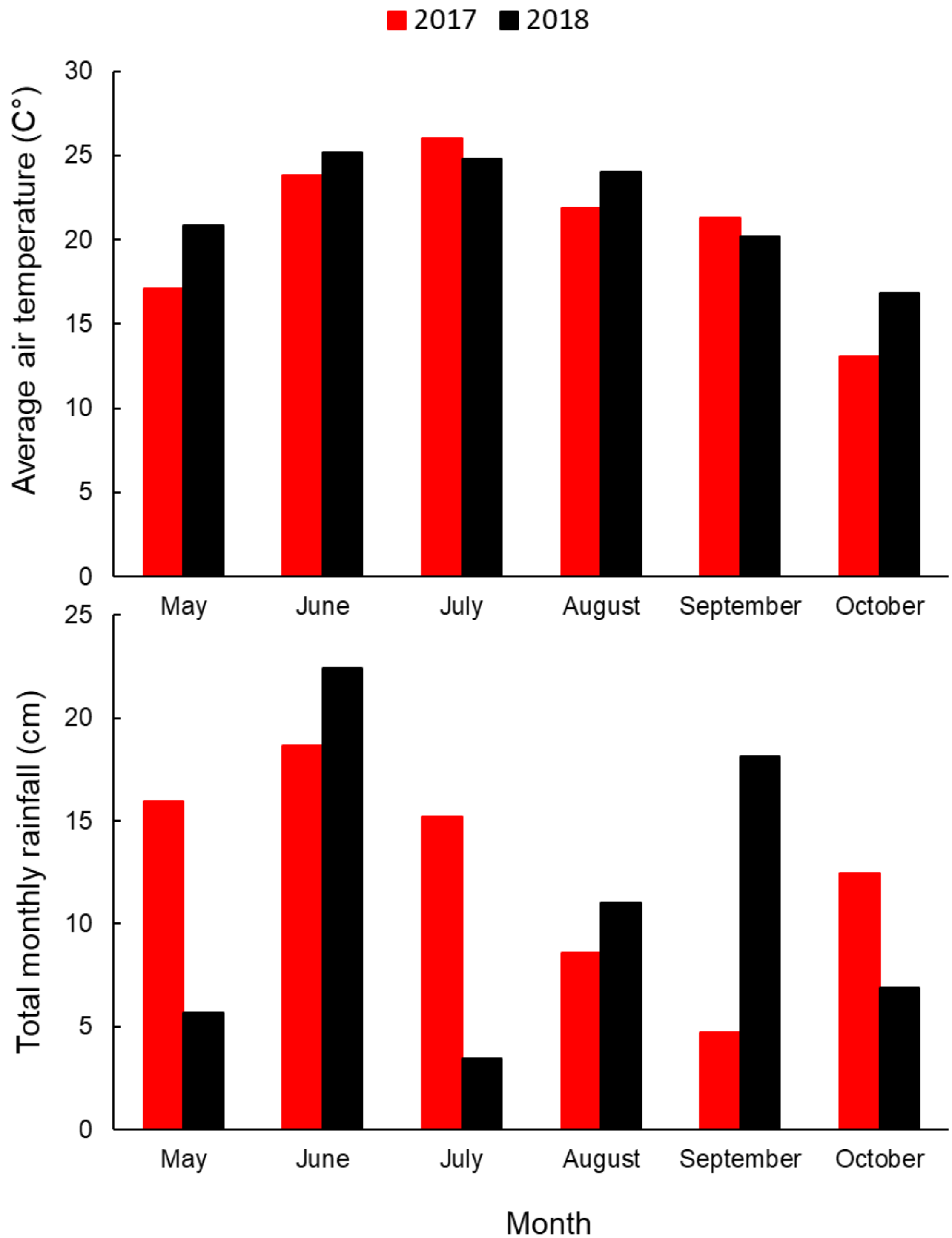

Figure 1.1. Monthly weather data during the 2017 and 2018 growing season.

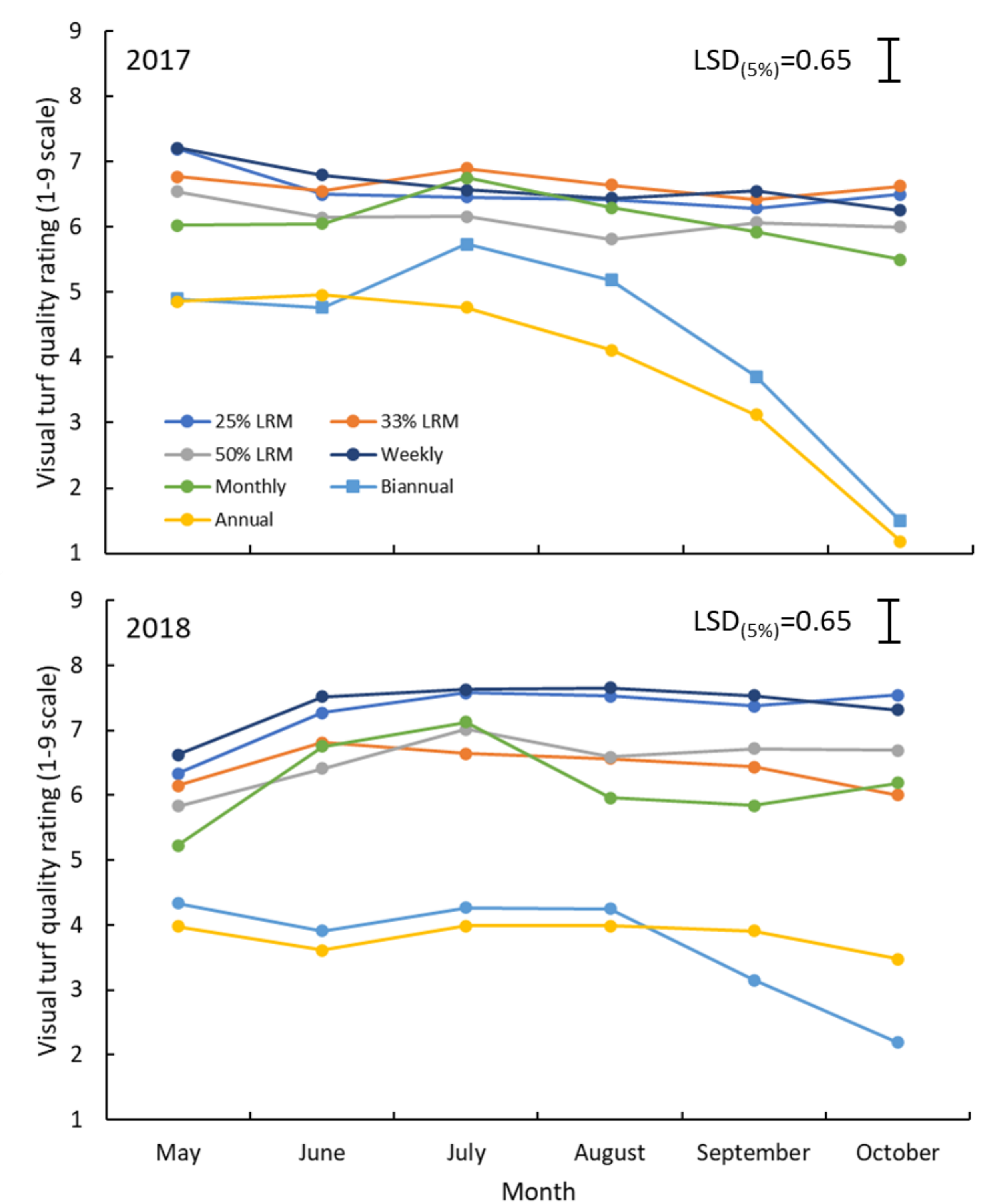

Figure 1.2. Average quality rating over 2017 and 2018 across all treatments. The mowing frequencies included 25% leaf removal at mowing (LRM), 33% LRM, 50% LRM, weekly, monthly, biannual, and annual. Quality scores were ranked on a 1 to 9 scale, with a score of 6 or greater being acceptable.

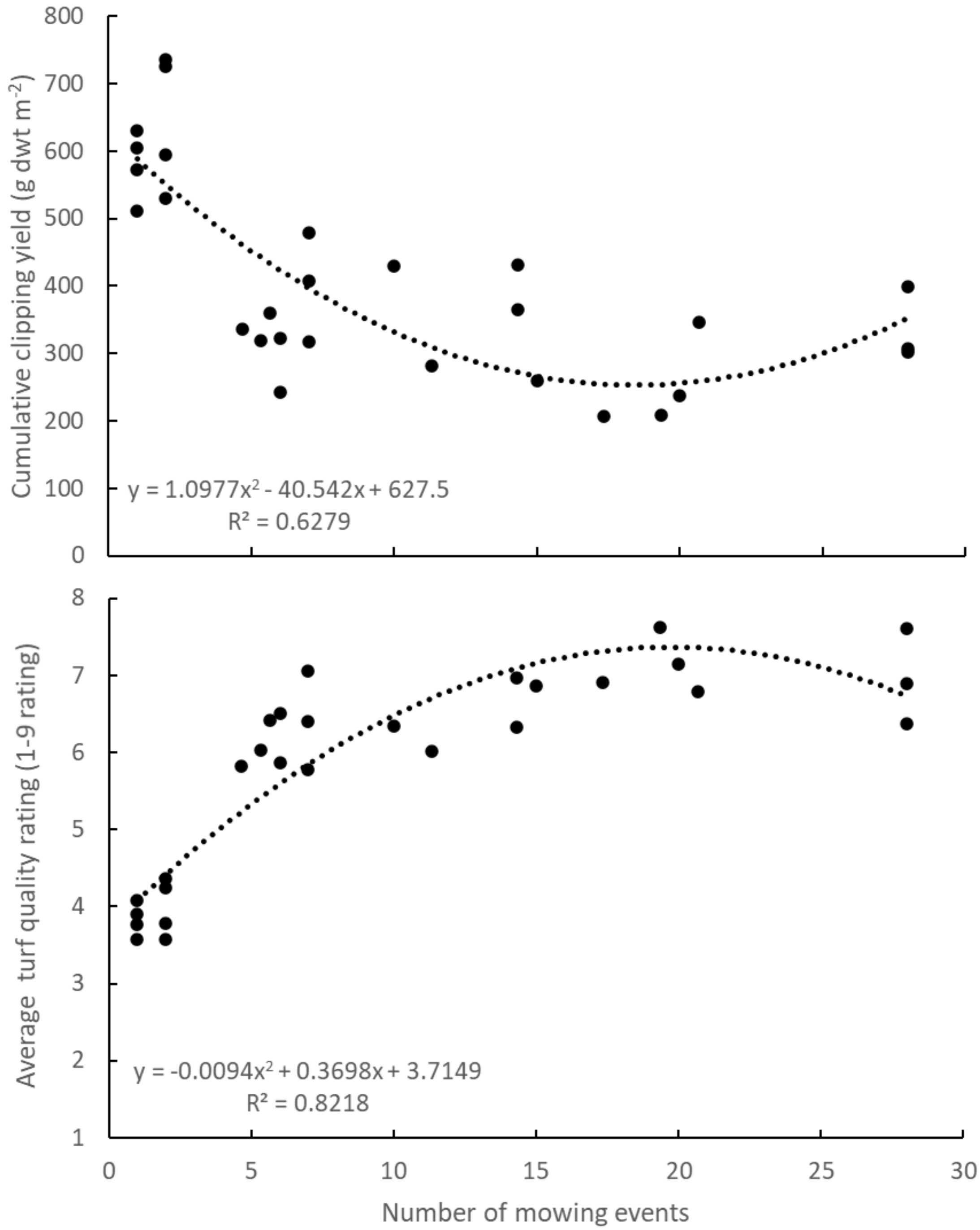

Figure 1.3. The relationships between the number of mowings cumulative annual clipping yield and average annual turfgrass quality rating from the seven mowing frequencies and two heights of cut. Data were pooled between 2017 and 2018.

CHAPTER TWO: INCREASING THE EFFICACY OF PRIMO MAXX AND CUTLESS MEC PLANT GROWTH REGULATORS USING DIFFERENT SURFACTANTS ON CREEPING BENTGRASS

ABSTRACT

Primo MAXX (PM) and Cutless MEC (CM) are commercial plant growth regulators (PGR) used to suppress clipping yield production and increase visual quality. Both PM and CM are re-applied throughout the growing season to maintain suppression. The duration of the suppression has been modeled with a sinewave regression inversely correlated to temperature, and growing degree re-application threshold. Surfactants have been used in the agriculture industry to increase the uptake and efficiency of herbicides. Increased efficacy of a PGR could allow for longer application intervals, an increased level of suppression, and fewer applications. The objective of this research was to determine whether different surfactants enhanced the performance of PM or CM when applied to creeping bentgrass fairway. The 2-yr study was conducted in Lincoln, NE. Treatments included two commercial PGRs, four surfactants, and an untreated control. The PGRs were applied alone and applied mixed with different surfactants. Treatments were initially applied and reapplied after the effects of the PGR diminished. Turfgrass clippings were collected twice a week for 1000 growing degree days (GDD) and once a week after the 1000 GDD. The treatments were modeled with sinewave regression to determine period, maximum suppression, and the ideal reapplication interval. Models showed that the addition of the surfactant to PM did not significantly impact the duration of clipping yield suppression (model period) compared to the PM applied alone, but differences in peak clipping yield occurred in some surfactants + PM. There was no significant difference between any of the CM periods. Suppression was reduced in one

surfactant + CM. timing of a mowing application can affect the growth rate and clipping yield of a turfgrass lawn. A plant growth regulator should not be used with the purpose of reducing the number of mowings.

INTRODUCTION

Primo MAXX (PM) (trinexapac-ethyl (TE) [4-(cyclopropyl-α-hydroxy-methylene)-3,5-dioxocyclohexanecarboxylic acid ethyl ester], Syngenta, Greensboro, NC) and Cutless MEC (CM) (flurprimidol, [2-methyl-1-pyrimidin-5-yl-1-(4-[trifluoromethoxy]phenyl)propan-1-ol]; SePRO Co., Carmel, IN) are two commercial plant growth regulators (PGRs) in the turfgrass industry used to suppress clipping yield production (Bigelow, 2012). The duration of clipping yield suppression following a PGR application is inversely correlated to temperature. Re-application intervals can be estimated with growing degree day (GDD) re-application thresholds (Kreuser and Soldat, 2011). There is interest to lengthen these GDD intervals by including tank-mix adjuvants with PGR applications. A previous study showed that mixing a surfactant with PM will increase cover and decrease irrigation in bermudagrass (Schiavon et al., 2019; Serena, et al., 2018). Fagerness and Penner (1998) showed that mixing a surfactant with an older formulation of TE called Primo increased uptake and absorption of the active ingredient. The original Primo formulation was replaced with PM in 1999. This new formulation uses a different inert package to improve TE uptake and ease use. The product label states that PM should not be tanked mixed with herbicide or wetting agents (Green Partners, 2007). Primo MAXX is foliar-absorbed while CM is root-absorbed. It is unknown whether adding additional surfactants to this new formulation will enhance or decrease PGR efficacy. It is unclear whether tank-mix surfactants improve efficacy of root-absorbed PGRs. The objective of this research was to determine whether different surfactants enhance the performance of PM or CM.

MATERIALS AND METHODS

Field research was conducted during 19 June 2017- 30 Oct. 2017 and 9 July 2018-30 Oct. 2018 on a bentgrass (*Agrostis stolonifera* Hud.) fairway at the University of Nebraska-Lincoln East Campus Turfgrass Plots. The site was mowed thrice weekly and irrigated to a calculated 80% of pET (Allen et al., 1989). The plot was fertilized with 12 kg N ha^{-1} (46-0-0 N-P-K) every two weeks. Soil surfactants, demethylation inhibiting fungicides, and sand topdressings were withheld throughout the study.

Experimental design was completely randomized with a minimum of three replicates. There were three replicates of PM and CM applied alone to assess surfactant performance and five non-treated control plots to calculate relative clipping yield for all treatments. Treatments (Table 2.1) were arranged in a 2x4 factorial of two PGRs and four surfactants. The initial applications occurred on 6 June 2017 and 9 July 2018 and were reapplied for second applications on 31 Aug. 2017 and 10 Sept. 2018 (Table 2.2). All products were applied with a 0.13m wide, three nozzle (Teejet AI8006, TeeJet Technologies, Wheaton, IL) boom backpack sprayer. The sprayer was calibrated to deliver a spray carrier volume of 810 L ha^{-1} at 276 kPA. Cutless MEC was hand watered in with 1.3 cm of water using a hose with a flow meter (Table 2.1).

Clippings were collected on Monday and Friday from 0-850 GDD (base 0°C) after treatment application and once weekly after 850 GDD. Clippings were collected, dried, and weighed using the methods of Kreuser and Soldat (2011). Sinewave regression of clipping yield over time was performed to determine the amplitude and period of the PGR response model using Sigma Plot (version 14; Systat Software Inc., San Jose, CA) as outlined in Kreuser et al. (2017). Data from each run were initially analyzed separately and each year was analyzed separately. Individual runs for the treatments were not statistically different and were pooled to increase the power (data not shown).

Visual quality was collected weekly using the National Turfgrass Evaluation Program (NTEP) 1-9 rating system, with a six or greater being acceptable (Krans and Morris, 2007). Quality ratings were averaged over the four runs using JMP (version 13; SAS Institute Inc., Cary, NC

RESULTS AND DISCUSSION

Primo MAXX

The addition of the surfactant to PM did not significantly impact the duration of clipping yield suppression (model period) compared to the PM applied alone (Table 2.3, Fig. 2.1). Differences occurred in peak clipping yield suppression between PM control and Straight Block Copolymer + PM and organosilicone + PM. Straight Block Copolymer + PM suppressed yield 0.37 g g^{-1} while PM control suppressed yield 0.58 g g^{-1}. Organosilicone + PM suppressed clipping yield 0.48 g g^{-1} compared to the non-treated control. Past research indicates that application rate influences the amount of suppression and not the duration of clipping yield suppression (Kreuser and Soldat, 2011). Fagerness and Penner (1998) showed that organosilicone adjuvants can increase TE absorption and enhance clipping yield suppression. Enhanced clipping yield suppression with no change in suppression duration suggests that the Straight Block Copolymer and organosilicone surfactant increased PM uptake.

Cutless MEC

The proprietary NIS + CM reduced suppression compared to CM applied alone (Fig. 2.2). The NIS + CM had a maximum clipping yield suppression 0.62 g g^{-1} (Fig. 2.2). The CM control suppressed yield 0.51 g g^{-1}. There was no significant difference between any of the CM periods (data not shown). These data suggest that a surfactant can decrease the effectiveness of the product. Mixing a surfactant with CM may have limited effects because CM is root absorbed.

Visual Quality

The overall visual quality ratings ranged from 6.0-6.8 among all treatments (Fig. 2.3). The addition of surfactants to PM and CM did not result in practically significant and unacceptable phytotoxicity. The PM control and PM with surfactants had visual quality ratings of 6.6-6.8. Mixing PM with a surfactant did not impact turfgrass visual quality rating. Application of CM alone had similar quality to all the PM treatments. However, the addition of the different surfactants to PM resulted in lower average quality than the CM control (Fig. 2.3). The magnitude of visual quality rating decline was less than one-half of a quality unit and mean visual quality rating was never <6.0.

CONCLUSION

Adding a surfactant to PM enhanced clipping yield suppression without causing phytotoxicity. This mirrors the result of Fagerness and Penner (1998) with the original Primo formation of TE. Adding surfactants to CM, a root absorbed PGR, did not enhance clipping yield suppression or lengthen product duration. The surfactants tested slightly reduced turfgrass quality. These results do not support the addition of tank-mix surfactants with CM.

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TABLES AND FIGURES

Table 2.1. PGR rates, surfactant rates, surfactant classification, and immediate action post application.

PGR	PGR Rate Kg ai	Surfactant	Surfactant Rate ml m^{-2}	Surfactant Classification	Immediate Action Post Application
Primo MAXXl†	0.10	None	Na ‡‡	NA	Dry
	0.10	Straight Block Copolymer§	0.027	Wetting Agent	Dry
	0.10	Revolution¶	0.027	Wetting Agent	Dry
	0.10	Organosilicone#	0.500	Adjuvant	Dry
	0.10	Proprietary NIS††	0.500	Adjuvant	Dry
Cutless MEC‡	0.28	None	NA	NA	1.3 cm water in
	0.28	Straight Block Copolymer	0.027	Wetting Agent	1.3 cm water in
	0.28	Revolution	0.027	Wetting Agent	1.3 cm water in
	0.28	Organosilicone	0.500	Adjuvant	1.3 cm water in
	0.28	Proprietary NIS	0.500	Adjuvant	1.3 cm water in

† Primo MAXX 11.3% A.I.(Syngenta Co., Greensboro, NC)
‡ Cutless MEC 16% A.I. (SePRO Co., Carmel, IN)
§ Straight block co-polymer (Tria Global Solutions, LLC., Crystal Lake, IL);
¶ Modified methyl capped co-polymer (Aquatrols Co., Paulsboro, NJ);
# Exacto 524 (Exacto, Inc., Sharon, WI);
†† Exacto 1057 (Exacto, Inc., Sharon, WI)
‡‡ NA- Not applicable

Table 2.2. Application dates and final clipping collection dates for 2017 and 2018. The second application of the year occurred after a minimum of 1000 GDD was reached.

Date Applied	**Final Clipping Collection Date**	**Accumulated GDD†**
M/D/Y	M/D/Y	GDD
6/19/2017	8/8/2017	1229
8/31/2017	10/26/2017	1037
7/9/2018	8/29/2018	1465
9/10/2018	10/26/2018	672

† GDD is the summation of daily average air temperature in degrees Celsius.

Table 2.3. The model period comparison, the number of GDDs to reach maximum suppression, and the percent of clipping yield suppressed for Primo MAXX.

Treatment	Period	Number of GDDs†† to reach maximum suppression	Clipping yield suppressed $g\ g^{-1}$
Primo MAXX (PM) †	1620.6 AB	341.9	0.58
PM + Straight Block Copolymer‡	1581.4 AB	328.0	0.37
PM + Revolution§	1708.0 A	364.0	0.54
PM + Organosilicone¶	1664.6 B	349.4	0.48
PM + Proprietary NIS#	1755.0 A	359.0	0.54

† PM-Primo MAXX 11.3% A.I.(Syngenta Co., Greensboro, NC)
‡ Straight block co-polymer (Tria Global Solutions, LLC., Crystal Lake, IL);
§Revolution- modified methyl capped co-polymer (Aquatrols Co., Paulsboro, NJ);
¶ Organosilicone-Exacto 524 (Exacto, Inc., Sharon, WI);
#Exacto 1057 (Exacto, Inc., Sharon, WI)
††§§ GDD is the summation of daily average air temperature in degrees Celsius

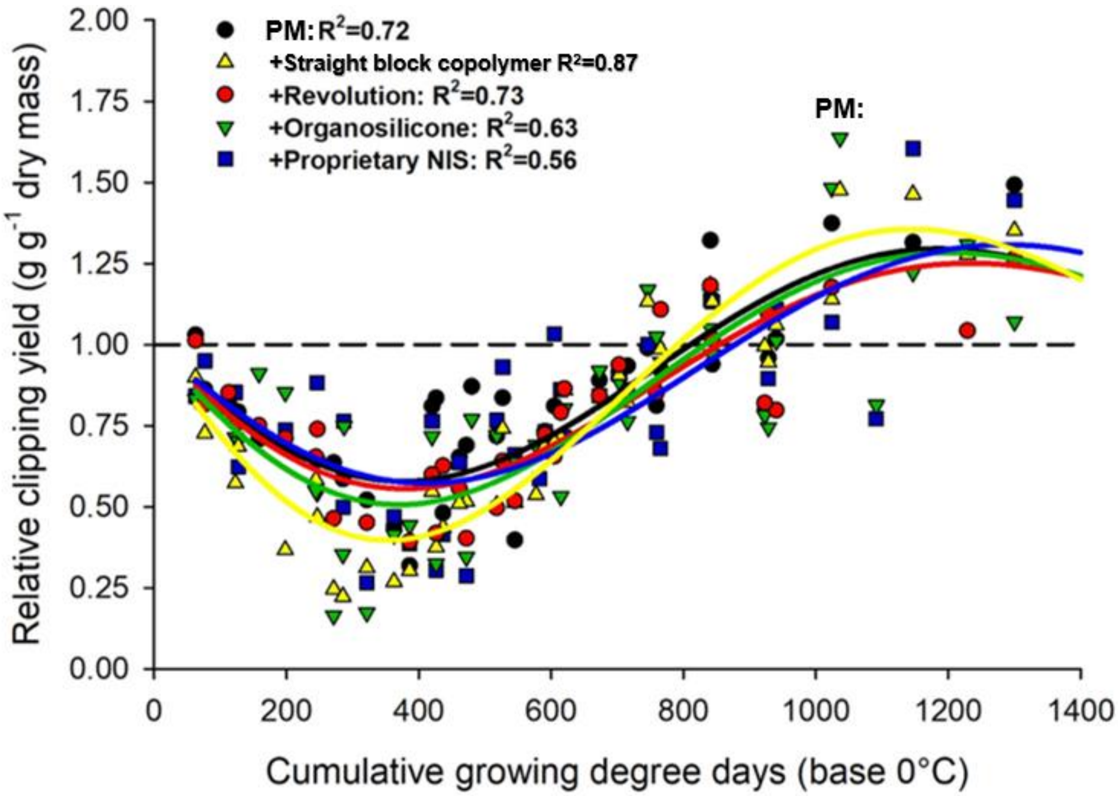

Figure 2.1. Sinewave regression model of the two different plant growth regulators. The predicted relative clipping yield is indicated by the dotted line. The dotted line represents the relative clipping yield of the control. Data from 2017 and 2018 were pooled together from both application for greater model resolution. (A) Primo MAXX (PM) was mixed with different surfactants (Straight Block Copolymer, Revolution, organosilicone, proprietary NIS) and applied separately.

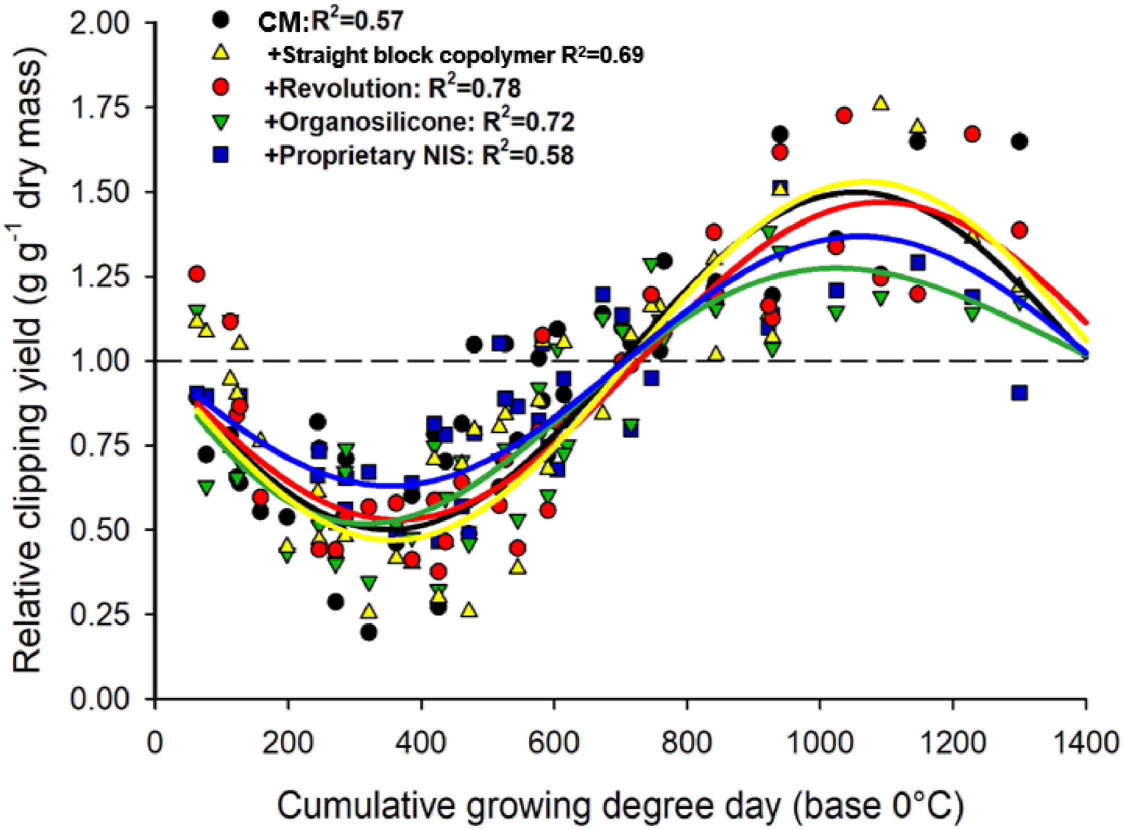

Figure 2.2. Sinewave regression model of the two different plant growth regulators. The predicted relative clipping yield is indicated by the dotted line. The dotted line represents the relative clipping yield of the control. Data from 2017 and 2018 were pooled together from both application for greater model resolution. Cutless MEC (CM) was mixed with different surfactants (Straight Block Copolymer, Revolution, organosilicone, proprietary NIS) and applied separately.

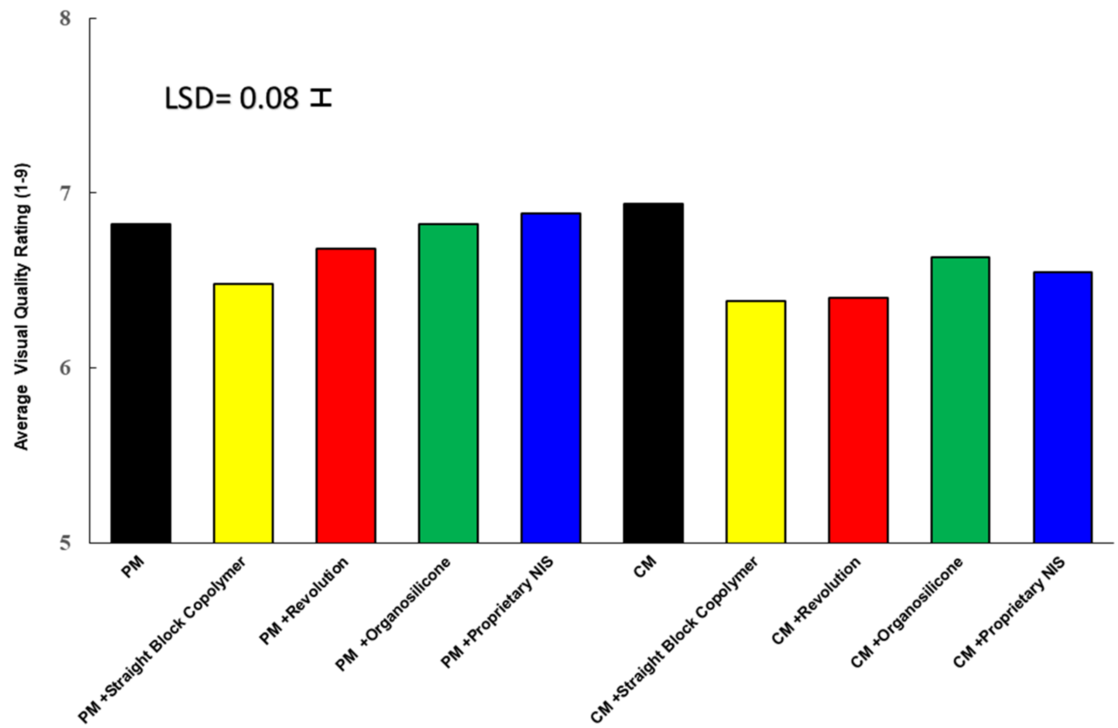

Figure 2.3. Average visual quality rating over 2017 and 2018 across all treatment applications from the fall and spring. Primo MAXX (PM) and Cutless MEC (CM) were mixed with four different surfactants (Straight Block Copolymer, Revolution, organosilicone, and a proprietary NIS). Quality scores were ranked on a 1-9 scale, with a six or greater being acceptable.