

CREEPING BENTGRASS (*AGROSTIS STOLONIFERA* L.) PUTTING GREEN  
ESTABLISHMENT STRATEGIES

By

Eric Christopher Chestnut

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## ABSTRACT

### CREEPING BENTGRASS (*AGROSTIS STOLONIFERA* L.) PUTTING GREEN ESTABLISHMENT STRATEGIES

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Creeping Bentgrass (*Agrostis stolonifera* L.) is the most widely used performance turf for putting greens in the temperate regions of the United States. Technological advances in breeding efforts since the mid-2000's have produced cultivars of creeping bentgrass that are, in general, far superior to their predecessors for a variety of reasons including increased density and tolerance to lower mowing heights. These advances have led many golf courses to consider renovation to these new cultivars, however not many studies have been performed to investigate factors that may expedite the establishment process. Two field studies were performed at Michigan State University investigating the effect of various cultural practices and chemical treatments on the establishment of *Agrostis stolonifera* L. 'Pure Distinction'.

The first study included four factors (initial mowing height of cut, nitrogen fertilizer application rate, plant growth regulator application, and vertical mowing), and the second study included three factors (nitrogen fertilizer application rate, wetting agent application, and brushing). Turf color and chlorophyll content index were enhanced with each increase in fertilizer rate, but a maximum was observed regarding percent cover. PGR treatment had a delayed but positive effect on turf chlorophyll content index. Vertical mowing and frequent wetting agent applications hindered turf development. Mowing height of cut and brushing treatments had little or no effect on turf quality.

Dedicated to my mom, Kay, and dad, Barry. Your unyielding love, support, and encouragement throughout the years provided me with the confidence to pursue my dreams. Thank you.

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## LITERATURE REVIEW

### Putting green significance and new cultivars

Putting greens are often considered the most important and most utilized features of a golf course. Due to the functional demands placed on putting greens and constant mechanical stresses such as low mowing heights of cut, light-weight rolling, and constant foot traffic, putting greens can exhibit the highest levels of biotic and abiotic stress symptoms on a golf course (Salaiz, et al., 1995; Young, et al., 2015). To maintain functionality and playability during these stressful periods, a significant amount of maintenance is required. The effects of these mechanical and physical stresses on putting greens are only exacerbated by the abiotic hardships of summer (i.e. heat and drought), when traffic is typically also at its peak. In cool-season environments, the most utilized grasses for putting greens are creeping bentgrass (CB) (*Agrostis stolonifera* L.) and annual bluegrass (AB) (*Poa annua*) (Beard et al. 1973; Beard, 1982), though AB is often considered a weed in high-performance turf fields (Beard et al., 1978; Cattani et al., 2002). AB contamination in putting greens is a problem for turf managers because although it is able to adapt to a variety of mowing heights and soil conditions, its prolific seedhead production at any mowing height, intolerance to extended periods of cold and ice cover, and tendency to wilt in summer heat and drought (Beard, 1970), among other factors, can be detrimental to playing conditions. In addition to problematic playing conditions, input requirements are different for AB and CB and therefore give rise to the inherent problem of chemical and cultural applications not meeting requirements for both species at the same time.

The advancement and improvement of CB cultivars through various breeding efforts in the last few decades have produced cultivars (sometimes known as ‘high-density’ or ‘improved’ cultivars) that are superior to both AB and older cultivars of CB for reasons including, but not

limited to: higher shoot densities (Sifers, et al., 2001; Sweeney, et al., 2001; Jones and Christians, 2013), higher overall quality at low mowing heights (Sifers et al., 2001), increased disease resistance (Weibel et al., 2014), tolerance to drought conditions (McCann and Huang, 2008), and resistance to the invasion of *Poa annua* (Croce et al., 1998; Beard et al., 2001). In general, these cultivars produce turf stands that are more dense and uniform than either AB or older cultivars of CB (Sweeney et al., 2001; Beard et al., 2001), and therefore provide better playing conditions. Some negative features of these new cultivars have been noted, such as decreased lateral recuperative ability due to a more upright growth habit (Jones and Christians, 2013) and susceptibility of some cultivars to certain diseases (Stier and Hollman, 2003; Weibel et al., 2014; NTEP, 2016). Various unfavorable qualities should be expected, however, since no turf species or cultivar is flawless. Most often, these improved cultivars exhibit qualities that can be utilized in a way that reduces the maintenance budget, and many courses are choosing to renovate putting greens and other course features to these new and improved cultivars of CB. One of those new, improved cultivars, Pure Distinction, was chosen for the studies that follow. Pure Distinction was chosen because it was among the most highly rated cultivars in recent National Turfgrass Evaluation Program (NTEP) trials. It was consistently in the highest rated group for characteristics such as overall visual quality, turfgrass leaf texture, density, and resistance to AB invasion (NTEP, 2012). Pure Distinction did, however rate poorly regarding some disease susceptibility, particularly *Sclerotinia homeocarpa* (dollar spot). For this reason, background applications of fungicides were made throughout the experiments to prevent disease from affecting results.

## **Renovation strategies and timing**

Renovation, or the process of improving a turf stand (Beard, 2005) can be executed in a number of ways, including: interseeding or intraseeding, eradicating the existing turf and removing the top few inches of soil, or complete removal of existing turf and the soil profile if the desire is to reshape a green or change the soil profile. The process of converting a turf surface from one grass type to another by means of introducing new seed into an established population is referred to as intraseeding if the introduced seed is the same species as the established plot of land; interseeding if the introduced seed is a different species than the established turf; and overseeding if the introduced seed is intended to perform as a temporary playing surface while the established species is in dormancy (Beard, 2005). These methods are regarded by some as the ideal method for renovation due to their inconspicuous nature and limited time required for course closure, as interseeding or intraseeding are the only methods available in which the existing surface is potentially not disturbed in a way that would interrupt play for an extended period of time. While this method can introduce some small percentage of the desired cultivar, it has been shown to be ineffective at conversion of entire greens (or fairways) to a new species or cultivar (Gaussoin and Branham, 1989; Kendrick and Danneberger, 2002; Jones, 2011). Lack of success is mainly due to the fact that seeds and juvenile plants cannot access enough resources to threaten existing, established populations (Cattani, 2001). Even scalping off live tissue but leaving existing root systems in tact resulted in no change to putting green cultivar composition (Kendrick and Danneberger, 2002), and conversions of AB fairways to CB required applications of glyphosate and resulted in only a 53% CB population (Bauer et al., 2012). From the literature it can be concluded that the only way to assure complete conversion from one species or cultivar to another is by removal or eradication of any and all existing live plant material.

Mid-summer seedings of CB have been suggested for reducing the potential of an AB invasion (Beard, 1973; Murphy et al., 2005), but due to heat and drought stress CB is typically seeded in late summer or early fall, which also allows the course to be open during the most of the active-use season in northern United States climates. Creeping bentgrass experiences reduced canopy photosynthesis at temperatures in excess of 30 to 34°C, depending on the duration of exposure and seeding in the late summer and early fall reduces the chance of above-ideal temperatures while still providing enough days that fall within the ideal growth range of 15 to 24°C before the winter induces dormancy (Beard, 1973; Huang and Gao, 2000).

Each establishment method and timing has its own expectations, benefits, and drawbacks, so considerable time and effort must be allotted to devise an effective plan. In order to minimize the time of closure and monetary losses, a rapid method of establishment must be employed. In the studies performed for this thesis, the intention was to as closely as possible replicate the conditions on a golf course; the methods that follow reflect these principles.

### **Nitrogen and creeping bentgrass**

Nitrogen is the nutrient that most affects plant growth under normal growing conditions (Christians et al., 1979; Hull and Liu, 2005). There are many types of nitrogen fertilizers and formulations that typically come in either a synthetic or organic and water-soluble (liquid) or granular form. Granular forms are most often chosen when administering a slow-release product that will continue to become available to plants throughout a growing season (or some other specified time period). Due to advances in sprayer technology and the discovery of the benefits of light and frequent applications (Engelsjord and Singh, 1997), many superintendents prefer to supply plants with nitrogen in liquid forms throughout the growing season that allow for more even distribution and accuracy at small application rates. Kaminski et al. (2004) detailed the

importance and benefits of using synthetic fertilizers during establishment of creeping bentgrass. Their study found that, when compared to organic, slow-release fertilizers (poultry meal and granular humate), synthetic fertilizers provided more rapid establishment, better visual quality, and decreased disease presence. Clippings can provide a significant amount of N to plants if they are left on the turf surface after mowing (Liu et al., 1993; Starr and DeRoo, 1981), but this practice is impractical on a putting green due to the desire for a smooth, uniform surface over which the ball can roll. This impracticality leaves fertilization as virtually the only option to achieve desired plant performance under normal growing conditions, as the majority of putting green soil profiles are recommended to have  $\geq 90\%$  sand by the USGA (USGA, 2004). High sand-content soil profiles such as USGA specification greens have a naturally low cation exchange capacity and therefore do not adequately support high-performance turfgrass fields without additional fertilizer inputs. Bowman (2003) conducted a study revealing that nitrogen applied to mature perennial ryegrass at an 8-day interval produced growth rates statistically equal to daily applications, which both produced increased growth rates and less fluctuation between treatments compared to longer application intervals. The results of that study indicate that, especially when considering the time and expense of daily applications, weekly nitrogen fertilizer applications (as is typical in golf course turfgrass systems) provide the best combination of quality and practicality.

A typical creeping bentgrass putting green receives anywhere from 100 to 250 kg N ha<sup>-1</sup> per year (Carrow et al., 2001). Baldwin and Brede (2012) showed that over a one-year growing period (~26 weeks) at fertilizer levels including 49, 147, or 294 kg N ha<sup>-1</sup> per year, the newer, improved cultivars (i.e. A-1, A-4, 007, etc.) produced better color ratings and chlorophyll index than more standard cultivars (i.e. Penncross and Seaside II). Even though these cultivars



performed better at low N rates than the standard cultivars, they still increased in quality with each subsequent increase in N rate, indicating that, at least when considering top growth, linear quality increases can be expected with increasing N fertilizer rates. In the same study, higher N application rates also led to increased lateral regrowth and reduced ball roll distance in all cultivars. Increased N rates are also directly correlated with increased clipping yield (Totten et al., 2008). In a putting green situation where fewer clippings and faster ball speeds (or increased ball roll distances) are desirable, top growth is managed carefully in order to provide adequate ground coverage and visual quality while ideally producing the least amount of clippings possible. When considered as a whole, these studies and results indicate that there is not one ideal rate of N application that can be applied to all putting greens, but that each situation and desired trait must be analyzed when creating a fertilizer plan.

While previous results have provided turf managers with a suggested formula to reduce fertilizer inputs and cost, limited information is available regarding nitrogen requirements for establishing a new turf stand from bare soil. Pease et al. (2011) performed a study establishing creeping bentgrass and velvet bentgrass at tee/fairway height and concluded that six treatments with 146 kg N ha<sup>-1</sup> applied evenly at 14-d intervals (~24.3 kg N ha<sup>-1</sup> biweekly) provided sufficient cover and quality ratings compared to 293 kg N ha<sup>-1</sup> (~48.8 kg N ha<sup>-1</sup> biweekly), and performed better than lower rates. However, their recommendation was made with the caveat that, “the ideal N rate during establishment for CBG and VBG is likely above 146 kg N/ha but below 293 kg/ha”. Watson et al. (2012) observed that creeping bentgrass (‘L-93’) established most efficiently at a rate of 19 kg N ha<sup>-1</sup> per week. In their study, 19 kg N ha<sup>-1</sup> per week performed better than any lower rate and was statistically the same as 28 kg N ha<sup>-1</sup> per week as measured by shoot dry weight, overall quality, and visual cover in a greenhouse experiment.

While these studies provide a good indication of what might be acceptable levels, neither combined the putting green height of cut, soil profile, and field-trial circumstances that will be investigated in this paper.

### **Mowing and creeping bentgrass**

Mowing is often considered the most important cultural practice performed on putting greens. Unlike most other practices, it is required almost daily to maintain a quality playing surface.

Fast greens, usually achieved by low heights of cut and rolling, are becoming the standard for a high-quality putting surface. There is ample evidence provided by multiple studies suggesting that lower heights of cut increase physiological stress on grass plants and roots, leading to unfavorable turf quality in some conditions, especially when combined with the heat stress of summer months (Salaiz et al., 1995; Huang and Gao, 2000; Liu and Huang, 2002; Young, et al., 2015). While this evidence provides a good basis of caution regarding frequent low height of cut (HOC) mowing during the hottest summer months, most of it was completed with standard cultivars of creeping bentgrass and not the improved cultivars available today. Advances in turf breeding and quality of cultivars have produced plants that are more accepting, and even prefer, lower mowing heights and these differences have been measured between cultivars (Stier and Hollman, 2003; Koeritz and Stier, 2009). Young et al. (2015) performed an experiment involving one of high-density cultivars (Penn G2) mowed at three different heights (2.5, 3.2, and 4.0 mm), which indicated HOC was not a factor in turf quality. While they observed a reduction in turf quality during the hottest summer months, overall visual quality never dropped below “acceptable”, and all heights reacted in the same manner. In that same experiment it was shown that an older, more standard cultivar (SR 1020) showed reduced quality

at the two lower mowing heights when compared to the highest height. While these results suggest older cultivars may be more susceptible to damage at lower mowing heights and improved cultivars appear to be more tolerant to such practices, the authors did still recommend increased mowing heights during stressful summer months.

Mowing is performed daily on most putting greens, and even multiple times per day at some golf courses. Increased mowing frequency has been shown to increase ball roll distances (McDonald et al., 2013), but also turf stress (Howieson and Christians, 2005), especially when applied multiple times per day (Gu, 2016). Madison (1962) experimented with “resting” greens from mowing and found that a one- to two-day rest per week increased vigor of *Agrostis stolonifera* ‘Seaside’ without increasing grain or decreasing population density. To alleviate the stress of mowing, other methods of maintaining putting green quality and ball roll distance have been investigated. McCullough et al. (2005) found that PGR application (flurprimidol, paclobutrazol, and trinexapac-ethyl) in combination with rolling instead of mowing produced results similar to daily mowing. A study performed on an AB putting green by McDonald et al. (2013) found that ball roll distance was most consistently affected by mowing and rolling (trinexapac-ethyl and roller weight treatments produced inconsistent results), and that the combination of daily mowing and daily rolling produced the longest ball roll distances, followed by daily mowing and 3x weekly rolling and 4x weekly mowing and daily rolling. Similar results were found by Richards (2009), who observed no reduction in ball roll distance for plots mowed every other day and rolled compared to plots that were only mowed daily with no rolling. Although it would appear that alternatives to daily mowing do exist, most courses still mow daily at reduced heights in order to facilitate faster green speeds. The introduction of new creeping bentgrass cultivars that are more tolerant to low mowing heights has alleviated some of the stress

concerns, but no studies have yet explored the ideal height of cut during the establishment process.

The initial mowing HOC for creeping bentgrass putting green establishment has not been studied in much depth. Koeritz and Stier (2009) had inconsistent results regarding mowing HOC and spring green up of two CB cultivars and two velvet bentgrass (*Agrostis canina* L.) cultivars. In their study, plots receiving the lowest mowing height (2.5 mm) received the lowest color ratings when compared with two higher HOC (4.0 and 6.4 mm) two seasons after initial seeding, but HOC had no effect on color ratings the following year. There are recommendations that suggest 0.508 cm to 0.635 cm are appropriate heights (Vavrek, 1999), but these are merely observational and not verified by scientific analysis. A lower initial HOC could allow turf managers to reduce mowing heights to acceptable putting green levels in a shorter time period, so analysis of turf quality under various heights of cut may provide a tool to reduce establishment times.

### **Plant growth regulators**

Plant growth regulators (PGRs) have been utilized since the early 1990's in order to reduce vegetative growth and frequency of mowing in some species of turfgrass. Trinexapac-ethyl (TE) is a Type II PGR (late gibberellin inhibitor) that is foliar absorbed and prevents the elongation of shoots in grasses (Ervin and Koski, 1998) without affecting rooting of creeping bentgrass (Fagerness and Yelverton, 2001; McCullough et al., 2006). Although it can cause some temporary discoloration, the overall effects of TE have been shown to be positive in turfgrasses by increasing overall visual color and quality over untreated plants, reducing the amount of clippings produced by plants by up to 20% for 1-2 weeks following application, and matching or increased ball roll distances compared to plots receiving extra mowing (Henderson, 2000;

McCullough et al., 2005; McCullough et al., 2006). While these benefits can produce a better playing surface, TE must be used with caution, as a rebound phase in which plants grow excessively after the PGR has been metabolized has been observed (Fagerness and Yelverton, 2000). The rebound phase and questions about the timing of TE applications led to research involving the use of growing degree-day (GDD) models (McCullough et al., 2006; Kreuser and Soldat, 2011) as a guide for application intervals.

Yet another benefit of TE was demonstrated by Kreuser and Soldat (2012), when they observed that TE use on a previously established putting green reduced N requirements by as much as 50%. Their study concluded that the use of TE on a 200-GDD application schedule decreased N lost via mowing and maintained color and canopy density at lower N levels, thereby reducing clipping yield by two separate means.

TE use in establishment of a turfgrass stand has not been thoroughly researched, though some efforts have been made. Ervin and Koski (1998) used ~60-d old perennial ryegrass (*Lolium perenne* L.) in a growth chamber study which showed plants treated with TE had reduced shoot length and increased tillering. These effects, however, were delayed to at least 40-d after a second application of TE had been made. Increased tillering is of particular importance to the establishment phase, as it may allow for an increased rate of ground cover. Henderson (2000) used TE in an effort to more rapidly establish a Kentucky bluegrass (*Poa pratensis*) athletic field. Results from one year of the study showed increased density and sod strength when TE was used compared to control plots, but these results were not observed during a repeat trial, and therefore were not deemed a reliable way to increase sod strength during establishment.

Studies involving the use of TE on immature turf have been promising but inconsistent. This study aims to identify what, if any, plant benefits result from applying TE regularly to a creeping bentgrass putting green that is less than one year old.

### **Vertical mowing**

Vertical mowing (VM) is a practice that is most often utilized to remove organic matter and prevent thatch accumulation in turfgrass stands (Callahan et al., 1998; McCarty et al., 2007). This practice, when performed at least four times per year, has been shown to be as effective as core cultivating at reducing thatch, and its effectiveness is increased with the application of sand topdressing (Callahan et al., 1998). It should be noted that McCarty et al. (2005) found that no VM treatment or combination with multiple other mechanical or biological treatments on a newer (less than two year old) green was effective in preventing the overall accumulation of thatch, but VM-treated plots in combination with core cultivation accumulated the least amount. These results suggest the accumulation of some amount of thatch is inevitable, but can be counteracted to some degree by the incorporation of VM into putting green maintenance plans.

Multiple studies have shown that incorporating VM can aid in achieving a firm, desirable putting surface, and can prevent scalping at the same effectiveness as core cultivation while being less invasive (McCarty et al., 2005; McCarty et al., 2007). Results from studies performed on established CB putting greens have shown that VM had no adverse affects on overall quality when performed once or twice per month at a depth just below the surface, and even increased color ratings over time (Salaiz et al., 1995; McCarty et al., 2007). Combined, these findings suggest that putting greens can benefit from VM, but frequency and depth of applications need to be considered to allow adequate time for plants to heal before subsequent applications.

Ball roll distance results have been inconsistent following VM treatments, which has mostly been attributed to the initial disruption in the turf surface and new plant growth that occurs following applications. Salaiz et al. (1995) observed a decrease in ball roll distance 4-d following application, and an increase in ball-roll distance on the fifth day, which was attributed to new shoot growth initiated by the void created from vertical mowing promoting a uniform, smooth surface. However, that result was not able to be repeated, which the authors claimed was possibly due to less frequent sampling during the follow-up year. McCarty et al. (2007) recorded reduced ball roll distances on vertically mowed plots 7-d after treatments, but distances increased in follow-up ratings at 14- and 21-d. The overall effects on ball roll distance from these studies, while not overwhelming, suggest that it can provide benefits to mature putting greens. While ball roll distance may not be essential for growing in a putting green, the reason that VM treatments have this effect is due to void-filling that occurs after application. Creating new voids via VM that will then be filled by new plants or tillers could be a potential way to increase the rate of establishment in a newly seeded area.

Evidence seems to suggest that a turf stand can tolerate at least four VM applications per year at depths below the canopy or even more frequently if done at a depth placed at the canopy surface. High-density CB cultivars can potentially benefit from VM applications during establishment, but the frequency they can tolerate and what effect that may have on the rate of growth and establishment has not been thoroughly investigated.

### **Wetting agents and establishment**

Wetting agents (WA) are chemicals that reduce the surface tension of water and allow it to more easily penetrate a soil surface (Rieke, 1981). They are most often administered to reduce hydrophobicity in high sand content soils and allow for water movement into the root zone

(Wilkinson and Miller, 1978). They are also used as water retention aids in certain soils, most of which are sandy soils that have more problems with water loss than sandy loams or most native soils (Leinauer et al., 2001; Lyons et al., 2009).

Anda (1975) found that WA, when tank-mixed with urea applications, had no effect on the germination of Kentucky bluegrass (*Poa pratensis* L.) seed. Henderson (2000) observed that during one year of a study, the application of wetting agents increased turf density when used as a solo treatment, but hindered turf growth and development when applied in combination with TE. Results from the second year of that study did not produce the same increase, and conversely a decrease in turf stability was observed in plots where wetting agent applications were made. A study was conducted by Lee (2014) examining the impact of WA and applied phosphorus (P) on the establishment of Kentucky bluegrass found that WA applied at 1.6 L ha<sup>-1</sup> (the maximum rate tested) produced significantly more turf coverage than lower rates at any P level, but at the maximum P rate (150 kg ha<sup>-1</sup>) both 0.8 and 1.6 L ha<sup>-1</sup> of WA produced similar percentages of coverage and were better than the lowest rate tested (0.4 L ha<sup>-1</sup>). The results suggest that WA application can help increase the rate of establishment, and if enough P is present the rate of WA applied may be reduced.

Overall, studies regarding the use of WA's on the establishment of turf have produced inconsistent results, but have shown potential to increase the rate of turf coverage. This study will examine the effectiveness of two different wetting agent rates and timings on the establishment of a creeping bentgrass putting green.

### **Brushing applications for putting greens**

Brushing a green prior to mowing with an attachment out in front of the mower is not a new concept; among the first observations of a brushing apparatus attached to mowing



equipment was from the Jacobsen Company in 1928 (Anonymous, 1928). Early brushing attachments meant for putting green use were made from metal, similar to a rake, and proved to be too aggressive for daily use, leading to their discontinued use as a mowing aid. Brushing by a push-broom style apparatus seems to have been developed in the 1980's (White, 1985), and is becoming more popular as technology and information become available (Whitlark, 2011). Brushes on greens have been used for a long time in a different capacity, however, that being a common way to incorporate topdressing into a green. Literature on the subject of brushing and putting greens almost exclusively revolves around incorporation of topdressing, but that is not the intended purpose of brushing greens in this study.

Supposed benefits of using a brush attachment in front of a mower are many, including: reduced grain, increased density, reduced leaf texture, reduced thatch, upright growth of turf blades, increased green speeds and potential physiologic impacts that have not yet been identified (Whitlark, 2011; Thomas, 2012). Although the claims and observations are very promising, there is very little scientific evidence to support them, and only a couple of studies have been published regarding brushes on putting greens. Langois (1985) used a rotary brush on a Pennncross putting green prior to mowing in an attempt to increase green speeds, but found that brushing treatments performed no better than check plots. Gu (2016) observed a visual reduction in leaf texture on Pennncross CB leaves that were brushed, but could not measure the visualization statistically. In the same study no statistical difference was found between brushing 0, 3, or 5 times per week regarding photochemical efficiency or visual quality. Stress, measured by malondialdehyde level, also did not produce statistical differences until the temperature dropped below 17° C, at which point brushing 5x per week was detrimental to visual quality and photochemical activity, but not more so than double-cut mowing the plots. Both double-cut

mowing and brushing (3 or 5x per week) reduced cuticle thickness compared to single-cut mowing, but this was only observed on one collection date during one year of the study.

Treating putting greens with push-broom attachments prior to mowing is a practice that has been utilized on and off since the 1920's, but there is very little convincing scientific evidence to support supposed benefits. This study will attempt to observe any benefits the practice may have on the establishment rate of a creeping bentgrass putting green.

### **Data collection methods**

Data collection is an essential process of any scientific experiment. Methods of data collection for turfgrass studies vary widely, and new technologies are being created each year that attempt to analyze new plant characteristics. Since early agronomic research, visual estimates have been utilized to describe plant characteristics such as color, disease presence and abundance, and percent of area covered (Beard, 1973). Such estimates are usually based on a scale from 1 to 9 and provide a fast, convenient data set (Morris, 2002). For these ratings to be considered valid, however, a highly trained professional is required to take the ratings, and even they have a high chance of human influence over results. It has been shown that evaluators remain consistent within their own ratings, but are not necessarily consistent with other evaluators (Landschoot and Mancino, 2000), which produces more subjective results. Horst et al. (1984) also measured a high variance in visual ratings between evaluators. Objective, quantitative methods to measure turf color and health have been sought since the 1960's (Birth and McVey, 1968). This desire inspired the utilization of lasers and later photography paired with computer software to effectively calculate differences between wavelength reflectance in turf stands (Birth and McVey, 1968; Richardson et al., 2001). Such data collection devices are

meant to eliminate as much human bias or error as possible while still correlating to qualitative data such as disease presence, wear, and color quality (Trenholm et al., 1999).

Spectrum Technologies, Inc. (Plainfield, IL) is a company that has created multiple devices that are used in the turfgrass industry and research: two of these devices are the Field Scout TCM 500 NDVI Turf Color Meter and the CM 1000 Turfgrass Chlorophyll Meter. Data collection devices such as the TCM 500 and CM 1000 are ideal for research purposes due to their non-invasive and rapid collection procedure, as well as continuity and conservation concerns of destructive data collection methods. These meters use ambient and reflected light to calculate an index of relative color (NDVI) and chlorophyll content (CM 1000). The TCM 500 is an insulated box with its own light source that measures a 7.6 cm diameter circular area of turf. Reflectance wavelengths of red (660 nm) and near infrared (850 nm) are collected and converted into a color scale (Spectrum Technologies, Inc., 2013). The CM 1000 uses the sun as a light source, so it is important to collect data around the same time period every day. The collection area is dependent on the distance the device is held above the turf surface, which in this study was 1.02 m and resulted in a circular collection area with a diameter of approximately 11.0 cm. This meter uses wavelengths of 700 and 840 nm to produce an estimated scale result of chlorophyll content (Spectrum Technologies, Inc., 2016).

The NDVI meter has been used in a variety of studies and is verified to correlate with visual turf quality measurements (Trenholm et al., 1999; Bell et al., 2002; Bremer et al., 2011). Bremer et al. (2011) found that while NDVI measurements were strongly correlated with visual quality ratings, the NDVI also recorded differences between turfgrasses that were not observed with the evaluators' visual ratings. This is partially due to the ability of the NDVI to perceive near-infrared differences between plots that are not visible to the human eye, though Bremer et

al. (2011) did note that the exact mechanics of how and why these differences occur do need to be investigated further. These results indicate that NDVI can be used as a reliable method of data collection.

Mangiafico and Guillard (2005) performed a study indicating CM 1000 data can be directly correlated to both chlorophyll concentrations ( $\text{mg g}^{-1}$ ) and turf population density. That same study, along with studies performed by Ma et al. (1996) and Trenholm et al. (1999), also showed that a linear relationship between CM 1000 results and plant density exists and is consistent throughout differing studies and crops. These spectral reflectors have also been suggested for use as indicators of N fertilization requirements (Richardson et al., 2001), and a study from Mangiafico and Guillard (2007) outlined an equation suggesting optimal timing of N applications.

Validation of the accuracy and correlations to known plant characteristics make these data collection devices credible for use in turfgrass research. Additionally, the non-destructive sampling method, ease of use, and ability to promptly collect large amounts of data are ideal for sizable studies such as the ones that follow in this thesis.

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## CHAPTER 1:

### EFFECTS OF INITIAL MOWING HEIGHT OF CUT, NITROGEN FERTILIZER APPLICATION RATE, TRINEXAPAC-ETHYL, AND VERTICAL MOWING ON *AGROSTIS STOLONIFERA* L. PUTTING GREEN ESTABLISHMENT

#### ABSTRACT

Putting green renovation can have significant positive effects on golf course playing conditions, but it is a costly and time-sensitive process. Research was conducted to isolate factors that may expedite establishment of a putting green. Results can potentially save golf courses direct costs in materials and labor as well as revenue lost due to closure. Creeping bentgrass (*Agrostis stolonifera* L.), the most commonly used cool-season putting green surface, was seeded into a sand-based soil profile in mid-August 2013 and replicated in 2014. Treatment factors consisted of the following: initial mowing height of cut (3.81 and 5.08 mm), nitrogen (urea 46-0-0) fertilizer application rate (2.44, 4.88, and 7.31 kg ha<sup>-1</sup> per week), vertical mowing (applied biweekly and control), and plant growth regulator (trinexapac-ethyl) use applied biweekly at the label recommended rate of 0.398 L ha<sup>-1</sup> and control. Results indicate nitrogen fertilizer application rate and vertical mowing significantly affected turf quality and establishment rate. Turfgrass chlorophyll content index was positively correlated to nitrogen rate. The vertical mowing regime, initiated in late spring of both years, was too aggressive to have any positive effects on turfgrass quality. Mowing height did not have any consistent effect on turf quality. Plant growth regulator application, initiated in late spring, had positive affects on turf color and quality at the end of each growing season.

## INTRODUCTION

Creeping bentgrass (*Agrostis stolonifera* L.) is one of the most common and widely used grasses for putting greens in cool-season climates in the United States. Its tolerance to low mowing heights and traffic, among other qualities, make it ideal for putting greens in the northern United States. Recently, breeding efforts have improved creeping bentgrass cultivars even further by increasing shoot density (Sweeney et al., 2001), reducing the amount of fertilizer (Baldwin and Brede, 2012) and water (McCann and Huang, 2008) that they require, and preventing the invasion of annual bluegrass (Beard et al., 2001) compared to older creeping bentgrass cultivars. These advances, among other factors such as the death of annual bluegrass in recent harsh winters, water restrictions, and aging putting greens constructed during the golf boom of the 1990's, have led many turf managers to consider renovating putting greens. Renovation of older putting greens, while expensive in the short-term, can provide a club with future financial savings and improved playing conditions.

Mowing is considered to be the most important cultural practice performed on putting greens. Improved varieties of creeping bentgrass, especially, perform better and require lower mowing heights than previous cultivars. Seeking greens that are fast, firm, and uniform is among the most desired attributes of any golf course. Past literature suggested that initially (at first mowing) most creeping bentgrass cultivars are not mowed any lower than 6.35 mm (Vavrek, 1999) on putting greens. This literature, however, is outdated since the improved cultivars of creeping bentgrass have been introduced and is also anecdotal, since no research has been published on the subject.

Nitrogen fertilizer applications, under normal growing conditions, are the single most important determining factor of turfgrass growth and development (Christians et al., 1979; Hull

and Liu, 2005). While it has been shown that nitrogen fertilizer applications of up to 19 kg N ha<sup>-1</sup> per week produce benefits to creeping bentgrass in a greenhouse setting (Watson et al., 2012), the ideal rate of N fertilizer for establishment in the field on a putting green has not been studied. While laboratory settings provide a good baseline for results in ideal or controlled conditions, findings should perform similarly in the unpredictable, natural field environment so practicing turf professionals are able to utilize test results with confidence.

Trinexapac-ethyl (TE) is a Type II plant growth regulator that has been shown to increase quality, color, and nitrogen efficiency in mature turf stands (Henderson, 2000; McCullough et al., 2006; Kreuser and Soldat, 2012). Attempts have been made to determine the usefulness of TE treatments to establishing turf, and Ervin and Koski (1998) saw increased tillering in perennial ryegrass cylinders grown in a greenhouse. An establishment field trial performed by Henderson (2000) could not determine conclusive results using TE on Kentucky bluegrass sod strength or percent cover, though he did observe increased plant color. While it is clear that TE can benefit established creeping bentgrass turf stands, its effects on establishment rate and quality are not available in refereed literature.

Vertical mowing (VM) has been used for many years on putting greens, and its effects on thatch removal have been well studied, but with varying results as to its effectiveness at reducing thatch (Carrow et al., 1987; Callahan et al., 1998; McCarty et al., 2005; McCarty et al., 2007). Most results seem dependent on both frequency and depth of VM applications, with deeper and more frequent applications having the greatest effect on thatch production, but also decreasing visual quality and ball roll distance compared to lesser applications. Salaiz et al. (1995) observed an increase in ball roll distance in one year of a study 5-d after VM application and suggested that the increase in ball roll distance was due to a denser surface created by plants filling in the

voids created by VM. This theory is of particular interest in this study, as the newer, high-density cultivars of creeping bentgrass could potentially establish more rapidly when VM is applied during establishment.

The objective of this study is to evaluate the use a variety of chemical applications and cultural practices on the establishment rate of one of the newest cultivars of creeping bentgrass (*Agrostis stolonifera* cv. 'Pure Distinction') available. This cultivar was chosen for its performance in recent NTEP trials, where it rated in the highest group for a variety of characteristics including overall visual quality, leaf texture, and density (NTEP, 2008). Pure Distinction did not perform well regarding disease resistance, and for that reason background fungicide applications were made throughout the experiment in order to prevent disease presence from affecting results. Factors in this study will include initial mowing height of cut (HOC), nitrogen fertilizer application rate (NFAR), plant growth regulator (PGR) (trinexapac-ethyl) use, and vertical mowing (VM).

The hypothesis is that plots being mowed at the lower initial mowing HOC will not establish as rapidly as the plots being mowed at a higher height. The NFAR treatments will increase plant establishment rate and quality with each increase in rate. Plant growth regulator use and vertical mowing will both have positive effects on turfgrass development.



## MATERIALS AND METHODS

The effects of initial mowing height of cut, nitrogen fertilizer application rate, plant growth regulators, and vertical mowing on *Agrostis stolonifera* L. putting green establishment was initiated on August 16, 2013 at the Hancock Turfgrass Research Center (HTRC) at Michigan State University (MSU) in East Lansing, MI and was replicated the following year (initiated August 15, 2014). This study included four factors: initial mowing height of cut (HOC) (3.81 and 5.08 mm), nitrogen fertilizer application rate (NFAR) (2.44, 4.88, and 7.31 kg N ha<sup>-1</sup>), plant growth regulator (PGR) (trinexapac-ethyl) application (0.398 L ha<sup>-1</sup> and control), and vertical mowing regimen (biweekly application and control).

The experimental plot area seeded for this study was 71.37 m<sup>2</sup> (7.32 x 9.75 m), and individual plots were 0.74 m<sup>2</sup> (0.61 x 1.22 m). Plots were seeded with *Agrostis stolonifera* L. cv. ‘Pure Distinction’ [Tee-2-Green Corporation, Hubbard, OR] at 36.69 kg ha<sup>-1</sup> into a 90/10 sand-based root zone (Table 1). In 2013, an additional 12.23 kg ha<sup>-1</sup> of seed was applied to the entire plot area 21 DAS due to a rain event that washed out significant portions of seed and fertilizer. Pre-treatment applications of a starter fertilizer (Lesco® Professional Starter Fertilizer 18-24-12) [SiteOne™ Landscape Supply, Roswell, GA] at 36.62 kg N ha<sup>-1</sup> and a controlled-release product (Harrell’s Polyon® Controlled Release Fertilizer 29-0-10) [Harrell’s LLC, Lakeland, FL] at 61.03 kg N ha<sup>-1</sup> were made at the time of seeding. Additionally, 24.46 kg N ha<sup>-1</sup> of the same starter fertilizer was applied after germination blankets were removed. Germination blankets were removed nine and 10 DAS in 2013 and 2014, respectively.

Table 1. Particle size distribution for the root zone used in both experiments. East Lansing, MI. 2016.

| Sieve Number | Particle Size Range (mm) | Percent          |
|--------------|--------------------------|------------------|
| 10           | > 2                      | 0.5              |
| 18           | 2-1                      | 7.0              |
| 35           | 1-0.5                    | 20.8             |
| 60           | 0.5-0.25                 | 41.9             |
| 140          | 0.25-0.1                 | 20.1             |
| 270          | 0.1-0.05                 | 1.5              |
| None         | < 0.05                   | 8.6 <sup>z</sup> |

<sup>z</sup> Totals add up to over 100 percent due to rounding.

Target irrigation for these studies was to keep the upper soil surface moist during the germination period and later to keep the upper portion of the soil profile moist as plants matured. The typical irrigation regime was 0.317 cm applied at midnight followed by four applications of 0.190 cm throughout the day, for a total of 1.08 cm daily. All irrigation was applied overhead via Rain Bird® Eagle 751 Golf Rotors [Rain Bird Corporation, Azusa, CA]. As plants matured, irrigation was reduced to the midnight application and two applications throughout the day. Irrigation ceased following rain events until the soil profile was returned to the point of typical irrigation requirement.

Background fungicide applications were made to the entire experimental area in order to prevent disease from affecting results. Products were applied as necessary depending on weather conditions and disease pressure.

Mowing HOC treatments began during the first mowing of each year of the study (36 and 14 DAS). There were two initial heights of cut: 5.08 and 3.81 mm, reduced weekly by 0.254 and 0.127 mm, respectively. Mowing heights were reduced starting in the spring (276 and 270 DAS) until each treatment reached 3.175 mm, at which point that height was maintained for the remainder of the experiment. The point at which mowing heights converged occurred 332 and 318 DAS in years one and two, respectively. The 14-d difference in dates to minimum height is due to the first two height reductions in the first year of the study, in which the height was reduced by 0.127 mm instead of 0.254. After the first two reductions, it was observed that in order to reach the minimum height in a reasonable amount of time, the height of cut had to be decreased more rapidly. Mowing treatments were made with a Jacobsen® PGM-22™ [Jacobsen Division of Textron Inc., Charlotte, NC] walk-behind mower in the fall and a Toro

Greensmaster® 1000 [The Toro Company, Bloomington, MN] in the spring. Mowing was performed five days per week.

NFAR treatments were initiated on September 24, 2013 (40 DAS) and September 23, 2014 (39 DAS) for years one and two, respectively. Nitrogen fertilizer applications were made with an R&D CO<sub>2</sub> backpack sprayer [Bellspray, Inc., Opelousas, Louisiana] that was equipped with a TeeJet 8003 EVS nozzle [TeeJet Technologies, Glendale Heights, IL] at a spray volume of approximately 475 L ha<sup>-1</sup>. The nitrogen source was urea (46-0-0) from The Andersons® [The Andersons, Inc., Maumee, OH] that was liquefied with water. Applications were made on a weekly basis (approximately 7-d intervals), dependent on weather conditions. Nitrogen fertilizer application rates (NFAR) were 2.44, 4.88, and 7.31 kg N ha<sup>-1</sup>. Over the course of one growing season 22 applications (5 fall and 17 spring/summer) were made in the first year of the study and 20 (4 fall and 16 spring/summer) were made in the second year. These applications totaled 53.68, 107.36, and 160.82 kg N ha<sup>-1</sup> per year in the first year and 48.80, 97.60, and 146.20 kg N ha<sup>-1</sup> per year in the second year of the study.

PGR applications were made using the same R&D CO<sub>2</sub> backpack sprayer described in the NFAR treatment section. The PGR used was Primo Maxx® from Syngenta® [Syngenta Corp., Greensboro, NC]. Applications were made at the label-recommended rate of 0.398 L ha<sup>-1</sup> at 14-day intervals, and controls of no application made. Treatments were initiated in the spring of both years following seeding (294 and 298 DAS).

Vertical mowing applications were applied using a True-Surface® vertical mowing unit [Turflite, Inc., Moscow Mills, MO] mounted on a Toro Greensmaster® Flex 2100 walk-behind mower. Applications were made biweekly and control plots of no application were included. Treatments began 285 and 297 DAS in years one and two, respectively.

## **Response Variables**

Plot ratings were performed on a weekly basis. Ratings began on October 18, 2013 (63 DAS) in year one and on October 7, 2014 (53 DAS) for year two of the study. Plots were rated for estimated visual ground cover on a percent basis (0-100%) using the National Turfgrass Evaluation Program (NTEP) rating system for living ground cover. Turf color ratings were made using a FieldScout® TCM 500 NDVI Turf Color Meter [Spectrum Technologies, Inc., Aurora, IL], which measures reflectance at 660 and 850 nm in a 7.6 cm diameter area and reports color on a scale from 0.000 to 1.000. Three measurements per plot were averaged to achieve the reported results. Turfgrass chlorophyll content index was measured using a FieldScout® CM 1000 Chlorophyll Meter [Spectrum Technologies, Inc., Aurora, IL], which uses ambient and reflected light at wavelengths of 700 and 840 nm to report relative chlorophyll content based on a scale from 0 to 999. The area recorded by this device is dependent on the distance it is held from the turf surface. In this study, it was held at 1.02 m and resulted in a circular collection area with a diameter of approximately 11.0 cm. Three measurements per plot area were averaged to achieve the reported results. Turf strength was measured at the conclusion of each experimental year using a Turf-Tec Shear Strength Tester [Turf-Tec International, Tallahassee, FL], which reports the amount of force (in Newton Meters) needed to sever the turf at 1.7 cm below the turf canopy. Three measurements were taken per plot and averaged to achieve the reported results. Because of the destructive nature of this measurement, ratings were only taken at the conclusion of each experimental season.

## **Statistical Analysis**

Data were analyzed as a 3x2x2x2 randomized factorial, complete split-block design with four replications. Statistics were analyzed using the PROC GLIMMIX procedure in SAS

(version 9.4) [SAS Institute Inc., Cary, NC]. Main effects were initial mowing height of cut (split-block), nitrogen fertilizer application rate (whole-plot), plant growth regulator use (whole-plot), and vertical mowing (whole-plot). Significance of effects were determined using analysis of variance at the  $P \leq 0.05$  level of probability. When significance occurred, means were separated using Fisher's Least Significant Difference (LSD).

## **RESULTS AND DISCUSSION**

All of the following tables and figures contain representative samples of collection dates. For full analysis of variance tables, please see the Appendix.

### **Effects on Chlorophyll Content Index**

Multiple main effects and interactions were significantly different regarding turfgrass chlorophyll content, as measured by the FieldScout® CM 1000 Chlorophyll Meter, during both years of data collection.

The HOC treatment was significant on only one collection date throughout both years of the study (Table 2 and 3). On May 25, 2015, HOC for the high and low treatments were 4.57 and 3.56 mm, respectively. On that date, the plots that were being mowed at the higher height of cut (4.57 mm) had significantly higher chlorophyll content index than the plots that were being mowed at the lower height of cut (3.56 mm). However, when the LSD is rounded to the nearest whole number (relative chlorophyll content is reported in whole numbers) the treatments are no longer significantly different. The overall insignificance of this main effect indicates that mowing a new putting green can be initiated at 3.56 mm with no negative consequences. Mowing could possibly be initiated at an even lower height of cut, but further research would need to be performed to confirm or deny that potential.

NFAR treatments were significantly different on every collection date for both years of the study (Table 2 and 3). With the exception of the early collection dates in the fall of each year, a stepwise increase in turf chlorophyll content was observed with each increase in NFAR. The plots receiving the lowest rate of nitrogen (2.44 kg N/ha) always

Table 2. Effects of initial mowing height of cut, nitrogen fertilizer application rate, trinexapac-ethyl, and vertical mowing on chlorophyll content index<sup>z</sup> of an establishing creeping bentgrass putting green. East Lansing, MI. 2014.

| Treatment                               | Application Rate | Chlorophyll Content <sup>y</sup> |        |         |         |         |
|-----------------------------------------|------------------|----------------------------------|--------|---------|---------|---------|
|                                         |                  | June 16                          | July 2 | July 14 | July 31 | Aug. 11 |
| Initial Mowing                          | 5.08             | 127                              | 135    | 148     | 169     | 183     |
| Height of Cut (M) <sup>x</sup>          | 3.81             | 123                              | 134    | 146     | 167     | 180     |
| LSD (P=0.05)                            |                  | NS <sup>t</sup>                  | NS     | NS      | NS      | NS      |
| Nitrogen Fertilizer                     | 7.31             | 138 a <sup>s</sup>               | 152 a  | 168 a   | 194 a   | 210 a   |
| Application Rate                        | 4.88             | 126 b                            | 139 b  | 151 b   | 172 b   | 186 b   |
| (F) <sup>w</sup>                        | 2.44             | 108 c                            | 114 c  | 122 c   | 138 c   | 148 c   |
| LSD (P=0.05)                            |                  | 6.5                              | 4.8    | 5.8     | 5.9     | 6.0     |
| Plant Growth Regulator (P) <sup>v</sup> | 0.398            | 126                              | 137    | 148     | 172     | 184     |
|                                         | None             | 125                              | 133    | 145     | 164     | 178     |
| LSD (P=0.05)                            |                  | NS                               | NS     | NS      | *       | *       |
| Vertical Mowing (V) <sup>u</sup>        | Biweekly         | 115                              | 121    | 131     | 153     | 171     |
|                                         | None             | 136                              | 149    | 162     | 183     | 192     |
| LSD (P=0.05)                            |                  | *                                | *      | *       | *       | *       |
| M x F                                   |                  | NS                               | NS     | NS      | NS      | NS      |
| M x P                                   |                  | NS                               | NS     | NS      | NS      | NS      |
| M x V                                   |                  | NS                               | NS     | NS      | NS      | NS      |
| F x P                                   |                  | NS                               | NS     | NS      | NS      | NS      |
| F x V                                   |                  | *                                | *      | *       | *       | NS      |
| P x V                                   |                  | *                                | *      | NS      | NS      | NS      |
| M x F x P                               |                  | NS                               | NS     | NS      | NS      | NS      |
| M x F x V                               |                  | NS                               | NS     | NS      | NS      | NS      |
| M x P x V                               |                  | NS                               | NS     | NS      | NS      | NS      |
| F x P x V                               |                  | NS                               | NS     | NS      | NS      | NS      |
| M x F x P x V                           |                  | NS                               | NS     | NS      | NS      | NS      |

<sup>z</sup> Chlorophyll content index measured by a FieldScout® CM 1000 Chlorophyll Meter.

<sup>y</sup> Relative chlorophyll content based on ambient and reflected light on a scale from 0 to 999.

<sup>x</sup> Mowing was performed with a Toro Greensmaster 1000 five times per week. Mowing heights were reduced weekly starting in (starting 270 DAS) by 0.254 and 0.127 for the high and low heights of cut, respectively, until both reached 3.17 mm.

<sup>w</sup> Nitrogen source used was urea (46-0-0) applied weekly (kg N ha<sup>-1</sup>).

<sup>v</sup> Plant growth regulator treatments were Primo Maxx (trinexapac-ethyl) in L ha<sup>-1</sup> every 14-d.

<sup>u</sup> Vertical mowing treatments were applied using a True-Surface vertical mower mounted on a Toro Flex 2100 walk-behind mower.

<sup>t</sup> \* and NS = significant and not significant at the P=0.05 level of probability, respectively.

<sup>s</sup> Columns with the same letter are not significantly different according to Fisher's LSD at P=0.05.



Table 3. Effects of initial mowing height of cut, nitrogen fertilizer application rate, trinexapac-ethyl, and vertical mowing on chlorophyll content index<sup>z</sup> of an establishing creeping bentgrass putting green. East Lansing, MI. 2015.

| Treatment                      | Application Rate | Chlorophyll Content <sup>y</sup> |        |         |         |         |
|--------------------------------|------------------|----------------------------------|--------|---------|---------|---------|
|                                |                  | June 17                          | July 1 | July 15 | July 30 | Aug. 12 |
| Initial Mowing                 | 5.08             | 138                              | 136    | 139     | 148     | 165     |
| Height of Cut (M) <sup>x</sup> | 3.81             | 142                              | 139    | 142     | 149     | 167     |
| LSD (P=0.05)                   |                  | NS <sup>t</sup>                  | NS     | NS      | NS      | NS      |
| Nitrogen Fertilizer            | 7.31             | 159 a <sup>s</sup>               | 156 a  | 162 a   | 174 a   | 195 a   |
| Application Rate               | 4.88             | 142 b                            | 138 b  | 141 b   | 149 b   | 167 b   |
| (F) <sup>w</sup>               | 2.44             | 119 c                            | 117 c  | 117 c   | 123 c   | 136 c   |
| LSD (P=0.05)                   |                  | 3.2                              | 3.3    | 3.2     | 3.9     | 4.8     |
| Plant Growth                   | 0.398            | 139                              | 137    | 142     | 150     | 168     |
| Regulator (P) <sup>v</sup>     | None             | 141                              | 137    | 139     | 147     | 164     |
| LSD (P=0.05)                   |                  | NS                               | NS     | *       | NS      | *       |
| Vertical Mowing                | Biweekly         | 135                              | 129    | 130     | 137     | 151     |
| (V) <sup>u</sup>               | None             | 145                              | 145    | 150     | 161     | 181     |
| LSD (P=0.05)                   |                  | *                                | *      | *       | *       | *       |
| M x F                          |                  | NS                               | *      | NS      | NS      | NS      |
| M x P                          |                  | NS                               | NS     | NS      | NS      | NS      |
| M x V                          |                  | NS                               | NS     | NS      | NS      | NS      |
| F x P                          |                  | NS                               | NS     | NS      | NS      | NS      |
| F x V                          |                  | NS                               | *      | *       | *       | *       |
| P x V                          |                  | NS                               | NS     | NS      | NS      | NS      |
| M x F x P                      |                  | NS                               | NS     | NS      | NS      | NS      |
| M x F x V                      |                  | NS                               | NS     | NS      | NS      | NS      |
| M x P x V                      |                  | NS                               | NS     | NS      | NS      | NS      |
| F x P x V                      |                  | *                                | NS     | NS      | NS      | NS      |
| M x F x P x V                  |                  | NS                               | NS     | NS      | NS      | NS      |

<sup>z</sup> Chlorophyll content index measured by a FieldScout® CM 1000 Chlorophyll Meter.

<sup>y</sup> Relative chlorophyll content based on ambient and reflected light on a scale from 0 to 999.

<sup>x</sup> Mowing was performed with a Toro Greensmaster 1000 five times per week. Mowing heights were reduced weekly starting in (starting 270 DAS) by 0.254 and 0.127 for the high and low heights of cut, respectively, until both reached 3.17 mm.

<sup>w</sup> Nitrogen source used was urea (46-0-0) applied weekly (kg N ha<sup>-1</sup>).

<sup>v</sup> Plant growth regulator treatments were Primo Maxx (trinexapac-ethyl) in L ha<sup>-1</sup> every 14-d.

<sup>u</sup> Vertical mowing treatments were applied using a True-Surface vertical mower mounted on a Toro Flex 2100 walk-behind mower.

<sup>t</sup> \* and NS = significant and not significant at the P=0.05 level of probability, respectively.

<sup>s</sup> Columns with the same letter are not significantly different according to Fisher's LSD at P=0.05.

received the lowest ratings, the highest rate (7.31 kg N/ha) always received the highest rating, and the middle rate (4.88 kg N/ha) rated between those two.

PGR treatments were significantly different from the controls on multiple dates during both years of the study (Table 2 and 3). In both years, it was observed that plots receiving plant growth regulator treatments had significantly higher chlorophyll content than control plots. In both years, the first significant date did not come until at least five weeks after the initial treatment. These results indicate that PGRs can have positive effects on turfgrass chlorophyll content in plants that are less than one year old, but it may be either an additive or a delayed response, which concurs with results from a study by Ervin and Koski (1998) that demonstrated delayed responses after multiple applications.

After initiation, the vertical mowing treatment produced significant differences on every collection date during both years. It was observed that control plots had significantly higher chlorophyll contents than the plots receiving biweekly vertical mowing treatments (Table 2 and 3). A previous study by McCarty, et al. (2005) did not observe a reduction in quality on a putting green less than two years old when VM treatments were applied up to four times between March and October of a growing season. Salaiz et al. (1995) recorded a reduction in turf color and overall quality immediately following VM treatments, followed by a steady increase in both measurements in the eight days immediately following. When taking in to account the results of previous studies and the results of this study, it is presumed that biweekly VM treatments applied to a creeping bentgrass putting green less than one year old are too aggressive and do not allow enough time in between applications to observe any plant benefits.

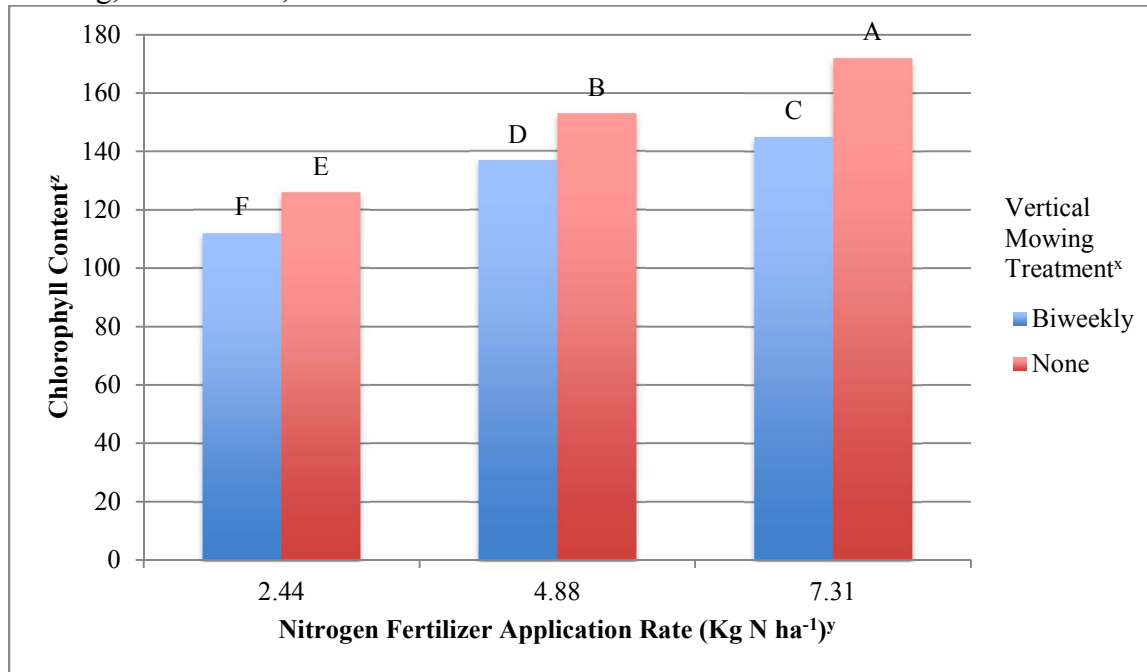
The NFAR x vertical mowing regime interaction was significant on nearly all collection dates (after vertical mowing initiation) during both years of the study (Table 2 and 3). This

interaction produced very similar results on all significant dates. An example of this interaction can be seen in Figure 1 and 2. The vertical mowing treatments proved to be so detrimental that plots receiving less fertilizer ( $4.88 \text{ kg N ha}^{-1}$ ) but no vertical mowing had higher chlorophyll contents than the plots receiving the highest fertilizer rate ( $7.31 \text{ kg N ha}^{-1}$ ) but which also received vertical mowing treatments. This effect, however, was not seen at the lowest rate of fertilizer ( $2.44 \text{ kg N ha}^{-1}$ ). This indicates that plants receiving less than  $7.31 \text{ kg N ha}^{-1}$ , while still negatively affected by vertical mowing, were not receiving enough nitrogen to properly grow to their potential. This is supported by the results from both of the main effects.

The PGR x vertical mowing interaction was significant during multiple dates during the first year of the study, but not on any dates during the second year of the study. On the dates in which this interaction was significant, plots receiving PGR treatments that were not being vertically mowed had higher chlorophyll contents than those that did not receive PGR treatments. However, the plots that were being vertically mowed showed no difference between PGR treatments (Figure 3). The separation of means on the plots that were not vertically mowed was not observed on the first date that this interaction was significant (June 16, 2014; Figure 4), but was on the subsequent days that this interaction was significant.

The following interactions were only significant on one day per year or less, and were therefore not seen as contributing to the overall significance of this study: mowing HOC x NFAR; mowing HOC x NFAR x PGR; NFAR x PGR x vertical mowing.

Figure 1. Effects of a nitrogen fertilizer application rate and vertical mowing treatment interaction on chlorophyll content index of an establishing creeping bentgrass putting green. East Lansing, MI. June 26, 2014.



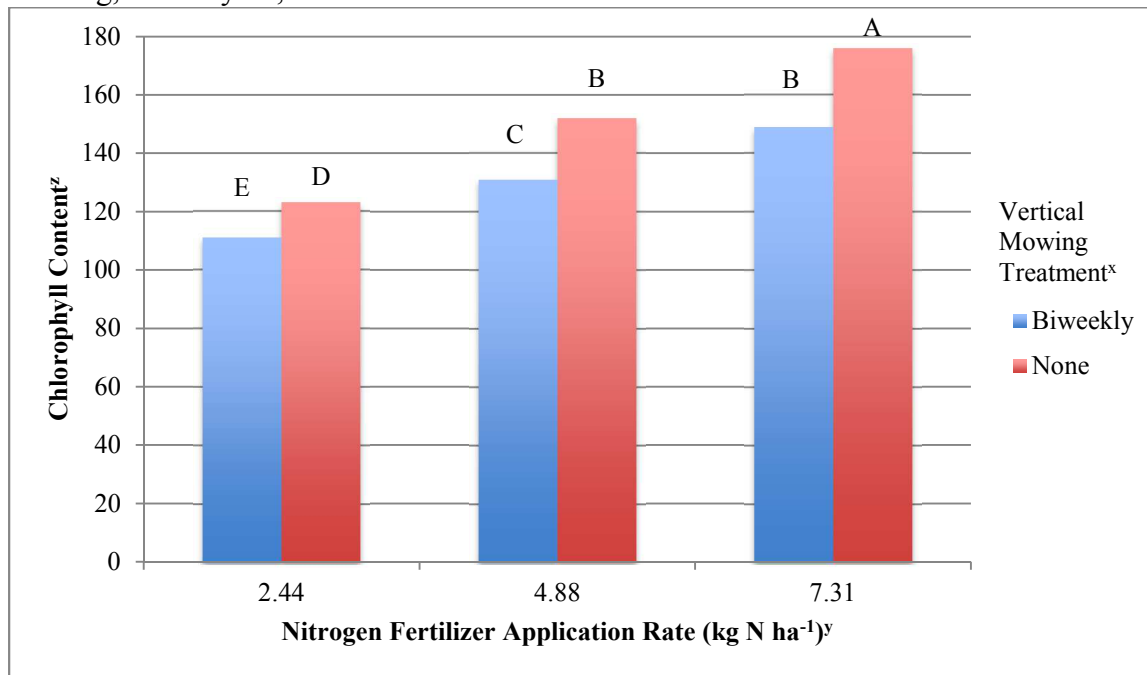
<sup>z</sup> Chlorophyll content measured by a FieldScout® CM 1000 Chlorophyll Meter. Relative chlorophyll content based on ambient and reflected light on a scale from 0 to 999.

<sup>y</sup> Nitrogen source used was liquefied urea (46-0-0). Applications were made weekly.

<sup>x</sup> Vertical mowing treatments were made with a True Surface vertical mowing unit mounted on a Toro Flex 2100 walk-behind mower.

Columns with the same letter are not significantly different according to Fisher's LSD at P=0.05.

Figure 2. Effects of a nitrogen fertilizer application rate and vertical mowing treatment interaction on chlorophyll content index of an establishing creeping bentgrass putting green. East Lansing, MI. July 15, 2015.



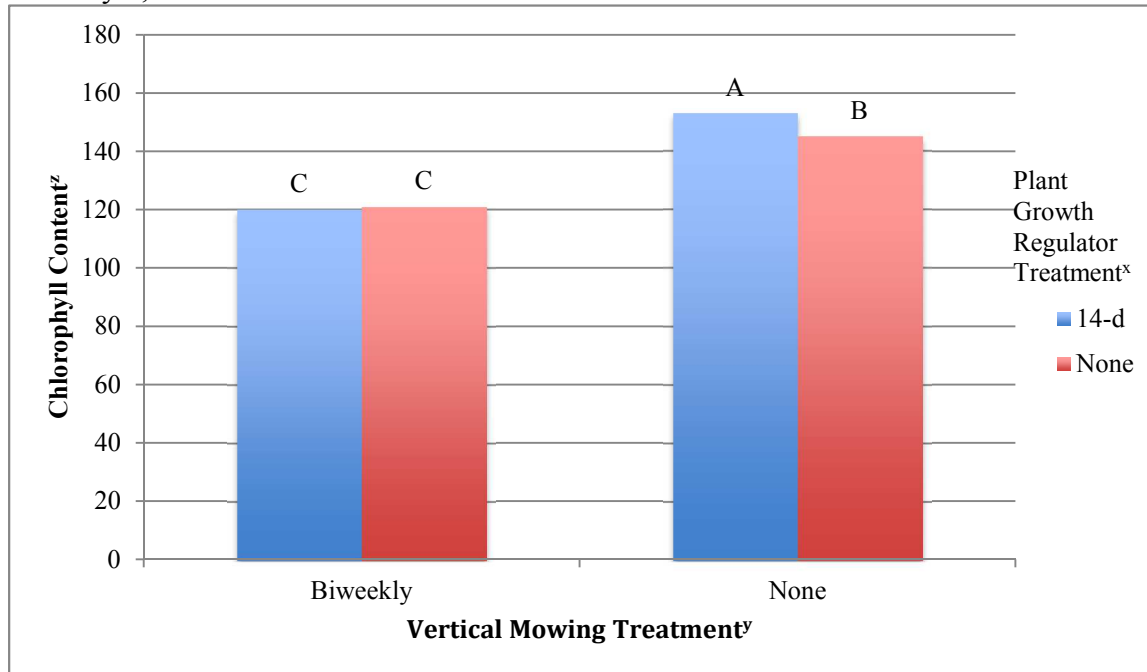
<sup>z</sup> Chlorophyll content measured by a FieldScout® CM 1000 Chlorophyll Meter. Relative chlorophyll content based on ambient and reflected light on a scale from 0 to 999.

<sup>y</sup> Nitrogen source used was liquefied urea (46-0-0). Applications were made weekly.

<sup>x</sup> Vertical mowing treatments were made with a True Surface vertical mowing unit mounted on a Toro Flex 2100 walk-behind mower.

Columns with the same letter are not significantly different according to Fisher's LSD at P=0.05.

Figure 3. Effects of a vertical mowing and plant growth regulator (trinexapac-ethyl) interaction on chlorophyll content index of an establishing creeping bentgrass putting green. East Lansing, MI. July 2, 2014.

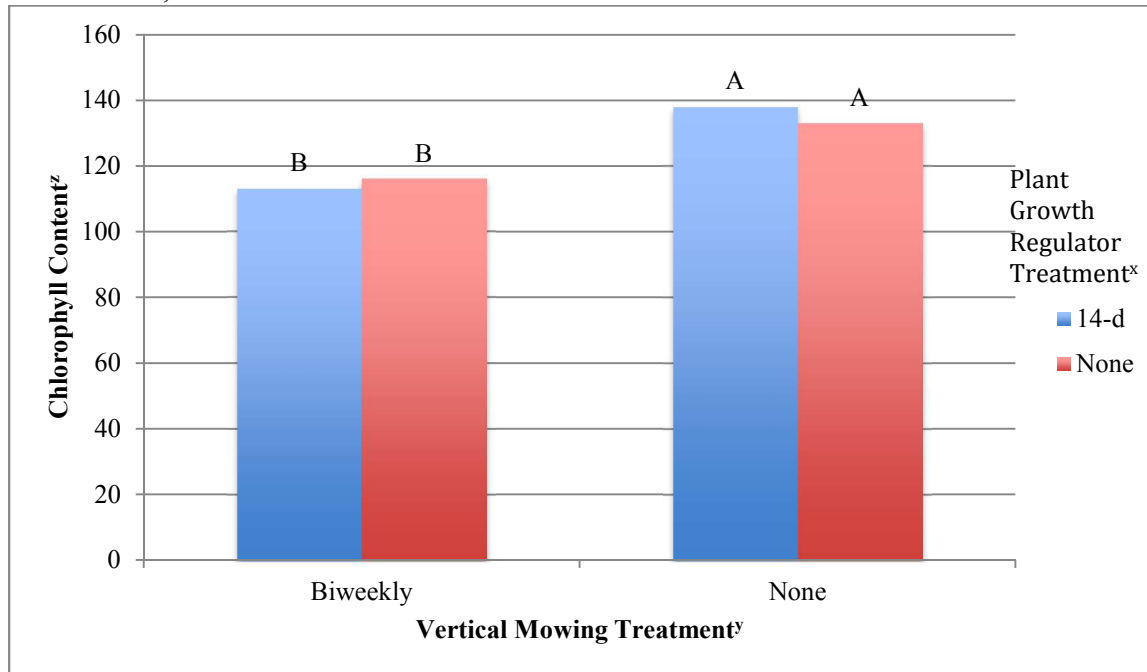


<sup>z</sup> Chlorophyll content measured by a FieldScout® CM 1000 Chlorophyll Meter. Relative chlorophyll content based on ambient and reflected light on a scale from 0 to 999.

<sup>y</sup> Vertical mowing treatments were made with a True Surface vertical mowing unit mounted on a Toro Flex 2100 walk-behind mower.

<sup>x</sup> Plant growth regulator treatments were made with Primo Maxx at a rate of 0.398 L ha<sup>-1</sup>. Columns with the same letter are not significantly different according to Fisher's LSD at P=0.05.

Figure 4. Effects of a vertical mowing and plant growth regulator (trinexapac-ethyl) interaction on chlorophyll content index of an establishing creeping bentgrass putting green. East Lansing, MI. June 16, 2014.



<sup>z</sup> Chlorophyll content measured by a FieldScout® CM 1000 Chlorophyll Meter. Relative chlorophyll content based on ambient and reflected light on a scale from 0 to 999.

<sup>y</sup> Vertical mowing treatments were made with a True Surface vertical mowing unit mounted on a Toro Flex 2100 walk-behind mower.

<sup>x</sup> Plant growth regulator treatments were made with Primo Maxx at a rate of 0.398 L ha<sup>-1</sup>. Columns with the same letter are not significantly different according to Fisher's LSD at P=0.05.

## **Effects on Turfgrass Color**

The results of this study showed significant differences between multiple main effects and interactions regarding turfgrass color content as measured by a FieldScout® TCM 500 NDVI Turf Color Meter. Significant differences were seen in both years of the study.

HOC treatments were significant during only four dates throughout the duration of the study. All of these dates occurred in the second year of the study. For the three significant dates in May of 2015, plots that were being mowed at a higher height of cut received higher NDVI ratings than plots at a lower height of cut. On June 25, 2015, however, plots that were mowed at the lower height of cut received slightly better ratings. These dates were not selected for Table 5, but because of the insignificance of the first year of the study and the fact that as the year went on the treatments switched significance, it can be inferred that initial mowing height does not have an effect on turfgrass color.

NFAR treatments were significant on every date throughout both years of the study. On four collection dates throughout both years of the study, all of which occurred during the fall of each year, a clear separation between all levels of fertilizer applications was not seen. For all other collection dates, a stepwise increase in turf NDVI was observed with each increase in fertilizer rate (Table 4 and 5). These results indicate that in this study there was no point of diminishing returns, and each increase in nitrogen fertilizer rate produced higher turf color quality.

The PGR factor was significant on only one date, which was in the second year of the study (June 17, 2015). On this date, plots receiving no plant growth regulator



Table 4. Effects of initial mowing height of cut, nitrogen fertilizer application rate, trinexapac-ethyl, and vertical mowing on turfgrass color<sup>z</sup> of an establishing creeping bentgrass putting green. East Lansing, MI. 2014.

| Treatment                               | Application Rate | NDVI <sup>y</sup>    |         |         |         |         |
|-----------------------------------------|------------------|----------------------|---------|---------|---------|---------|
|                                         |                  | June 16              | July 2  | July 14 | July 31 | Aug. 11 |
| Initial Mowing                          | 5.08             | 0.569                | 0.605   | 0.616   | 0.679   | 0.704   |
| Height of Cut (M) <sup>x</sup>          | 3.81             | 0.552                | 0.598   | 0.620   | 0.680   | 0.701   |
| LSD (P=0.05)                            |                  | NS <sup>t</sup>      | NS      | NS      | NS      | NS      |
| Nitrogen Fertilizer                     | 7.31             | 0.613 a <sup>s</sup> | 0.656 a | 0.671 a | 0.731 a | 0.752 a |
| Application Rate                        | 4.88             | 0.581 b              | 0.623 b | 0.635 b | 0.701 b | 0.725 b |
| (F) <sup>w</sup>                        | 2.44             | 0.488 c              | 0.523 c | 0.548 c | 0.607 c | 0.631 c |
| LSD (P=0.05)                            |                  | 0.017                | 0.021   | 0.016   | 0.014   | 0.017   |
| Plant Growth Regulator (P) <sup>v</sup> | 0.398            | 0.560                | 0.605   | 0.622   | 0.684   | 0.707   |
|                                         | None             | 0.561                | 0.598   | 0.614   | 0.675   | 0.699   |
| LSD (P=0.05)                            |                  | NS                   | NS      | NS      | NS      | NS      |
| Vertical Mowing (V) <sup>u</sup>        | Biweekly         | 0.516                | 0.555   | 0.576   | 0.651   | 0.648   |
|                                         | None             | 0.606                | 0.648   | 0.660   | 0.708   | 0.722   |
| LSD (P=0.05)                            |                  | *                    | *       | *       | *       | *       |
| M x F                                   |                  | NS                   | NS      | NS      | NS      | NS      |
| M x P                                   |                  | NS                   | NS      | NS      | NS      | NS      |
| M x V                                   |                  | NS                   | NS      | NS      | NS      | NS      |
| F x P                                   |                  | NS                   | NS      | NS      | *       | NS      |
| F x V                                   |                  | NS                   | NS      | NS      | NS      | NS      |
| P x V                                   |                  | NS                   | NS      | NS      | NS      | NS      |
| M x F x P                               |                  | NS                   | NS      | NS      | NS      | NS      |
| M x F x V                               |                  | NS                   | NS      | NS      | NS      | NS      |
| M x P x V                               |                  | NS                   | NS      | NS      | NS      | NS      |
| F x P x V                               |                  | NS                   | NS      | NS      | NS      | NS      |
| M x F x P x V                           |                  | NS                   | NS      | NS      | NS      | NS      |

<sup>z</sup> Turfgrass color based on results from a FieldScout TCM 500 NDVI Turf Color Meter.

<sup>y</sup> Turf color based on a scale from 0.000 to 1.000.

<sup>x</sup> Mowing was performed with a Toro Greensmaster 1000 five times per week. Mowing heights were reduced weekly starting in (starting 270 DAS) by 0.254 and 0.127 for the high and low heights of cut, respectively, until both reached 3.17 mm.

<sup>w</sup> Nitrogen source used was urea (46-0-0) applied weekly (kg N ha<sup>-1</sup>).

<sup>v</sup> Plant growth regulator treatments were Primo Maxx (trinexapac-ethyl) in L ha<sup>-1</sup> every 14-d.

<sup>u</sup> Vertical mowing treatments were applied using a True-Surface vertical mower mounted on a Toro Flex 2100 walk-behind mower.

<sup>t</sup> \* and NS = significant and not significant at the P=0.05 level of probability, respectively.

<sup>s</sup> Columns with the same letter are not significantly different according to Fisher's LSD at P=0.05.

Table 5. Effects of initial mowing height of cut, nitrogen fertilizer application rate, trinexapac-ethyl, and vertical mowing on turfgrass color<sup>z</sup> of an establishing creeping bentgrass putting green. East Lansing, MI. 2015.

| Treatment                               | Application Rate | NDVI <sup>y</sup>    |         |         |         |         |
|-----------------------------------------|------------------|----------------------|---------|---------|---------|---------|
|                                         |                  | June 17              | July 1  | July 15 | July 30 | Aug. 12 |
| Initial Mowing                          | 5.08             | 0.619                | 0.628   | 0.638   | 0.656   | 0.680   |
| Height of Cut (M) <sup>x</sup>          | 3.81             | 0.635                | 0.645   | 0.652   | 0.657   | 0.683   |
| LSD (P=0.05)                            |                  | NS <sup>t</sup>      | NS      | NS      | NS      | NS      |
| Nitrogen Fertilizer                     | 7.31             | 0.683 a <sup>s</sup> | 0.687 a | 0.708 a | 0.716 a | 0.733 a |
| Application Rate                        | 4.88             | 0.638 b              | 0.647 b | 0.660 b | 0.671 b | 0.694 b |
| (F) <sup>w</sup>                        | 2.44             | 0.560 c              | 0.575 c | 0.569 c | 0.582 c | 0.616 c |
| LSD (P=0.05)                            |                  | 0.013                | 0.014   | 0.015   | 0.016   | 0.015   |
| Plant Growth Regulator (P) <sup>v</sup> | 0.398            | 0.621                | 0.632   | 0.648   | 0.657   | 0.680   |
|                                         | None             | 0.633                | 0.642   | 0.643   | 0.656   | 0.682   |
| LSD (P=0.05)                            |                  | *                    | NS      | NS      | NS      | NS      |
| Vertical Mowing (V) <sup>u</sup>        | Biweekly         | 0.609                | 0.612   | 0.619   | 0.626   | 0.651   |
|                                         | None             | 0.645                | 0.661   | 0.671   | 0.687   | 0.711   |
| LSD (P=0.05)                            |                  | *                    | *       | *       | *       | *       |
| M x F                                   |                  | NS                   | NS      | NS      | NS      | NS      |
| M x P                                   |                  | NS                   | NS      | NS      | NS      | NS      |
| M x V                                   |                  | NS                   | *       | NS      | NS      | NS      |
| F x P                                   |                  | NS                   | NS      | NS      | NS      | NS      |
| F x V                                   |                  | NS                   | NS      | NS      | NS      | NS      |
| P x V                                   |                  | NS                   | NS      | NS      | NS      | NS      |
| M x F x P                               |                  | NS                   | NS      | NS      | NS      | NS      |
| M x F x V                               |                  | NS                   | NS      | NS      | NS      | NS      |
| M x P x V                               |                  | *                    | NS      | NS      | NS      | NS      |
| F x P x V                               |                  | NS                   | NS      | NS      | NS      | NS      |
| M x F x P x V                           |                  | NS                   | NS      | NS      | NS      | NS      |

<sup>z</sup> Turfgrass color based on results from a FieldScout TCM 500 NDVI Turf Color Meter.

<sup>y</sup> Turf color based on a scale from 0.000 to 1.000.

<sup>x</sup> Mowing was performed with a Toro Greensmaster 1000 five times per week. Mowing heights were reduced weekly starting in (starting 270 DAS) by 0.254 and 0.127 for the high and low heights of cut, respectively, until both reached 3.17 mm.

<sup>w</sup> Nitrogen source used was urea (46-0-0) applied weekly (kg N ha<sup>-1</sup>).

<sup>v</sup> Plant growth regulator treatments were Primo Maxx (trinexapac-ethyl) in L ha<sup>-1</sup> every 14-d.

<sup>u</sup> Vertical mowing treatments were applied using a True-Surface vertical mower mounted on a Toro Flex 2100 walk-behind mower.

<sup>t</sup> \* and NS = significant and not significant at the P=0.05 level of probability, respectively.

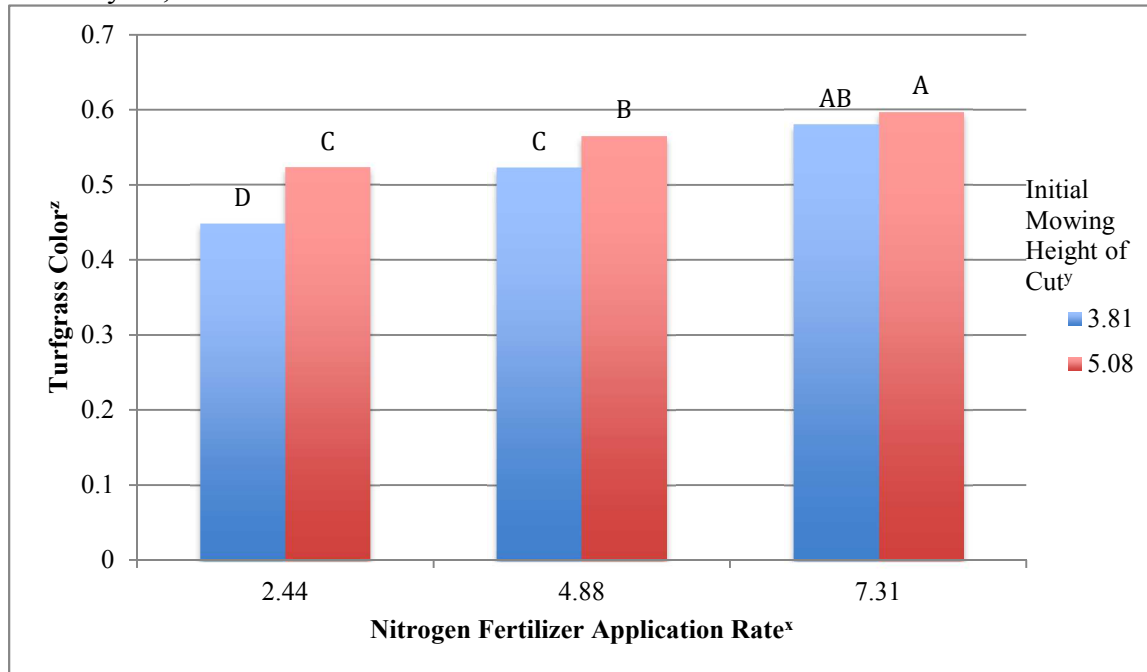
<sup>s</sup> Columns with the same letter are not significantly different according to Fisher's LSD at P=0.05.

treatment had significantly higher NDVI than plants not receiving treatment (Table 5).

Vertical mowing treatments were significant on every collection date for both years from the time that they were implemented (May 28, 2014 and June 8, 2015 for years one and two, respectively) until the end of each experimental year. Plots receiving the vertical mowing treatments always received lower ratings than plots that were vertically mowed, as shown in Table 4 and 5.

The mowing HOC x NFAR treatment interaction was significant on one date in the first year of the study (October 18, 2013) and three dates in the second year of the study (October 17 and 23, 2014, and May 21, 2015) (Figure 5). On the three dates in the second year of the study, the interaction occurred at the lowest level of fertility ( $2.44 \text{ kg N ha}^{-1}$ ) and the higher height of cut, which rated at the same level as the next highest level of fertilizer ( $4.88 \text{ kg N ha}^{-1}$ ) at the lower HOC. On October 17, only the lowest fertilizer rate at the low HOC was rated lower than all the other plots. Throughout the next two dates, plot ratings separated out more, mostly based on the fertilizer rate (higher rate of fertilizer was synonymous with higher ratings). The only plots that rated out of this trend were the aforementioned low fertilizer and high height of cut plots. As the growing season progressed this interaction disappeared. This leads to the conclusion that as plants progress through the establishment process, they require more nutrients to develop and grow and no other practices can replace those nutrients. Watson et al. (2012) performed a creeping bentgrass establishment study that supports this claim. They observed peak responses in creeping bentgrass shoot mass, overall quality, color quality, and cover five and 10 weeks after establishment at  $19 \text{ kg N ha}^{-1}$  per week compared to

Figure 5. Effects of a nitrogen fertilizer application rate and initial mowing height of cut interaction on turfgrass color of an establishing creeping bentgrass putting green. East Lansing, MI. May 21, 2015.



<sup>z</sup> Turfgrass color results are from a FieldScout NDVI TCM 500 Turf Color Meter. Results are reported on a scale from 0.000 to 1.000.

<sup>y</sup> Mowing height treatments (reported in mm) were performed five days per week with a Toro Greensmaster 1000.

<sup>x</sup> Fertilizer treatments are reported in kg N ha<sup>-1</sup> per week.

Columns with the same letter are not significantly different according to Fisher's LSD at P=0.05.

any lower rates and above which point no increases were observed. However, they also reported decreased root mass at rates above  $9.6 \text{ kg N ha}^{-1}$  per week, so careful observation and planning must be utilized to maintain healthy root:shoot ratios at establishment and beyond.

Four other interactions occurred only one time or less per experimental year: NFAR x PGR; mowing HOC x vertical mowing; PGR x vertical mowing; and mowing HOC x PGR x vertical mowing. Because of the infrequent significance of these factors, they are considered statistical anomalies and do not contribute to the conclusions based on NDVI color quality for this study.

## Effects on Visual Percent Ground Cover

The results from estimated visual ground cover ratings show multiple significant main effects and interactions throughout the experiment.

The HOC factor was significant on four dates total during the duration of the study, and results were inconsistent (Table 6 and 7). On half of significant dates, plots that started at a higher height of cut had more estimated visual percent turfgrass cover, and on the other half of significant dates plots that started with a lower height of cut had more percent cover. Overall, these results indicate that initial height of cut alone probably does not contribute to estimated visual percent turfgrass ground cover.

NFAR treatments were significant on all dates that ratings were collected throughout both years of the study (Table 6 and 7). During year one of the study, there was less separation than in year two. In both years, the lowest rate of fertilizer applied resulted in the lowest percent groundcover. In year one, separation between 4.88 and 7.31 kg N ha<sup>-1</sup> did not occur as often as it did in the second year, when nearly every date showed that higher rates of nitrogen fertilizer resulted in a greater percentage of turfgrass cover. Even though the separation was not as pronounced in the first year of the study, results generally indicate the highest rate used in this study (7.31 kg N ha<sup>-1</sup>) resulted in an increased percentage of estimated visual turfgrass ground cover when compared to lower rates. These outcomes are similar to those observed using the chlorophyll content index and NDVI mentioned earlier, though they aren't as consistent. The subjective nature of visual estimations compared to more objective, mechanical data collection methods has been documented (Horst et al., 1984; Landschoot and Mancino, 2000).

Table 6. Effects of initial mowing height of cut, nitrogen fertilizer application rate, trinexapac-ethyl, and vertical mowing on visual percent turfgrass cover<sup>z</sup> of an establishing creeping bentgrass putting green. East Lansing, MI. 2014.

| Treatment                               | Application Rate | Percent Turfgrass Cover <sup>y</sup> |        |         |         |         |
|-----------------------------------------|------------------|--------------------------------------|--------|---------|---------|---------|
|                                         |                  | June 16                              | July 2 | July 14 | July 31 | Aug. 11 |
| Initial Mowing                          | 5.08             | 82.0                                 | 87.1   | 87.8    | 89.8    | 91.6    |
| Height of Cut (M) <sup>x</sup>          | 3.81             | 76.9                                 | 84.0   | 83.8    | 85.7    | 90.4    |
| LSD (P=0.05)                            |                  | NS <sup>t</sup>                      | NS     | NS      | 3.5     | NS      |
| Nitrogen Fertilizer                     | 7.31             | 86.4 a <sup>s</sup>                  | 92.7 a | 92.9 a  | 94.4 a  | 96.9 a  |
| Application Rate                        | 4.88             | 83.1 a                               | 88.1 b | 90.0 b  | 91.6 b  | 95.0 a  |
| (F) <sup>w</sup>                        | 2.44             | 68.8 b                               | 75.8 c | 74.7 c  | 77.3 c  | 81.1 b  |
| LSD (P=0.05)                            |                  | 3.6                                  | 3.8    | 2.7     | 2.6     | 2.4     |
| Plant Growth Regulator (P) <sup>v</sup> | 0.398            | 79.5                                 | 85.0   | 85.6    | 87.6    | 90.9    |
|                                         | None             | 79.4                                 | 86.0   | 86.0    | 87.9    | 91.0    |
| LSD (P=0.05)                            |                  | NS                                   | NS     | NS      | NS      | NS      |
| Vertical Mowing (V) <sup>u</sup>        | Biweekly         | 75.7                                 | 82.3   | 80.0    | 82.1    | 86.6    |
|                                         | None             | 83.1                                 | 88.7   | 91.7    | 93.4    | 95.4    |
| LSD (P=0.05)                            |                  | *                                    | *      | *       | *       | *       |
| M x F                                   |                  | NS                                   | NS     | NS      | NS      | NS      |
| M x P                                   |                  | NS                                   | NS     | NS      | NS      | NS      |
| M x V                                   |                  | NS                                   | NS     | *       | *       | *       |
| F x P                                   |                  | NS                                   | NS     | NS      | *       | NS      |
| F x V                                   |                  | NS                                   | NS     | *       | NS      | *       |
| P x V                                   |                  | NS                                   | NS     | NS      | NS      | NS      |
| M x F x P                               |                  | NS                                   | NS     | NS      | NS      | NS      |
| M x F x V                               |                  | NS                                   | NS     | NS      | NS      | NS      |
| M x P x V                               |                  | NS                                   | NS     | NS      | NS      | NS      |
| F x P x V                               |                  | NS                                   | NS     | NS      | NS      | NS      |
| M x F x P x V                           |                  | NS                                   | *      | *       | NS      | NS      |

<sup>z</sup> Turfgrass cover based on a visual estimate using the NTEP Protocol.

<sup>y</sup> Turf cover is reported in percent (0-100%) area covered.

<sup>x</sup> Mowing was performed with a Toro Greensmaster 1000 five times per week. Mowing heights were reduced weekly starting in (starting 270 DAS) by 0.254 and 0.127 for the high and low heights of cut, respectively, until both reached 3.17 mm.

<sup>w</sup> Nitrogen source used was urea (46-0-0) applied weekly (kg N ha<sup>-1</sup>).

<sup>v</sup> Plant growth regulator treatments were Primo Maxx (trinexapac-ethyl) in L ha<sup>-1</sup> every 14-d.

<sup>u</sup> Vertical mowing treatments were applied using a True-Surface vertical mower mounted on a Toro Flex 2100 walk-behind mower.

<sup>t</sup> \* and NS = significant and not significant at the P=0.05 level of probability, respectively.

<sup>s</sup> Columns with the same letter are not significantly different according to Fisher's LSD at P=0.05.

Table 7. Effects of initial mowing height of cut, nitrogen fertilizer application rate, trinexapac-ethyl, and vertical mowing on visual percent turfgrass cover<sup>z</sup> of an establishing creeping bentgrass putting green. East Lansing, MI. 2015.

| Treatment                               | Application Rate | Percent Turfgrass Cover <sup>y</sup> |         |         |         |         |
|-----------------------------------------|------------------|--------------------------------------|---------|---------|---------|---------|
|                                         |                  | June 17                              | June 25 | July 15 | July 30 | Aug. 12 |
| Initial Mowing                          | 5.08             | 86.8                                 | 71.8    | 69.8    | 70.9    | 74.1    |
| Height of Cut (M) <sup>x</sup>          | 3.81             | 85.2                                 | 78.3    | 76.1    | 75.5    | 80.3    |
| LSD (P=0.05)                            |                  | NS <sup>t</sup>                      | NS      | 5.9     | NS      | 5.2     |
| Nitrogen Fertilizer                     | 7.31             | 92.5 a <sup>s</sup>                  | 84.4 a  | 87.3 a  | 86.2 a  | 88.1 a  |
| Application Rate                        | 4.88             | 87.8 b                               | 77.0 b  | 76.7 b  | 78.3 b  | 82.0 b  |
| (F) <sup>w</sup>                        | 2.44             | 77.7 c                               | 63.7 c  | 54.8 c  | 55.2 c  | 61.4 c  |
| LSD (P=0.05)                            |                  | 2.7                                  | 3.9     | 3.5     | 4.3     | 4.0     |
| Plant Growth Regulator (P) <sup>v</sup> | 0.398            | 85.9                                 | 75.1    | 72.1    | 73.3    | 77.6    |
|                                         | None             | 86.0                                 | 75.0    | 73.8    | 73.1    | 76.8    |
| LSD (P=0.05)                            |                  | NS                                   | NS      | NS      | NS      | NS      |
| Vertical Mowing (V) <sup>u</sup>        | Biweekly         | 84.8                                 | 67.8    | 61.1    | 59.4    | 64.8    |
|                                         | None             | 87.2                                 | 82.3    | 84.8    | 87.1    | 89.6    |
| LSD (P=0.05)                            |                  | *                                    | *       | *       | *       | *       |
| M x F                                   |                  | NS                                   | NS      | NS      | NS      | NS      |
| M x P                                   |                  | NS                                   | NS      | NS      | NS      | NS      |
| M x V                                   |                  | NS                                   | *       | *       | *       | NS      |
| F x P                                   |                  | NS                                   | NS      | NS      | NS      | NS      |
| F x V                                   |                  | NS                                   | *       | *       | *       | *       |
| P x V                                   |                  | *                                    | NS      | NS      | NS      | *       |
| M x F x P                               |                  | NS                                   | NS      | NS      | NS      | NS      |
| M x F x V                               |                  | NS                                   | NS      | NS      | NS      | NS      |
| M x P x V                               |                  | NS                                   | *       | NS      | NS      | NS      |
| F x P x V                               |                  | NS                                   | *       | NS      | NS      | NS      |
| M x F x P x V                           |                  | NS                                   | NS      | NS      | NS      | NS      |

<sup>z</sup> Turfgrass cover based on a visual estimate using the NTEP Protocol.

<sup>y</sup> Turf cover is reported in percent (0-100%) area covered.

<sup>x</sup> Mowing was performed with a Toro Greensmaster 1000 five times per week. Mowing heights were reduced weekly starting in (starting 270 DAS) by 0.254 and 0.127 for the high and low heights of cut, respectively, until both reached 3.17 mm.

<sup>w</sup> Nitrogen source used was urea (46-0-0) applied weekly (kg N ha<sup>-1</sup>).

<sup>v</sup> Plant growth regulator treatments were Primo Maxx (trinexapac-ethyl) in L ha<sup>-1</sup> every 14-d.

<sup>u</sup> Vertical mowing treatments were applied using a True-Surface vertical mower mounted on a Toro Flex 2100 walk-behind mower.

<sup>t</sup> \* and NS = significant and not significant at the P=0.05 level of probability, respectively.

<sup>s</sup> Columns with the same letter are not significantly different according to Fisher's LSD at P=0.05.



PGR treatments, initiated June 6, 2014 and June 9, 2015 in years one and two, respectively, were never significant on any date. Based on these results, it appears that PGR treatments have no effect on percentage turfgrass cover in this study. This is contrary to results that were observed by Ervin and Koski (1998), who found that 60-d old perennial ryegrass exhibited increased tillering after multiple applications of TE. Possible explanations for these differences include differing data collection methods, laboratory vs. field trial, or the use of different turfgrass species. While this study found no evidence that TE applications would increase turfgrass cover during establishment, further experimentation could result in positive observations.

Once initiated, vertical mowing treatments were significant on nearly every collection date (Table 6 and 7). Plots that received vertical mowing treatments did not recover enough in the biweekly time frame to fill in voids, and therefore had less ground cover than plots not receiving vertical mowing treatments.

The NFAR x PGR interaction was significant on July 31 and August 6, 2014 and no other dates. The PGR x vertical mowing interaction was significant on June 17 and August 12, 2015 and no other dates. Because of the limited number of days these interactions were significant and their significance during only one year each, they are not thought to contribute much to the overall conclusions of this study. If anything, they could be said to show that PGR treatments are more likely than other factors to be influenced by other treatments, as the trend in these interactions seemed to be driven by the other factor in both scenarios and not by PGR treatments, but further investigations would have to be performed to verify this hypothesis.

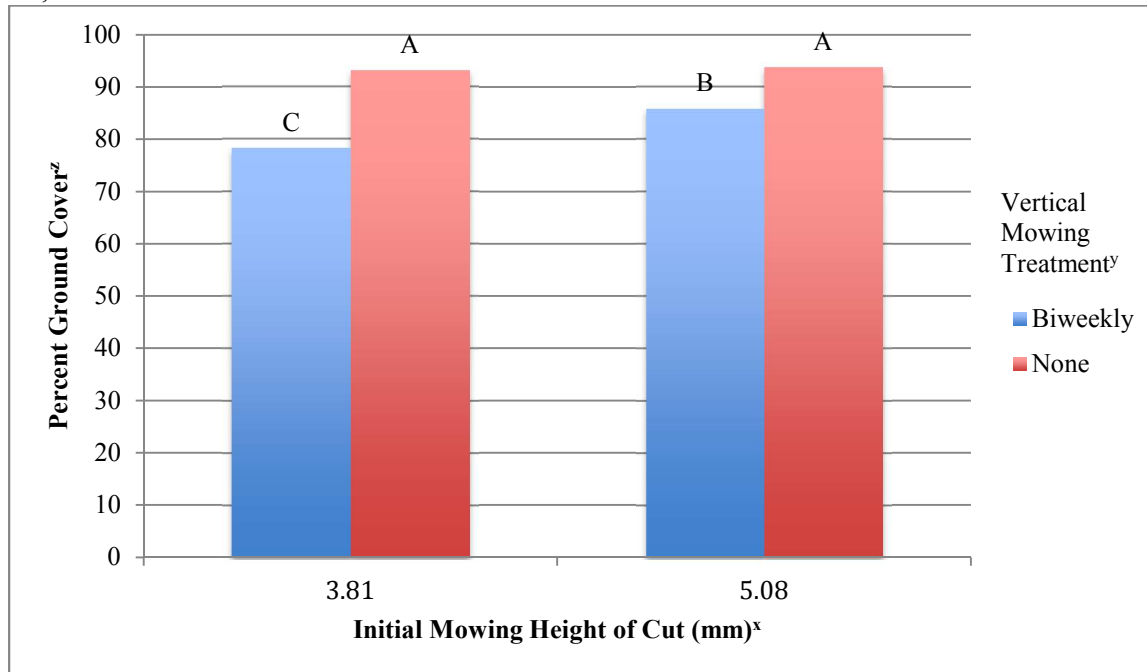
On multiple dates during both years the HOC x vertical mowing interaction was significant, as Tables 6 and 7 show. Figures 6 and 7 are representative dates from each year that

were picked at random. They demonstrate that regardless of mowing height of cut, plots receiving vertical mowing treatments rated much worse. Mowing treatments within each vertical mowing factor were not consistent, leading to the belief that the factor most affecting this interaction was the vertical mowing regime.

The NFAR x vertical mowing interaction was also significant on multiple dates throughout both years (Tables 6 and 7). Figures 8 and 9 are representative dates for this interaction. This interaction indicates that biweekly vertical mowing, even at the highest rate of fertilizer used in this study, is so detrimental to new seedlings that lower rates of fertilizer can produce similar, if not better, results on plots in which vertical mowing is not being implemented. Unlike the main effect of NFAR treatments, where each increase in fertilizer rate corresponds to an increase in percent ground cover, even plots at the highest rate of fertilizer do not cover as much ground as lower rates when they are treated with biweekly vertical mowing.

The mowing HOC x NFAR, mowing HOC x PGR x vertical mowing, and NFAR x PGR x vertical mowing interactions were all significant on one date throughout the entirety of the experiment. Because they only had one date of significance, those interactions are seen as a statistical anomaly and do not provide any useful information to the overall conclusions of this study. A four-way interaction between all factors was significant on three dates during the first year of this study. The complexity of this interaction and the difficulty in visualizing or explaining it suggests that there is little, if any, value in describing it. For these reasons, it will not be discussed.

Figure 6. Effects of an initial mowing height of cut and vertical mowing treatment interaction on visual percent cover of an establishing creeping bentgrass putting green. East Lansing, MI. July 31, 2014.



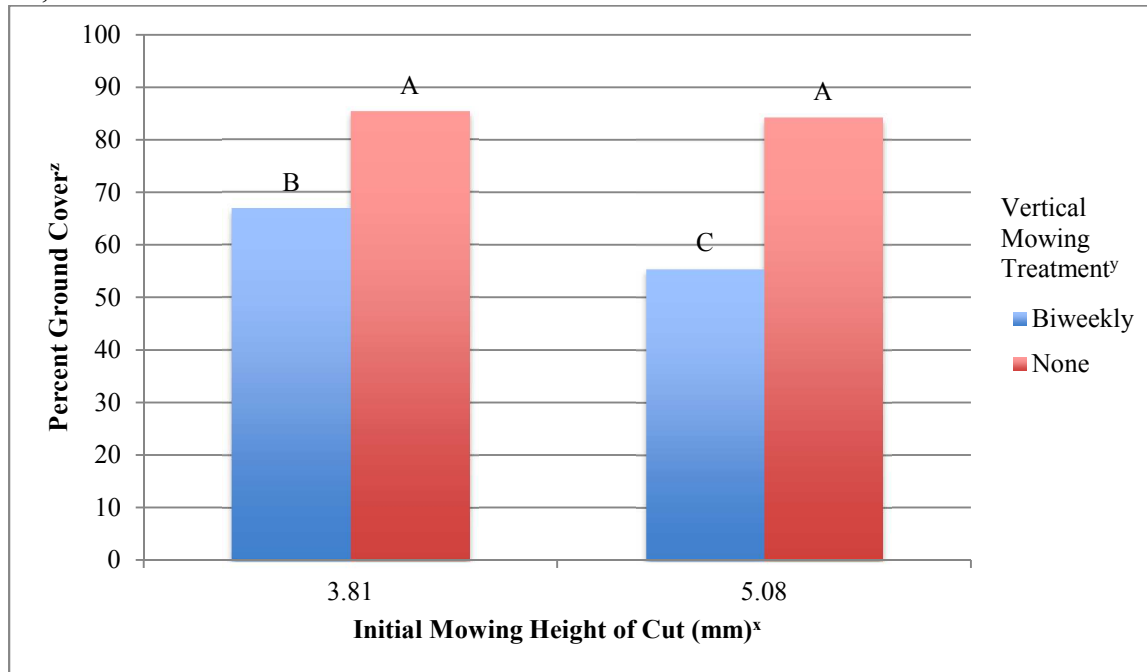
<sup>z</sup> Percent ground cover is based on a visual estimate from 0-100%.

<sup>y</sup> Vertical mowing treatments were applied using a True-Surface vertical mower mounted on a Toro Flex 2100 walk-behind mower.

<sup>x</sup> Mowing was performed with a Toro Greensmaster 1000 five times per week. Mowing heights were reduced every week (starting 270 DAS) by 0.254 and 0.127 for the high and low heights of cut, respectively.

Columns with the same letter are not significantly different according to Fisher's LSD at P=0.05.

Figure 7. Effects of an initial mowing height of cut and vertical mowing treatment interaction on visual percent cover of an establishing creeping bentgrass putting green. East Lansing, MI. July 15, 2015.



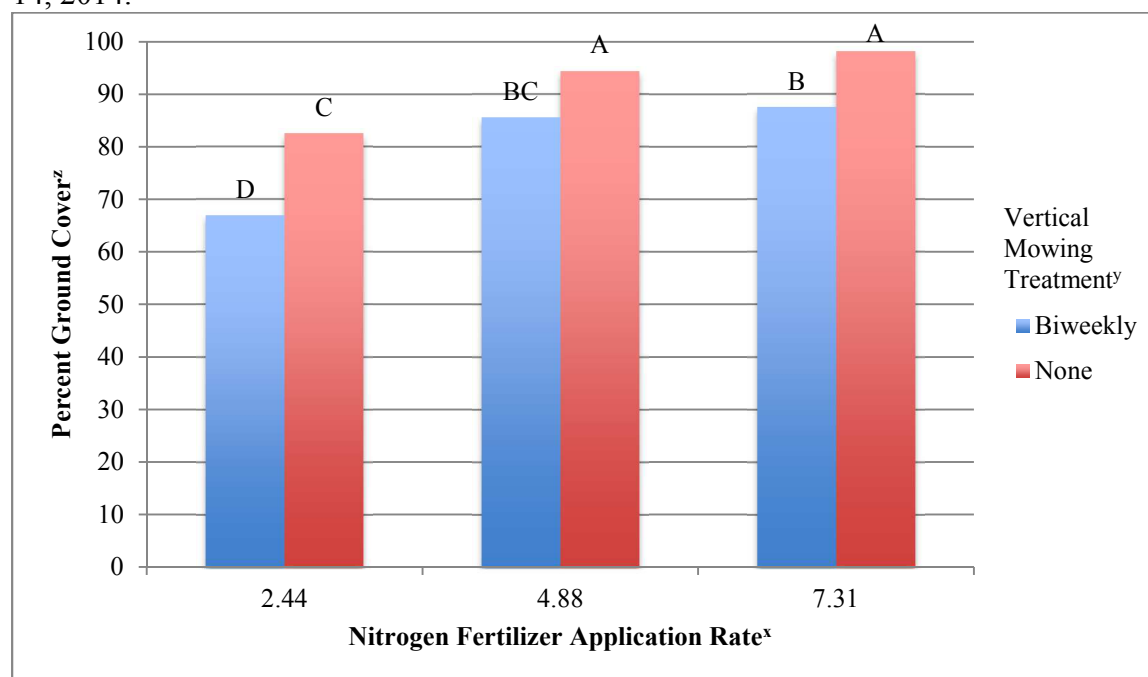
<sup>z</sup> Percent ground cover is based on a visual estimate from 0-100%.

<sup>y</sup> Vertical mowing treatments were applied using a True-Surface vertical mower mounted on a Toro Flex 2100 walk-behind mower.

<sup>x</sup> Mowing was performed with a Toro Greensmaster 1000 five times per week. Mowing heights were reduced every week (starting 270 DAS) by 0.254 and 0.127 for the high and low heights of cut, respectively.

Columns with the same letter are not significantly different according to Fisher's LSD at P=0.05.

Figure 8. Effects of a nitrogen fertilizer application rate and vertical mowing interaction on visual percent cover of an establishing creeping bentgrass putting green. East Lansing, MI. July 14, 2014.



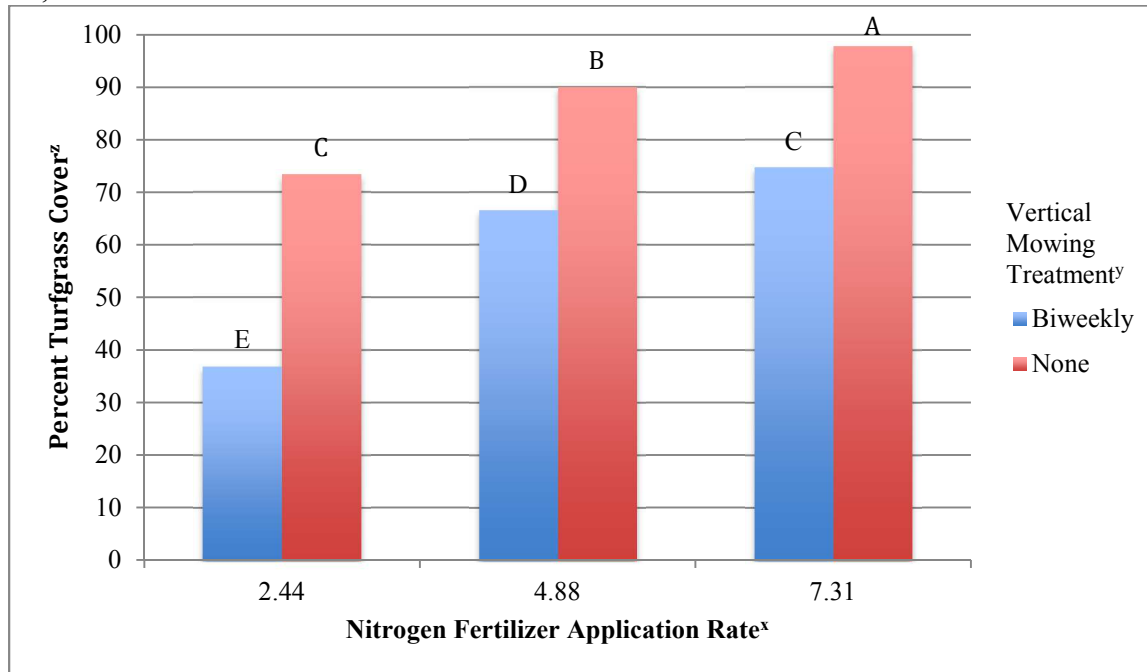
<sup>z</sup> Percent ground cover is based on a visual estimate from 0-100%.

<sup>y</sup> Vertical mowing treatments were applied using a True-Surface vertical mower mounted on a Toro Flex 2100 walk-behind mower.

<sup>x</sup> Treatment rates are given in kg N ha<sup>-1</sup> per week.

Columns with the same letter are not significantly different according to Fisher's LSD at P=0.05.

Figure 9. Effects of a nitrogen fertilizer application rate and vertical mowing interaction on visual percent cover of an establishing creeping bentgrass putting green. East Lansing, MI. July 30, 2015.



<sup>z</sup> Percent ground cover is based on a visual estimate from 0-100%.

<sup>y</sup> Vertical mowing treatments were applied using a True-Surface vertical mower mounted on a Toro Flex 2100 walk-behind mower.

<sup>x</sup> Treatment rates are given in kg N ha<sup>-1</sup> per week.

Columns with the same letter are not significantly different according to Fisher's LSD at P=0.05.

## Effects on Turfgrass Stability

Turfgrass stability in this study was measured with a Turf-Tec Shear Strength Tester. This device gives a reading of turf root strength measured in Newton Meters by inserting prongs into the ground and applying force until the turf is no longer stable and is severed from its surroundings. Due to the destructive nature of this measurement, it was only performed one time during each study period, which was on the last collection date each year (August 11, 2014 and August 12, 2015). Significant differences for main effects and interactions were observed during each collection year and are seen in Table 8.

Similar to other data collection devices, initial mowing HOC treatments were not significant for turfgrass stability. NFAR treatments were significant, and produced an increase in turf stability with each increase in rate. Plots receiving the lowest fertilizer rate were sheared with the least amount of force and each increase in fertilizer rate after that produced a step-wise increase in turf stability. Plant growth regulator treatments did not have any effect on turfgrass stability. Vertical mowing treatments had a negative effect on turfgrass shear strength. This is logical, because areas that received vertical mowing treatments were not able to heal in time, and therefore already had voids and injuries in the turf surface before shear strength data was collected.

The interaction between initial mowing HOC and vertical mowing was significant during the second year of the study. In this interaction (Figure 10), both of the HOC treatments that were not being vertically mowed had the highest strength test ratings, while the low initial HOC plots were stronger than the ones that started off being mowed higher for plots that were vertically mowed. According to this reaction, plots that started

Table 8. Effects of initial mowing height of cut, nitrogen fertilizer application rate, trinexapac-ethyl, and vertical mowing on turfgrass stability<sup>z</sup> of an establishing creeping bentgrass putting green. East Lansing, MI. 2014/2015.

| Treatment                               | Application Rate | Turfgrass Stability <sup>y</sup> |                 |
|-----------------------------------------|------------------|----------------------------------|-----------------|
|                                         |                  | August 13, 2014                  | August 12, 2015 |
| Initial Mowing                          | 5.08             | 12.7                             | 8.3             |
| Height of Cut (M) <sup>x</sup>          | 3.81             | 11.8                             | 8.4             |
| LSD (P=0.05)                            |                  | NS <sup>t</sup>                  | NS              |
| Nitrogen Fertilizer                     | 7.31             | 13.9 a <sup>x</sup>              | 9.8 a           |
| Application Rate                        | 4.88             | 12.9 b                           | 8.4 b           |
| (F) <sup>w</sup>                        | 2.44             | 9.9 c                            | 6.8 c           |
| LSD (P=0.05)                            |                  | 0.9                              | 0.5             |
| Plant Growth Regulator (P) <sup>v</sup> | 0.398            | 12.4                             | 8.4             |
|                                         | None             | 12.1                             | 8.3             |
| LSD (P=0.05)                            |                  | NS                               | NS              |
| Vertical Mowing (V) <sup>u</sup>        | Biweekly         | 10.4                             | 7.5             |
|                                         | None             | 14.1                             | 9.2             |
| LSD (P=0.05)                            |                  | *                                | *               |
| M x F                                   |                  | NS                               | NS              |
| M x P                                   |                  | NS                               | *               |
| M x V                                   |                  | NS                               | *               |
| F x P                                   |                  | NS                               | NS              |
| F x V                                   |                  | *                                | *               |
| P x V                                   |                  | NS                               | NS              |
| M x F x P                               |                  | NS                               | NS              |
| M x F x V                               |                  | NS                               | NS              |
| M x P x V                               |                  | NS                               | NS              |
| F x P x V                               |                  | NS                               | NS              |
| M x F x P x V                           |                  | NS                               | NS              |

<sup>z</sup> Turfgrass stability measured by a Turf-Tec Shear Strength Tester.

<sup>y</sup> Turfgrass stability is reported in Newton Meters required to shear the turf from its surroundings.

<sup>x</sup> Mowing (reported in mm) was performed with a Toro Greensmaster 1000 five times per week. Mowing heights were reduced weekly starting in (starting 270 DAS) by 0.254 and 0.127 for the high and low heights of cut, respectively, until both reached 3.17 mm.

<sup>w</sup> Nitrogen source used was urea (46-0-0) applied weekly (kg N ha<sup>-1</sup>).

<sup>v</sup> Plant growth regulator treatments were Primo Maxx (trinexapac-ethyl) in L ha<sup>-1</sup> every 14-d.

<sup>u</sup> Vertical mowing treatments were applied using a True-Surface vertical mower mounted on a Toro Flex 2100 walk-behind mower.

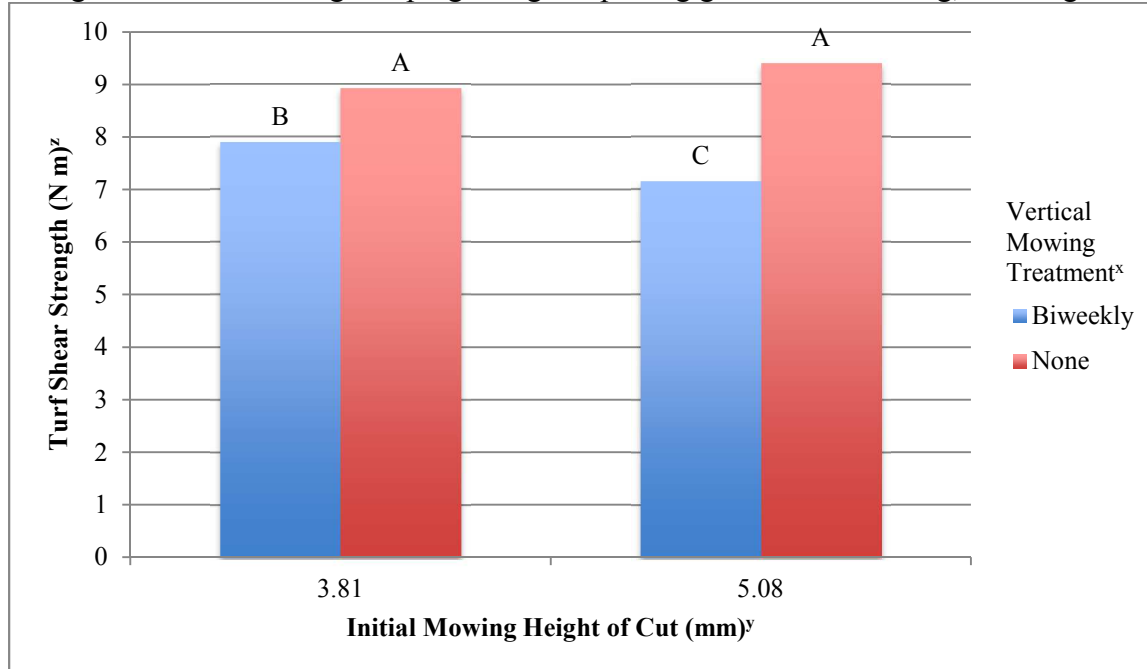
<sup>t</sup> \* and NS = significant and not significant at the P=0.05 level of probability, respectively.

<sup>s</sup> Columns with the same letter are not significantly different according to Fisher's LSD at P=0.05.

<sup>r</sup> Although it was reported as a significant interaction, the means for this interaction did not produce different levels of significance.



Figure 10. Effects of a mowing height of cut and vertical mowing interaction on turf shear strength of an establishing creeping bentgrass putting green. East Lansing, MI. August 12, 2015.



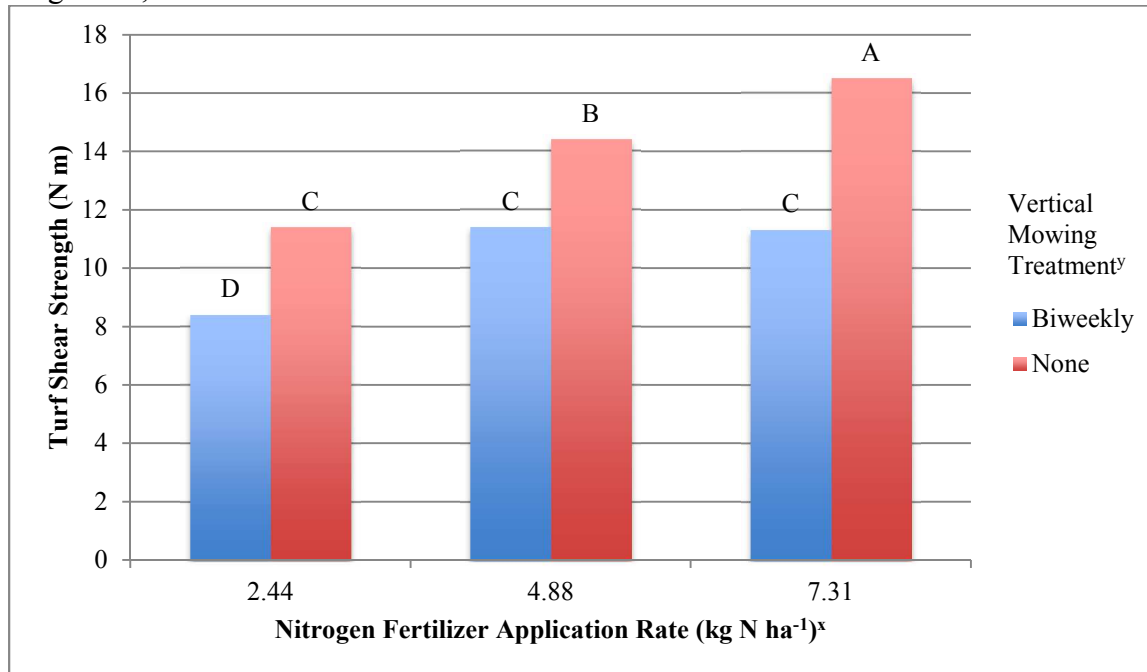
<sup>z</sup> Turfgrass shear strength is measured by a Turf-Tec Shear Strength Tester.

<sup>y</sup> Mowing treatments were performed five days per week with a Toro Greensmaster 1000. At the time of data collection, both treatments were being mowed at a 3.17 mm height of cut.

<sup>x</sup> Vertical mowing treatments were applied using a True-Surface vertical mower mounted on a Toro Flex 2100 walk-behind mower.

Columns with the same letter are not significantly different according to Fisher's LSD at P=0.05.

Figure 11. Effects of a nitrogen fertilizer application rate and vertical mowing interaction on turfgrass shear strength of an establishing creeping bentgrass putting green. East Lansing, MI. August 13, 2014.



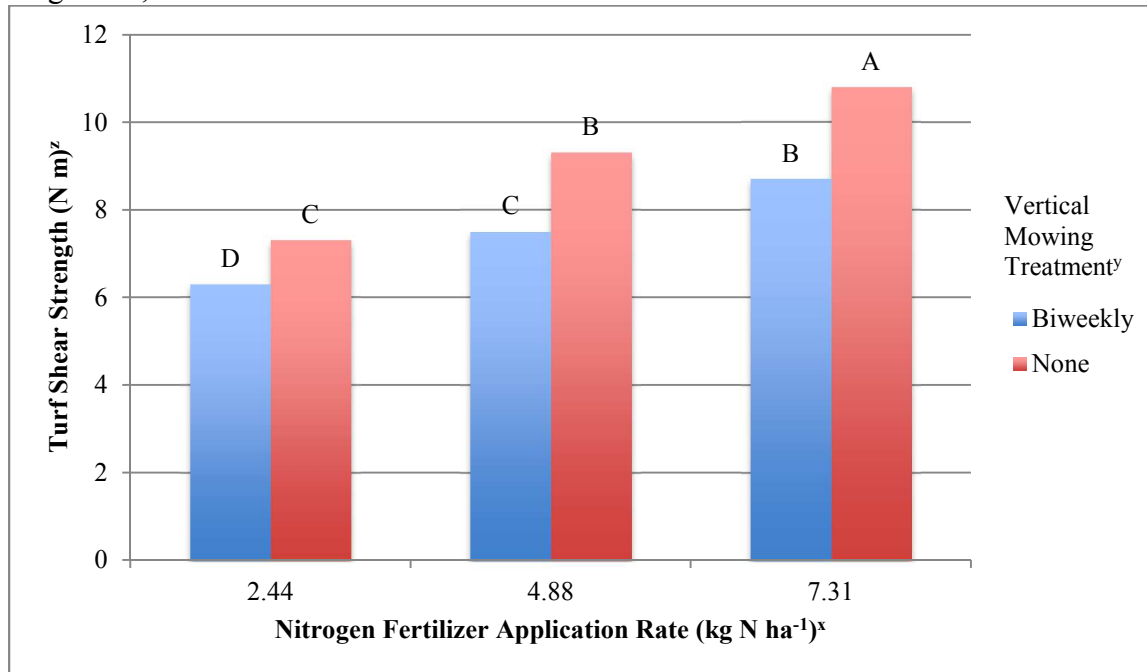
<sup>z</sup> Turfgrass shear strength is measured by a Turf-Tec Shear Strength Tester.

<sup>y</sup> Vertical mowing treatments were applied using a True-Surface vertical mower mounted on a Toro Flex 2100 walk-behind mower.

<sup>x</sup> Nitrogen source used was liquefied urea (46-0-0) and was applied weekly.

Columns with the same letter are not significantly different according to Fisher's LSD at P=0.05.

Figure 12. Effects of a nitrogen fertilizer application rate and vertical mowing interaction on turfgrass shear strength of an establishing creeping bentgrass putting green. East Lansing, MI. August 12, 2015.



<sup>z</sup> Turfgrass shear strength is measured by a Turf-Tec Shear Strength Tester.

<sup>y</sup> Vertical mowing treatments were applied using a True-Surface vertical mower mounted on a Toro Flex 2100 walk-behind mower.

<sup>x</sup> Nitrogen source used was liquefied urea (46-0-0) and was applied weekly.

Columns with the same letter are not significantly different according to Fisher's LSD at P=0.05.

out at a lower height of cut took more force to be sheared from their surroundings after being vertically mowed than plots that were started out at a higher height of cut.

The NFAR x vertical mowing interaction was significant for both years of the study (Figure 11 and 12). This interaction produced similar results to those seen in the same interaction for chlorophyll content data. In this interaction, plots receiving low amounts of fertilizer but are not vertically mowed are either rated the same or in some cases better than plots which receive more fertilizer but are vertically mowed. This is just one more point adding to the conclusion that the vertical mowing in this study (biweekly beginning approximately 290 DAS) was too aggressive and may have been implemented too soon to have any plant benefits.

## CONCLUSIONS

The results from this study show conclusively that certain measures can be taken while growing in a new creeping bentgrass putting green in order to expedite the establishment process. Increases in turfgrass percent cover, chlorophyll content, color, and stability were observed throughout the entirety of this experiment due to the factors used in this study.

NFAR treatments were observed to have significant effects on the quality, color, stability, and overall establishment of the experimental area. Each increase in NFAR resulted in an increase in each of the data collection methods. The use of nitrogen rates at (or possibly above)  $7.31 \text{ kg N ha}^{-1}$  per week is essential to producing a quality putting green as quickly as possible. The majority of plots receiving lower levels of nitrogen ( $2.44$  or  $4.88 \text{ kg N ha}^{-1}$  per week) did not achieve 100% ground cover. Color ratings and stability were also significantly lower for plots receiving less than the maximum amount of nitrogen used in this study. No plateau in turfgrass chlorophyll content index or color was observed in this study (i.e. each increase in fertilizer rate resulted in increases in quality), therefore the highest rate of nitrogen used may not be the optimal rate. Even though ‘Pure Distinction’ is one of the newest and most highly rated (Morris, 2013) cultivars available, the ideal N rate to use during establishment may be closer to  $19 \text{ kg N ha}^{-1}$  per week, as suggested by Watson et al. (2012), than the maximum rate used in this study,  $7.31 \text{ kg N ha}^{-1}$  per week. A concern with high rates of nitrogen fertilization is the reduction of root growth and development (Schlossberg and Karnok, 2001; Watson et al., 2012). Even though root masses were not specifically collected in this study, shear-vane data indicated increasing root strength with N levels up to  $7.31 \text{ kg N ha}^{-1}$  per week, which would agree with a study performed by Watson et al. (2012), who observed peak root dry mass at N fertilizer application rates up to  $9.6 \text{ kg N ha}^{-1}$  per week compared to varying rates from  $1.2$  to  $28.0 \text{ kg N ha}^{-1}$  per week.

That study also observed greater rooting in a 100% sand rootzone over and 80:20 sand/peat rootzone, which could be another contributing factor to the root strength in this study, where the soil profile consisted of greater than 90% sand (Table 1).

Plant growth regulator (trinexapac-ethyl) treatments were shown to increase plant chlorophyll content index in this study towards the end of each growing season. These results coincide with results from Ervin and Koski (1998), which also demonstrated delayed onset of effects from TE applications. Treatment with TE did not have a consistent effect or interaction on turfgrass color, percent ground cover, or stability. The overall insignificance of the effect of TE on those response variables was surprising considering the increased turfgrass rooting, color, and tillering observed in other studies on a variety of turf species at different stages in their lifecycles (Ervin and Koski, 1998; Henderson, 2000; McCullough et al., 2006; Kreuser and Soldat, 2012). The explanation for this is presumably a combination of a couple things: differences in data collection techniques in this study and others (i.e. root mass and tiller counts vs. shear vane measurements) and the immaturity of the green. TE can be a buffer for N loss, which is a partial explanation for some of its benefits (Kreuser and Soldat, 2012), and a green that is less than one year old has most likely not reached an equilibrium at which point it isn't using all available soil N right away. While TE did provide some benefit to the chlorophyll content index and was clearly not a hindrance to plant growth and development in this study, it did not increase the percent ground cover that was anticipated before treatments began.

Vertical mowing has the ability to promote new plant growth on mature, established greens (Salaiz et al., 1995), but proved detrimental to growth and development during the establishment phase. VM treatments were either too aggressive, too frequent, or most likely a

combination of both, to provide any benefits to a green that has not yet been able to establish completely and accumulate much, if any, thatch layer.

Mowing HOC treatments were mostly insignificant for all data collection devices. These results were unexpected, considering all the studies detailing the damage that can be inflicted on turf at low mowing heights (Salaiz et al., 1995; Huang and Gao, 2000; Liu and Huang, 2002; Young, et al., 2015). This study, however, suggests that mowing can be initiated at a lower height than previously presumed with no detriment to plant chlorophyll content index, NDVI, establishment cover percentage, or shear strength when using newer, high-density creeping bentgrass cultivars. In the past, conventional wisdom stated initial mowing should not be lower than 5.08 mm in order to preserve plant health, but we found no evidence of detrimental characteristics when mowing was initiated at 3.81 mm. Potential explanations could be that the initial HOC in this study, while lower than old conventions, is still much higher than putting green turf (especially a high-density cultivar like ‘Pure Distinction’) would be cut using current practices. Even the final height of cut (3.17 mm) was higher than most putting greens are currently mowed, regardless of what cultivar is being used. This result provides turf managers with the potential to reduce the amount of time it takes for putting greens to go from establishment to playable mowing height.

Plots showing the best overall results in this study came from a combination of the highest NFAR treatment (7.31 kg N ha<sup>-1</sup> per week), treatment with trinexapac-ethyl every 14-d, and no vertical mowing, with mowing HOC not contributing to the final results.

## **APPENDIX**



Table 9. Analysis of Variance results for the effects of initial mowing height of cut, nitrogen fertilizer application rate, plant growth regulator use, and vertical mowing on chlorophyll contents<sup>z</sup>. East Lansing, MI. 2013/2014.

|                | 10-<br>18 | 10-<br>25 | 11-<br>14 | 4-<br>23 | 5-<br>6 | 5-<br>19 | 6-<br>3 | 6-<br>9 | 6-<br>16 | 6-<br>26 | 7-<br>2 | 7-<br>9 | 7-<br>14 | 7-<br>21 | 7-<br>31 | 8-<br>6 | 8-<br>11 |
|----------------|-----------|-----------|-----------|----------|---------|----------|---------|---------|----------|----------|---------|---------|----------|----------|----------|---------|----------|
| M <sup>y</sup> | NS        | NS        | NS        | NS       | NS      | NS       | --      | NS      | NS       | NS       | NS      | NS      | NS       | NS       | NS       | NS      | NS       |
| F              | ***       | ***       | ***       | ***      | ***     | ***      | --      | ***     | ***      | ***      | ***     | ***     | ***      | ***      | ***      | ***     | ***      |
| M*F            | NS        | NS        | NS        | NS       | NS      | NS       | --      | NS      | NS       | NS       | NS      | NS      | NS       | NS       | NS       | NS      | NS       |
| P              | --        | --        | --        | --       | --      | --       | --      | NS      | NS       | NS       | NS      | NS      | NS       | NS       | **       | NS      | *        |
| M*P            | --        | --        | --        | --       | --      | --       | --      | NS      | NS       | NS       | NS      | NS      | NS       | NS       | NS       | NS      | NS       |
| F*P            | --        | --        | --        | --       | --      | --       | --      | NS      | NS       | NS       | NS      | NS      | NS       | NS       | NS       | NS      | NS       |
| M*F*P          | --        | --        | --        | --       | --      | --       | --      | NS      | NS       | NS       | NS      | NS      | NS       | *        | NS       | NS      | NS       |
| V              | --        | --        | --        | --       | --      | --       | --      | ***     | ***      | ***      | ***     | ***     | ***      | ***      | ***      | ***     | ***      |
| M*V            | --        | --        | --        | --       | --      | --       | --      | NS      | NS       | NS       | NS      | NS      | NS       | NS       | NS       | NS      | NS       |
| F*V            | --        | --        | --        | --       | --      | --       | --      | **      | ***      | **       | ***     | **      | ***      | ***      | ***      | **      | NS       |
| M*F*V          | --        | --        | --        | --       | --      | --       | --      | NS      | NS       | NS       | NS      | NS      | NS       | NS       | NS       | NS      | NS       |
| P*V            | --        | --        | --        | --       | --      | --       | --      | NS      | *        | *        | *       | NS      | NS       | NS       | NS       | *       | NS       |
| M*P*V          | --        | --        | --        | --       | --      | --       | --      | NS      | NS       | NS       | NS      | NS      | NS       | NS       | NS       | NS      | NS       |
| F*P*V          | --        | --        | --        | --       | --      | --       | --      | NS      | NS       | NS       | NS      | NS      | NS       | NS       | NS       | *       | NS       |
| M*F*P*V        | --        | --        | --        | --       | --      | --       | --      | NS      | NS       | NS       | NS      | NS      | NS       | NS       | NS       | NS      | NS       |

\*, \*\*, \*\*\* represent significance at the P<0.05, 0.01, and 0.0001 level of probability.

-- represent dates on which data was not collected because the selected treatments had not yet been initiated.

<sup>z</sup> Chlorophyll content measured by a FieldScout® CM 1000 Chlorophyll Meter.

<sup>y</sup> M, F, P, and V represent initial mowing height of cut, nitrogen fertilizer application rate, plant growth regulator, and vertical mowing treatments, respectively.

Table 10. Analysis of Variance results for the effects of initial mowing height of cut, nitrogen fertilizer application rate, plant growth regulator use, and vertical mowing on turfgrass color quality<sup>z</sup>. East Lansing, MI. 2013/2014.

|                | 10-<br>18 | 10-<br>25 | 11-<br>14 | 4-<br>23 | 5-<br>6 | 5-<br>19 | 6-<br>3 | 6-<br>9 | 6-<br>16 | 6-<br>26 | 7-<br>2 | 7-<br>9 | 7-<br>14 | 7-<br>21 | 7-<br>31 | 8-<br>6 | 8-<br>11 |
|----------------|-----------|-----------|-----------|----------|---------|----------|---------|---------|----------|----------|---------|---------|----------|----------|----------|---------|----------|
| M <sup>y</sup> | NS        | NS        | NS        | NS       | NS      | NS       | NS      | NS      | NS       | NS       | NS      | NS      | NS       | NS       | NS       | NS      | NS       |
| F              | ***       | ***       | ***       | ***      | ***     | ***      | ***     | ***     | ***      | ***      | ***     | ***     | ***      | ***      | ***      | ***     | ***      |
| M*F            | *         | NS        | NS        | NS       | NS      | NS       | NS      | NS      | NS       | NS       | NS      | NS      | NS       | NS       | NS       | NS      | NS       |
| P              | --        | --        | --        | --       | --      | --       | --      | NS      | NS       | NS       | NS      | NS      | NS       | NS       | NS       | NS      | NS       |
| M*P            | --        | --        | --        | --       | --      | --       | --      | NS      | NS       | NS       | NS      | NS      | NS       | NS       | NS       | NS      | NS       |
| F*P            | --        | --        | --        | --       | --      | --       | --      | NS      | NS       | NS       | NS      | NS      | NS       | NS       | *        | NS      | NS       |
| M*F*P          | --        | --        | --        | --       | --      | --       | --      | NS      | NS       | NS       | NS      | NS      | NS       | NS       | NS       | NS      | NS       |
| V              | --        | --        | --        | --       | --      | --       | *       | ***     | ***      | ***      | ***     | ***     | ***      | ***      | ***      | ***     | ***      |
| M*V            | --        | --        | --        | --       | --      | --       | NS      | NS      | NS       | NS       | NS      | NS      | NS       | NS       | NS       | NS      | NS       |
| F*V            | --        | --        | --        | --       | --      | --       | NS      | NS      | NS       | NS       | NS      | NS      | NS       | NS       | NS       | NS      | NS       |
| M*F*V          | --        | --        | --        | --       | --      | --       | NS      | NS      | NS       | NS       | NS      | NS      | NS       | NS       | NS       | NS      | NS       |
| P*V            | --        | --        | --        | --       | --      | --       | --      | NS      | NS       | NS       | NS      | NS      | NS       | NS       | NS       | *       | NS       |
| M*P*V          | --        | --        | --        | --       | --      | --       | --      | NS      | NS       | NS       | NS      | NS      | NS       | NS       | NS       | NS      | NS       |
| F*P*V          | --        | --        | --        | --       | --      | --       | --      | NS      | NS       | NS       | NS      | NS      | NS       | NS       | NS       | NS      | NS       |
| M*F*P*V        | --        | --        | --        | --       | --      | --       | --      | NS      | NS       | NS       | NS      | NS      | NS       | NS       | NS       | NS      | NS       |

\*, \*\*, \*\*\* represent significance at the P<0.05, 0.01, and 0.0001 level of probability.

-- represent dates on which data was not collected because the selected treatments had not yet been initiated.

<sup>z</sup> Turfgrass color quality is based on results from a FieldScout® TCM 500 NDVI Turf Color Meter.

<sup>y</sup> M, F, P, and V represent initial mowing height of cut, nitrogen fertilizer application rate, plant growth regulator, and vertical mowing treatments, respectively.

Table 11. Analysis of Variance results for the effects of initial mowing height of cut, nitrogen fertilizer application rate, plant growth regulator use, and vertical mowing on visual percent ground cover<sup>z</sup>. East Lansing, MI. 2013/2014.

|                | 10-<br>18 | 10-<br>25 | 11-<br>14 | 4-<br>23 | 5-<br>6 | 5-<br>19 | 6-<br>3 | 6-<br>9 | 6-<br>16 | 6-<br>26 | 7-<br>2 | 7-<br>9 | 7-<br>14 | 7-<br>21 | 7-<br>31 | 8-<br>6 | 8-<br>11 |
|----------------|-----------|-----------|-----------|----------|---------|----------|---------|---------|----------|----------|---------|---------|----------|----------|----------|---------|----------|
| M <sup>y</sup> | NS        | --        | NS        | NS       | NS      | NS       | NS      | *       | NS       | NS       | NS      | NS      | NS       | NS       | *        | NS      | NS       |
| F              | --        | ***       | ***       | ***      | ***     | ***      | ***     | ***     | ***      | ***      | ***     | ***     | ***      | ***      | ***      | ***     | ***      |
| M*F            | --        | NS        | NS        | NS       | NS      | *        | NS      | NS      | NS       | NS       | NS      | NS      | NS       | NS       | NS       | NS      | NS       |
| P              | --        | --        | --        | --       | --      | --       | --      | NS      | NS       | NS       | NS      | NS      | NS       | NS       | NS       | NS      | NS       |
| M*P            | --        | --        | --        | --       | --      | --       | --      | NS      | NS       | NS       | NS      | NS      | NS       | NS       | NS       | NS      | NS       |
| F*P            | --        | --        | --        | --       | --      | --       | --      | NS      | NS       | NS       | NS      | NS      | NS       | NS       | *        | *       | NS       |
| M*F*P          | --        | --        | --        | --       | --      | --       | --      | NS      | NS       | NS       | NS      | NS      | NS       | NS       | NS       | NS      | NS       |
| V              | --        | --        | --        | --       | --      | --       | --      | **      | ***      | ***      | ***     | ***     | ***      | ***      | ***      | ***     | ***      |
| M*V            | --        | --        | --        | --       | --      | --       | NS      | NS      | NS       | NS       | NS      | NS      | *        | **       | **       | *       | *        |
| F*V            | --        | --        | --        | --       | --      | --       | NS      | NS      | NS       | NS       | NS      | NS      | *        | **       | NS       | ***     | **       |
| M*F*V          | --        | --        | --        | --       | --      | --       | NS      | NS      | NS       | NS       | NS      | NS      | NS       | NS       | NS       | NS      | NS       |
| P*V            | --        | --        | --        | --       | --      | --       | --      | NS      | NS       | NS       | NS      | NS      | NS       | NS       | NS       | NS      | NS       |
| M*P*V          | --        | --        | --        | --       | --      | --       | --      | NS      | NS       | NS       | NS      | NS      | NS       | NS       | NS       | NS      | NS       |
| F*P*V          | --        | --        | --        | --       | --      | --       | --      | NS      | NS       | NS       | NS      | NS      | NS       | NS       | NS       | NS      | NS       |
| M*F*P*V        | --        | --        | --        | --       | --      | --       | --      | NS      | NS       | NS       | *       | *       | *        | NS       | NS       | NS      | NS       |

\*, \*\*, \*\*\* represent significance at the P<0.05, 0.01, and 0.0001 level of probability.

-- represent dates on which data was not collected because the selected treatments had not yet been initiated.

<sup>z</sup> Percent ground cover is based on a visual estimate using the NTEP protocol.

<sup>y</sup> M, F, P, and V represent initial mowing height of cut, nitrogen fertilizer application rate, plant growth regulator, and vertical mowing treatments, respectively.

Table 12. Analysis of Variance results for the effects of initial mowing height of cut, nitrogen fertilizer application rate, plant growth regulator use, and vertical mowing on chlorophyll contents<sup>z</sup>. East Lansing, MI. 2014/2015.

|                | 10-<br>7 | 10-<br>17 | 10-<br>23 | 4-<br>14 | 5-<br>7 | 5-<br>14 | 5-<br>21 | 5-<br>29 | 6-<br>4 | 6-<br>10 | 6-<br>17 | 6-<br>25 | 7-<br>1 | 7-<br>9 | 7-<br>15 | 7-<br>23 | 7-<br>30 | 8-<br>6 | 8-<br>11 |
|----------------|----------|-----------|-----------|----------|---------|----------|----------|----------|---------|----------|----------|----------|---------|---------|----------|----------|----------|---------|----------|
| M <sup>y</sup> | NS       | NS        | NS        | --       | NS      | NS       | NS       | *        | NS      | NS       | NS       | NS       | NS      | NS      | NS       | NS       | NS       | NS      | NS       |
| F              | ***      | ***       | ***       | ***      | ***     | ***      | ***      | ***      | ***     | ***      | ***      | ***      | ***     | ***     | ***      | ***      | ***      | ***     | ***      |
| M*F            | NS       | NS        | NS        | NS       | NS      | NS       | NS       | NS       | NS      | NS       | NS       | NS       | *       | NS      | NS       | NS       | NS       | NS      | NS       |
| P              | --       | --        | --        | --       | --      | --       | --       | --       | --      | NS       | NS       | NS       | NS      | *       | *        | **       | NS       | *       | *        |
| M*P            | --       | --        | --        | --       | --      | --       | --       | --       | --      | NS       | NS       | NS       | NS      | NS      | NS       | NS       | NS       | NS      | NS       |
| F*P            | --       | --        | --        | --       | --      | --       | --       | --       | --      | NS       | NS       | NS       | NS      | NS      | NS       | NS       | NS       | NS      | NS       |
| M*F*P          | --       | --        | --        | --       | --      | --       | --       | --       | --      | NS       | NS       | NS       | NS      | *       | NS       | NS       | NS       | NS      | NS       |
| V              | --       | --        | --        | --       | --      | --       | --       | --       | --      | ***      | ***      | ***      | ***     | ***     | ***      | ***      | ***      | ***     | ***      |
| M*V            | --       | --        | --        | --       | --      | --       | --       | --       | --      | NS       | NS       | NS       | NS      | NS      | NS       | NS       | NS       | NS      | NS       |
| F*V            | --       | --        | --        | --       | --      | --       | --       | --       | --      | **       | NS       | ***      | **      | ***     | ***      | ***      | ***      | ***     | ***      |
| M*F*V          | --       | --        | --        | --       | --      | --       | --       | --       | --      | NS       | NS       | NS       | NS      | NS      | NS       | NS       | NS       | NS      | NS       |
| P*V            | --       | --        | --        | --       | --      | --       | --       | --       | --      | NS       | NS       | NS       | NS      | NS      | NS       | NS       | NS       | NS      | NS       |
| M*P*V          | --       | --        | --        | --       | --      | --       | --       | --       | --      | NS       | NS       | NS       | NS      | NS      | NS       | NS       | NS       | NS      | NS       |
| F*P*V          | --       | --        | --        | --       | --      | --       | --       | --       | --      | NS       | *        | NS       | NS      | NS      | NS       | NS       | NS       | NS      | NS       |
| M*F*P*V        | --       | --        | --        | --       | --      | --       | --       | --       | --      | NS       | NS       | NS       | NS      | *       | NS       | NS       | NS       | NS      | NS       |

\*, \*\*, \*\*\* represent significance at the P<0.05, 0.01, and 0.0001 level of probability.

-- represent dates on which data was not collected because the selected treatments had not yet been initiated.

<sup>z</sup> Chlorophyll content measured by a FieldScout® CM 1000 Chlorophyll Meter.

<sup>y</sup> M, F, P, and V represent initial mowing height of cut, nitrogen fertilizer application rate, plant growth regulator, and vertical mowing treatments, respectively.

Table 13. Analysis of Variance results for the effects of initial mowing height of cut, nitrogen fertilizer application rate, plant growth regulator use, and vertical mowing on turfgrass color quality<sup>z</sup>. East Lansing, MI. 2014/2015.

|                | 10-<br>7 | 10-<br>17 | 10-<br>23 | 4-<br>14 | 5-<br>7 | 5-<br>14 | 5-<br>21 | 5-<br>29 | 6-<br>4 | 6-<br>10 | 6-<br>17 | 6-<br>25 | 7-<br>1 | 7-<br>9 | 7-<br>15 | 7-<br>23 | 7-<br>30 | 8-<br>4 | 8-<br>12 |
|----------------|----------|-----------|-----------|----------|---------|----------|----------|----------|---------|----------|----------|----------|---------|---------|----------|----------|----------|---------|----------|
| M <sup>y</sup> | NS       | NS        | NS        | NS       | NS      |          |          |          | NS      | NS       | NS       |          | NS      | NS      | NS       | NS       | NS       | NS      | NS       |
| F              | ***      | ***       | ***       | ***      | ***     | ***      | ***      | ***      | ***     | ***      | ***      | ***      | ***     | ***     | ***      | ***      | ***      | ***     | ***      |
| M*F            | NS       | *         | *         | NS       | NS      | NS       | **       | NS       | NS      | NS       | NS       | NS       | NS      | NS      | NS       | NS       | NS       | NS      | NS       |
| P              | --       | --        | --        | --       | --      | --       | --       | --       | --      | NS       | *        | NS       | NS      | NS      | NS       | NS       | NS       | NS      | NS       |
| M*P            | --       | --        | --        | --       | --      | --       | --       | --       | --      | NS       | NS       | NS       | NS      | NS      | NS       | NS       | NS       | NS      | NS       |
| F*P            | --       | --        | --        | --       | --      | --       | --       | --       | --      | NS       | NS       | NS       | NS      | NS      | NS       | NS       | NS       | NS      | NS       |
| M*F*P          | --       | --        | --        | --       | --      | --       | --       | --       | --      | NS       | NS       | NS       | NS      | NS      | NS       | NS       | NS       | NS      | NS       |
| V              | --       | --        | --        | --       | --      | --       | --       | --       | --      | ***      | ***      | ***      | ***     | ***     | ***      | ***      | ***      | ***     | ***      |
| M*V            | --       | --        | --        | --       | --      | --       | --       | --       | --      | NS       | NS       | NS       | *       | NS      | NS       | NS       | NS       | NS      | NS       |
| F*V            | --       | --        | --        | --       | --      | --       | --       | --       | --      | NS       | NS       | NS       | NS      | NS      | NS       | NS       | NS       | NS      | NS       |
| M*F*V          | --       | --        | --        | --       | --      | --       | --       | --       | --      | NS       | NS       | NS       | NS      | NS      | NS       | NS       | NS       | NS      | NS       |
| P*V            | --       | --        | --        | --       | --      | --       | --       | --       | --      | NS       | NS       | NS       | NS      | NS      | NS       | NS       | NS       | NS      | NS       |
| M*P*V          | --       | --        | --        | --       | --      | --       | --       | --       | --      | NS       | *        | NS       | NS      | NS      | NS       | NS       | NS       | NS      | NS       |
| F*P*V          | --       | --        | --        | --       | --      | --       | --       | --       | --      | NS       | NS       | NS       | NS      | NS      | NS       | NS       | NS       | NS      | NS       |
| M*F*P*V        | --       | --        | --        | --       | --      | --       | --       | --       | --      | NS       | NS       | NS       | NS      | NS      | NS       | NS       | NS       | NS      | NS       |

\*, \*\*, \*\*\* represent significance at the P<0.05, 0.01, and 0.0001 level of probability.

-- represent dates on which data was not collected because the selected treatments had not yet been initiated.

<sup>z</sup> Turfgrass color quality is based on results from a FieldScout® TCM 500 NDVI Turf Color Meter.

<sup>y</sup> M, F, P, and V represent initial mowing height of cut, nitrogen fertilizer application rate, plant growth regulator, and vertical mowing treatments, respectively.

Table 14. Analysis of Variance results for the effects of initial mowing height of cut, nitrogen fertilizer application rate, plant growth regulator use, and vertical mowing on visual percent ground cover<sup>z</sup>. East Lansing, MI. 2014/2015.

|                | 10-<br>7 | 10-<br>17 | 10-<br>23 | 4-<br>14 | 5-<br>7 | 5-<br>14 | 5-<br>21 | 5-<br>29 | 6-<br>4 | 6-<br>10 | 6-<br>17 | 6-<br>25 | 7-<br>1 | 7-<br>9 | 7-<br>15 | 7-<br>23 | 7-<br>30 | 8-<br>4 | 8-<br>12 |
|----------------|----------|-----------|-----------|----------|---------|----------|----------|----------|---------|----------|----------|----------|---------|---------|----------|----------|----------|---------|----------|
| M <sup>y</sup> | --       | NS        | NS        | --       | NS      | NS       | NS       | *        | --      | NS       | NS       | NS       | --      | --      | *        | --       | NS       | --      | *        |
| F              | --       | ***       | ***       | --       | ***     | ***      | ***      | ***      | --      | ***      | ***      | ***      | --      | --      | ***      | --       | ***      | --      | ***      |
| M*F            | --       | NS        | NS        | --       | NS      | NS       | NS       | NS       | --      | NS       | NS       | NS       | --      | --      | NS       | --       | NS       | --      | NS       |
| P              | --       | --        | --        | --       | --      | --       | --       | --       | --      | NS       | NS       | NS       | --      | --      | NS       | --       | NS       | --      | NS       |
| M*P            | --       | --        | --        | --       | --      | --       | --       | --       | --      | NS       | NS       | NS       | --      | --      | NS       | --       | NS       | --      | NS       |
| F*P            | --       | --        | --        | --       | --      | --       | --       | --       | --      | NS       | NS       | NS       | --      | --      | NS       | --       | NS       | --      | NS       |
| M*F*P          | --       | --        | --        | --       | --      | --       | --       | --       | --      | NS       | NS       | NS       | --      | --      | NS       | --       | NS       | --      | NS       |
| V              | --       | --        | --        | --       | --      | --       | --       | --       | --      | **       | *        | ***      | --      | --      | ***      | --       | ***      | --      | ***      |
| M*V            | --       | --        | --        | --       | --      | --       | --       | --       | --      | NS       | NS       | **       | --      | --      | **       | --       | *        | --      | NS       |
| F*V            | --       | --        | --        | --       | --      | --       | --       | --       | --      | NS       | NS       | *        | --      | --      | *        | --       | **       | --      | *        |
| M*F*V          | --       | --        | --        | --       | --      | --       | --       | --       | --      | NS       | NS       | NS       | --      | --      | NS       | --       | NS       | --      | NS       |
| P*V            | --       | --        | --        | --       | --      | --       | --       | --       | --      | NS       | *        | NS       | --      | --      | NS       | --       | NS       | --      | *        |
| M*P*V          | --       | --        | --        | --       | --      | --       | --       | --       | --      | NS       | NS       | *        | --      | --      | NS       | --       | NS       | --      | NS       |
| F*P*V          | --       | --        | --        | --       | --      | --       | --       | --       | --      | NS       | NS       | *        | --      | --      | NS       | --       | NS       | --      | NS       |
| M*F*P*V        | --       | --        | --        | --       | --      | --       | --       | --       | --      | NS       | NS       | NS       | --      | --      | NS       | --       | NS       | --      | NS       |

\*, \*\*, \*\*\* represent significance at the P<0.05, 0.01, and 0.0001 level of probability.

-- represent dates on which data was not collected because the selected treatments had not yet been initiated.

<sup>z</sup> Percent ground cover is based on a visual estimate using the NTEP protocol.

<sup>y</sup> M, F, P, and V represent initial mowing height of cut, nitrogen fertilizer application rate, plant growth regulator, and vertical mowing treatments, respectively.

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## LITERATURE CITED

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**CHAPTER 2:**  
EFFECTS OF NITROGEN FERTILIZER APPLICATION RATE, BRUSHING  
TREATMENTS, AND WETTING AGENTS ON *AGROSTIS STOLONIFERA* L. PUTTING  
GREEN ESTABLISHMENT

**ABSTRACT**

The continual search for putting greens that provide fast, firm playing conditions while maintaining color and appearance during summer months led breeding efforts to improve creeping bentgrass cultivars that far exceed the quality of their predecessors. Establishment of these cultivars, however, has not been readily studied. A study was designed and executed at Michigan State University in East Lansing, MI, to evaluate the effects of nitrogen fertilizer rate, brushing treatments, and wetting agent applications on a newly seeded creeping bentgrass putting green. The factors implemented in this study were as follows: nitrogen fertilizer application rates of 7.31, 9.78, and 12.23 kg N ha<sup>-1</sup> per week; brushing treatments (five applications per week) using a Transformer B-2.5 brush, Toro Push Broom Brush Kit, and control (no brush); and wetting agent (Symphony by Harrell's) applications of 7.96 L ha<sup>-1</sup> every 15-d, 15.93 L ha<sup>-1</sup> every 30-d, and controls (no wetting agent). Results from this study indicate that nitrogen rates of up to 12.23 kg N ha<sup>-1</sup> per week provide plants with increased chlorophyll content index and color, but may be equally as effective as 9.78 kg N ha<sup>-1</sup> regarding establishment rate and stability after one year of growth. Wetting agent treatments were mostly insignificant, but did have a negative effect on turfgrass chlorophyll content and volumetric water content when applied more frequently (every 15-d). Brushing treatments in this study did not have an effect on any of the measured parameters.

## INTRODUCTION

The reconstruction of golf course putting greens is, by any measure, an expensive and time consuming process. While the planning and shaping of new features are normally the responsibility of an architect and their construction crew, the crucial assignment of establishing high-quality playing surfaces as rapidly as possible is the duty of the superintendent and their crew. Slow putting green establishment can drastically increase the costs associated with putting green renovation due to increased labor costs and lost income from the members or the public.

In Chapter 1 (Effects of initial mowing height of cut, nitrogen fertilizer application rate, trinexapac-ethyl, and vertical mowing on *Agrostis stolonifera* L. putting green establishment), it was observed that nitrogen fertilizer rates of up to 7.31 kg N ha<sup>-1</sup> applied on a weekly basis resulted in increased turfgrass cover, NDVI, and chlorophyll content index when compared to lower rates, with no decrease in turf stability. That discovery and the rates suggested in studies by Pease et al. (2011) and Watson et al. (2012) of 12.2 and 19 kg N ha<sup>-1</sup> per week, respectively, led to the adoption of higher fertilizer rates (7.31, 9.78, and 12.23 kg N ha<sup>-1</sup> applied weekly) for this study. The theory was that there would be a point at which the observed plant benefits no longer justify the time and cost of applying additional N.

The study discussed in Chapter 1 also undeniably demonstrated that attempting to promote lateral stolon growth (and vertical leaf growth) in newly established seedlings via biweekly vertically mowing was not effective, and was definitively detrimental to plant growth and development at that stage in its lifecycle (less than one year from the time of seeding). Even though vertical mowing was too aggressive for immature turf, it would still be desirable to have the ability to control thatch, promote vertical leaf growth, and enhance density at an early stage of plant development. The cultural practice of brushing a putting green immediately prior to

mowing is intended to increase the efficiency of mowing by lifting horizontal grass blades so that they can be mowed and promote a more vertical growth for an even playing surface (Beard, 2005). Brushing a putting green before mowing is an idea that dates back as far as the 1920's, when Jacobson developed a wire brush placed in front of a greens mower (Anonymous, 1928). This practice, while initially popular, went out of favor for many decades before a relatively recent resurgence (Whitlark, 2011). This brushing renaissance has most likely been prompted by better technology in brushes (i.e. improving from wire rakes and shop brooms to apparatuses specifically engineered for this purpose) and breeding efforts that have produced bermudagrass and bentgrass cultivars that grow more rapidly and are denser than their predecessors (Sifers, et al., 2001; Sweeney, et al., 2001; Jones and Christians, 2013), and therefore can potentially handle more aggressive cultural practices. The proposed benefits of frequent brushing include such characteristics as increased green speed, reduced need for aeration (due to less thatch accumulation), reduced leaf texture, and increased plant density, among others. While there is anecdotal evidence to support these assertions, there is little or no published research to statistically confirm or reject any such claims. Most research involving brushing is in regard to topdressing incorporation, which may be a side effect of push-brushing before mowing, but is not of interest in this study.

Wetting agents (WA) are primarily used to modify hydrophobic soil layers, a common affliction of high sand-content rootzones, and allow water to penetrate the profile (Wilkinson and Miller, 1978). They do this by reducing the surface tension of water, preventing it from forming drops (Reike, 1981), and allowing it to penetrate the soil profile. WA are effective at reducing localized dry spot (LSD) (Wilkinson and Miller, 1978), increasing turfgrass quality and rooting under conditions of LSD, and improving water penetration rates (Lyons et al., 2009), but their

effects on turfgrass establishment are inconclusive. Henderson (2000) attempted to discover the effects of WA (Aqueduct™ by Aquatrols) use to establish Kentucky bluegrass (*Poa pratensis*) at athletic field height, but the study concluded with mixed results. Lee (2014) attempted to discover the effects of WA and phosphorus fertilizer on establishment rates of Kentucky bluegrass, but was also unable to produce decisive results. No current published research has examined the effects of wetting agents on the establishment rate of creeping bentgrass.

The objective of this study is to utilize the information collected in Chapter 1 to further investigate factors that may expedite the creeping bentgrass putting green establishment process. Factors implemented in this study were: NFAR treatments (at increased rates from Chapter 1), push-brushing treatments immediately prior to mowing, and the use of wetting agents. It is hypothesized that turfgrass response to nitrogen fertilizer (as measured by methods that follow) will reach a peak level at one of the rates available in this study. Brushing treatments will increase plant density and therefore chlorophyll content index, NDVI, and other establishment ratings. Wetting agents will have plant benefits on the high sand-content root zone on which this study was performed.

## MATERIALS AND METHODS

A study investigating the effects of nitrogen fertilizer application rate (NFAR), brushing treatments, and wetting agents on the establishment of a creeping bentgrass putting green was initiated on August 15, 2014 and repeated the following year (beginning August 21, 2015). This study included three factors: NFAR (7.34, 9.78, and 12.23 kg N ha<sup>-1</sup>), brushing (control, Transformer, and Toro), and wetting agent application (control, 7.96, and 15.93 L ha<sup>-1</sup>).

The total experimental area was 80.3 m<sup>2</sup>, and individual plots were 0.74 m<sup>2</sup> (0.61 x 1.22 m). The plot area was seeded on the above dates with *Agrostis stolonifera* cv. 'Pure Distinction' at 36.69 kg ha<sup>-1</sup> into a 90/10 sand-based root zone (Table 9). Pre-treatment applications of a starter fertilizer (Lesco® Professional Starter Fertilizer 18-24-12) at 36.62 kg N ha<sup>-1</sup> and a controlled-release product (Harrell's Polyon® Controlled Release Fertilizer 29-0-10) at 61.03 kg N ha<sup>-1</sup> were made at the time of seeding. An additional application of starter fertilizer was made at a rate of 24.46 kg N ha<sup>-1</sup> after germination blankets were removed. Germination blankets were applied at the time of seeding and were removed after germination had occurred on greater than 50 percent of the total plot area. Mowing was initiated on August 29, 2014 (14 DAS) and September 15, 2015 (25 DAS) in years one and two, respectively. For both years of the study, mowing height was initiated at 5.08 mm and reduced by 0.25 mm weekly, beginning in the spring of each year, until reaching a height of 3.18 mm. Mowing treatments were made with two separate Toro Greensmaster® 1000 [The Toro Company, Bloomington, MN] walk-behind mowers.

Table 15. Particle size distribution for the root zone used in both experiments. East Lansing, MI. 2016.

| Sieve Number | Particle Size Range (mm) | Percent          |
|--------------|--------------------------|------------------|
| 10           | > 2                      | 0.5              |
| 18           | 2-1                      | 7.0              |
| 35           | 1-0.5                    | 20.8             |
| 60           | 0.5-0.25                 | 41.9             |
| 140          | 0.25-0.1                 | 20.1             |
| 270          | 0.1-0.05                 | 1.5              |
| None         | < 0.05                   | 8.6 <sup>z</sup> |

<sup>z</sup> Totals add up to over 100 percent due to rounding.

Target irrigation for these studies was to keep the upper soil surface moist during the germination period and later to keep the upper portion of the soil profile moist as plants matured. The typical irrigation regime was 0.317 cm applied at midnight followed by four applications of 0.190 cm throughout the day, for a total of 1.08 cm daily. All irrigation was applied overhead via Rain Bird® Eagle 751 Golf Rotors [Rain Bird Corporation, Azusa, CA]. As plants matured, irrigation was reduced to the midnight application and two applications throughout the day. Irrigation ceased following rain events until the soil profile was returned to the point of typical irrigation requirement.

Background fungicide applications were made to the entire experimental area in order to prevent disease from affecting results. Products were applied as necessary depending on weather conditions and disease pressure.

NFAR treatments were initiated on September 23, 2014 (39 DAS) and September 25, 2015 (35 DAS). Treatments were made using an R&D CO<sub>2</sub> backpack sprayer [Bellspray, Inc., Opelousas, Louisiana] with a TeeJet 8003 EVS nozzle [TeeJet Technologies, Glendale Heights, IL]. Treatments were applied weekly at one of three rates: (1) 7.34, (2) 9.78, or (3) 12.23 kg N ha<sup>-1</sup>. These rates were applied 20 (4 spring/16 summer) and 20 (5 fall and 15 spring/summer) times in the first and second year of each study, respectively. Yearly, those rates equal 139.46, 185.82, and 232.37 kg N ha<sup>-1</sup> and 146.80, 195.60, and 244.60 kg N ha<sup>-1</sup> for years one and two, respectively. In the fall of each year

Brushing treatments were initiated on May 14, 2015 (272 DAS) and April 20, 2016 (243 DAS). The brushing factor had three levels: (1) control, (2) plots were treated with a Transformer™ B-2.5 brush from the Transformer Brushing System® [Turfscience, Inc. Phoenix, AZ], or (3) plots were treated with a Toro Push Broom Brush Kit (with 2.27 kg of weights that



were included on top) from the The Toro Company [The Toro Company, Bloomington, MN]. Both brushing attachments were mounted on the front of Toro Greensmaster® 1000 walk-behind mowers.

Wetting agent treatments were initiated on May 8, 2015 (266 DAS) and May 17, 2016 (270 DAS). The wetting agent that was used for this study was Symphony® by Harrell's [Harrell's LLC, Lakeland, FL], which was applied using the same R&D CO<sub>2</sub> backpack sprayer that was described in the NFAR treatments. Wetting agent treatments had three levels: (1) control, (2) 7.96 L ha<sup>-1</sup> every 15 days, or (3) 15.93 L ha<sup>-1</sup> every 30 days (weather permitting).

### **Response Variables**

Data for this study was collected weekly beginning in the fall and lasting throughout the entire growing season. Response variables include visual percent ground cover, chlorophyll content index, color rating, volumetric water content (VWC), and turf strength. For all of these measurements except visual percent ground cover, three readings were taken per plot and then averaged to achieve the reported result.

Visual percent ground cover ratings were taken on a 0-100% basis using the NTEP procedure of rating. These ratings were taken almost every week of the study until plots all reached 90 percent or more ground cover, at which point ratings ceased. Turf color ratings were made using a FieldScout® TCM 500 NDVI Turf Color Meter [Spectrum Technologies, Inc., Aurora, IL], which measures reflectance in a 7.6 cm diameter area and reports color on a scale from 0.000 to 1.000. Turfgrass chlorophyll content was measured using a FieldScout® CM 1000 Chlorophyll Meter [Spectrum Technologies, Inc., Aurora, IL], which uses ambient and reflected light to report relative chlorophyll content based on a scale from 0 to 999. VWC was measured using a FieldScout® TDR 300 Soil Moisture Meter at both 3.81 and 7.62 cm depth. TDR ratings

are based on electrical signals sent to the device and then converted to VWC using a proven equation. Turf strength was measured at the conclusion of each experimental year using a Turf-Tec Shear Strength Tester [Turf-Tec International, Tallahassee, FL], which reports the amount of force (in Newton Meters) needed to sever the turf 1.7 cm below the turf canopy. Three measurements were taken per plot and averaged to achieve the reported results. Because of the destructive nature of this measurement, ratings were only taken at the conclusion of each experimental season.

### **Statistical Analysis**

Statistical analysis for this experiment was performed as a 3x3x3 randomized, complete block design with four replications. Data were analyzed using SAS PROC GLIMMIX (SAS version 9.4) [SAS Institute Inc., Cary, NC]. Significance of main effects was analyzed at the  $P \leq 0.05$  probability level. When differences were significant, means were separated using Fisher's Protected Least Significant Difference (LSD).

## **RESULTS AND DISCUSSION**

Results for chlorophyll content, turfgrass color quality, and the first year of visual percent cover are representative dates selected throughout the study. For complete analysis of variance tables, please see the Appendix.

### **Effects on Chlorophyll Content Index**

Data collected using the FieldScout® CM 1000 Chlorophyll Meter indicate that both main effects and some interactions were significant during the two-year period of this study.

On many collection dates throughout both years of this experiment, NFAR had a significant effect on turfgrass chlorophyll content index. A representative sample of results from randomly selected collection dates can be found in Table 10 and 11. The overriding theme for these treatments was that with each increase in NFAR, a significant increase in chlorophyll content index occurred. In 2016, there were dates in which differences between some treatments (or even all treatments) were insignificant, but for the majority of dates, it followed the same pattern as the first year. The hypothesis was that at some point increasing nitrogen levels would no longer be beneficial to the plant, but that was not observed in this study. Results were similar to Chapter 1 in that each increase in fertilizer rate produced higher chlorophyll content index. These results were similar to those observed by Mangiafico and Guillard (2005), who noticed a linear increase in chlorophyll content index from the CM 1000 with increases in plant nitrogen rates.

Brushing treatments had only two dates during the entirety of the experiment on which significant differences occurred, both of which were during the first year of the study (Table 10 and 11). On June 4, 2015, plots receiving no brushing and plots being brushed with the Transformer brush had significantly higher chlorophyll contents than plots being brushed with

the Toro attachment. On August 12, 2015, control plots rated significantly better than plots receiving either brushing treatment. The overall insignificance of this factor may lead to the belief that brushing has no effect on turfgrass establishment or chlorophyll content index. However, an issue with the spacing of plots and the lack of different directions to mow the plots could have affected the results in this study. The 0.61 x 1.22 m<sup>2</sup> plots could only be mowed and brushed in two directions, which were forward and backward along the longest axis. If the plot sizes were increased and plots could be mowed in four directions, results could potentially have been different.

Wetting agent applications had mixed effects on turfgrass quality throughout the experiment. In the first year of the study, there were six dates (starting July 1, 2015 and continuing through the end of the experiment) in which significant differences were seen (Table 10). Of these dates, the most common effect observed was the 15-d application rate having a detrimental effect on turf chlorophyll content index. This could be due to an unusually high amount of rainfall the experimental site (East Lansing, MI) received in July and August of 2015 (Table 12). These record amounts of rainfall combined with frequent applications of a wetting agent that were not needed could have culminated in an excess of water retention that reduced the quality of the turf. This would also explain why that effect was not seen in the second year of the experiment when rainfall was within historical measurements (Table 12).

Table 16. Effects of nitrogen fertilizer, brushing, and wetting agents on chlorophyll content index<sup>z</sup> of an establishing creeping bentgrass putting green. East Lansing, MI. 2015.

| Treatment                                | Application Rate | Chlorophyll Content <sup>y</sup> |        |        |         |         |
|------------------------------------------|------------------|----------------------------------|--------|--------|---------|---------|
|                                          |                  | May 14                           | June 4 | July 1 | July 23 | Aug. 12 |
| Nitrogen Fertilizer                      | 12.23            | 147 a <sup>u</sup>               | 182 a  | 178 a  | 189 a   | 226 a   |
| Application Rate                         | 9.78             | 139 b                            | 170 b  | 168 b  | 177 b   | 211 b   |
| (F) <sup>x</sup>                         | 7.34             | 131 c                            | 154 c  | 154 c  | 159 c   | 187 c   |
| LSD (P=0.05)                             |                  | 4.8                              | 5.8    | 4.5    | 4.2     | 5.1     |
| Brush Treatment (B) <sup>w</sup>         | None             | 140                              | 172 a  | 167    | 177     | 212 a   |
|                                          | Transformer      | 141                              | 171 a  | 167    | 176     | 206 b   |
|                                          | Toro             | 137                              | 164 b  | 166    | 173     | 205 b   |
| LSD (P=0.05)                             |                  | NS <sup>t</sup>                  | 5.8    | NS     | NS      | 5.1     |
| Wetting Agent Treatment (W) <sup>v</sup> | None             | 142                              | 170    | 169 a  | 178 a   | 210 a   |
|                                          | 7.96             | 139                              | 169    | 163 b  | 172 b   | 203 b   |
|                                          | 15.93            | 136                              | 168    | 167 ab | 175 ab  | 212 a   |
| LSD (P=0.05)                             |                  | NS                               | NS     | 4.5    | 4.2     | 5.1     |
| F x B                                    |                  | NS                               | NS     | NS     | NS      | NS      |
| F x W                                    |                  | NS                               | NS     | NS     | NS      | NS      |
| B x W                                    |                  | NS                               | NS     | NS     | NS      | NS      |
| F x B x W                                |                  | NS                               | NS     | NS     | NS      | NS      |

<sup>z</sup> Chlorophyll content index measured by a FieldScout® CM 1000 Chlorophyll Meter.

<sup>y</sup> Relative chlorophyll content based on ambient and reflected light on a scale from 0 to 999.

<sup>x</sup> Nitrogen source used was urea (46-0-0) applied weekly (kg N ha<sup>-1</sup>).

<sup>w</sup> Brushing treatments were performed five times per week with a push broom mounted in front of a Toro Greensmaster 1000 walk-behind mower.

<sup>v</sup> Wetting agent treatments were made with Symphony from Harrell's at a low rate (7.96 L ha<sup>-1</sup>) every 15-d or a full rate (15.93 L ha<sup>-1</sup>) every 30-d.

<sup>u</sup> Columns with the same letter are not significantly different according to Fisher's LSD at P=0.05.

<sup>t</sup> NS = not significant at the P=0.05 level of probability.

Table 17. Effects of nitrogen fertilizer, brushing, and wetting agents on chlorophyll content index of an establishing creeping bentgrass putting green. East Lansing, MI. 2016.

| Treatment                                             | Application Rate | Chlorophyll Content <sup>y</sup> |         |        |         |         |
|-------------------------------------------------------|------------------|----------------------------------|---------|--------|---------|---------|
|                                                       |                  | May 24                           | June 15 | July 6 | July 19 | Aug. 11 |
| Nitrogen Fertilizer Application Rate (F) <sup>x</sup> | 12.23            | 148 a <sup>u</sup>               | 181 a   | 181 a  | 192 a   | 262 a   |
|                                                       | 9.78             | 140 b                            | 171 b   | 170 b  | 181 b   | 251 b   |
|                                                       | 7.34             | 127 c                            | 161 c   | 164 b  | 174 b   | 238 c   |
| LSD (P=0.05)                                          |                  | 4.6                              | 4.5     | 7.2    | 7.6     | 8.2     |
| Brush Treatment (B) <sup>w</sup>                      | None             | 140                              | 171     | 173    | 184     | 253     |
|                                                       | Transformer      | 138                              | 169     | 169    | 180     | 248     |
|                                                       | Toro             | 137                              | 173     | 173    | 182     | 250     |
| LSD (P=0.05)                                          |                  | NS <sup>t</sup>                  | NS      | NS     | NS      | NS      |
| Wetting Agent Treatment (W) <sup>v</sup>              | None             | 141                              | 174 a   | 173    | 183     | 252     |
|                                                       | 7.96             | 137                              | 171 ab  | 172    | 183     | 251     |
|                                                       | 15.93            | 137                              | 168 b   | 170    | 180     | 248     |
| LSD (P=0.05)                                          |                  | NS                               | 4.4     | NS     | NS      | NS      |
| F x B                                                 |                  | NS                               | *       | NS     | NS      | NS      |
| F x W                                                 |                  | NS                               | NS      | NS     | NS      | NS      |
| B x W                                                 |                  | NS                               | NS      | NS     | NS      | NS      |
| F x B x W                                             |                  | NS                               | NS      | NS     | NS      | NS      |

<sup>z</sup> Chlorophyll content index measured by a FieldScout® CM 1000 Chlorophyll Meter.

<sup>y</sup> Relative chlorophyll content based on ambient and reflected light on a scale from 0 to 999.

<sup>x</sup> Nitrogen source used was urea (46-0-0) applied weekly (kg N ha<sup>-1</sup>).

<sup>w</sup> Brushing treatments were performed five times per week with a push broom mounted in front of a Toro Greensmaster 1000 walk-behind mower.

<sup>v</sup> Wetting agent treatments were made with Symphony from Harrell's at a low rate (7.96 L ha<sup>-1</sup>) every 15-d or a full rate (15.93 L ha<sup>-1</sup>) every 30-d.

<sup>u</sup> Columns with the same letter are not significantly different according to Fisher's LSD at P=0.05.

<sup>t</sup> NS = significant and not significant at the P=0.05 level of probability, respectively.

A two-way interaction between NFAR and brushing treatments occurred on two dates during the second year of the study (Figure 13 and 14). This interaction occurred at the highest nitrogen level, where the Transformer brush lowered turf chlorophyll content index compared to the control plot and Toro brush. No brushing effects were observed at any other level of fertilizer rate.

A three-way interaction between all factors occurred on one date during the first year of the study (July 30, 2015). Because this interaction only occurred once, it was considered a statistical anomaly and provides no further knowledge about the effects of these factors on creeping bentgrass establishment.

Table 18. Precipitation totals of the experimental site. East Lansing, MI.  
2015/2016.

| Start Date               | End Date        | Total Rainfall (cm) |
|--------------------------|-----------------|---------------------|
| May 1, 2015 <sup>z</sup> | August 12, 2015 | 38.20               |
| May 1, 2016 <sup>z</sup> | August 12, 2016 | 15.52               |
| May 1 <sup>y</sup>       | August 12       | 25.42               |

<sup>z</sup> Precipitation data were taken from the Enviro-weather Automated Weather Station Network provided by Michigan State University.

Weather station location: Hancock Turfgrass Research Center

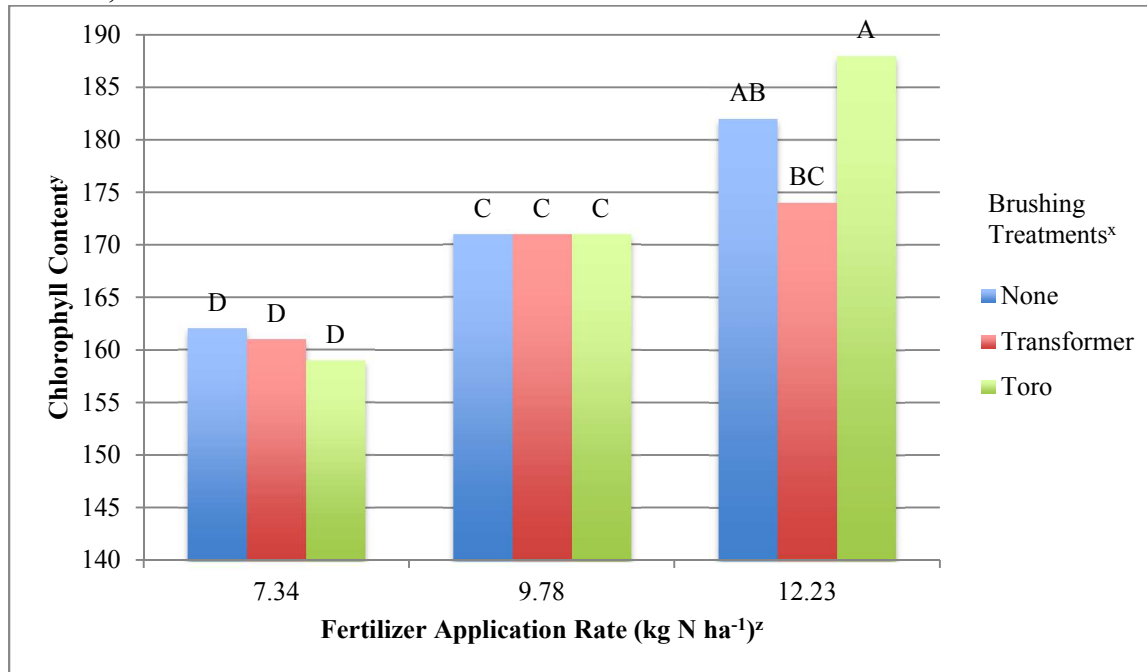
Latitude: 42.7110 deg.

Longitude: -84.4760 deg.

<sup>y</sup> The data reported are a “Historical Average” between the dates indicated in East Lansing, MI as reported from Intellicast by The Weather Company, LLC.



Figure 13. Effects of a nitrogen fertilizer application rate and brushing treatment interaction on chlorophyll content index of an establishing creeping bentgrass putting green. East Lansing, MI. June 15, 2016.

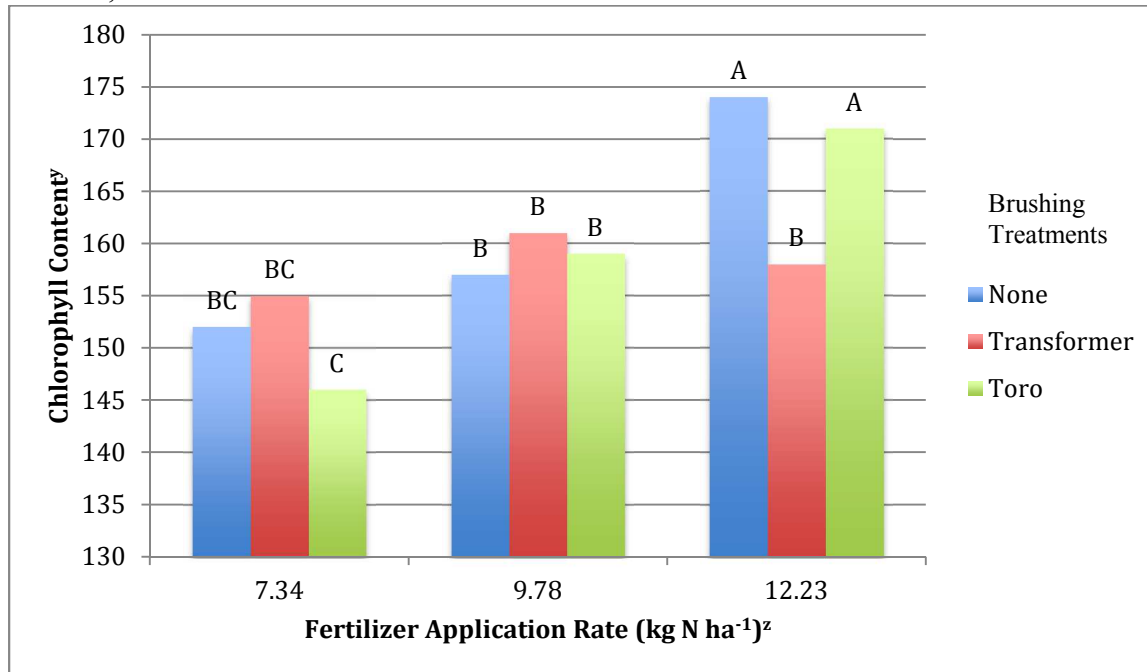


<sup>z</sup> Fertilizer source was urea (46-0-0) applied weekly.

<sup>y</sup> Chlorophyll content is measure on a scale from 0-999 by a FieldScout CM 1000 Chlorophyll Meter.

<sup>x</sup> Brushing treatments were applied five times per week using the indicated brush mounted in front of a Toro Greensmaster 1000 walk-behind mower.

Figure 14. Effects of a nitrogen fertilizer application rate and brushing treatment interaction on chlorophyll content index of an establishing creeping bentgrass putting green. East Lansing, MI. June 28, 2016.



<sup>z</sup> Fertilizer source was urea (46-0-0) applied weekly.

<sup>y</sup> Chlorophyll content is measure on a scale from 0-999 by a FieldScout CM 1000 Chlorophyll Meter.

<sup>x</sup> Brushing treatments were applied five times per week using the indicated brush mounted in front of a Toro Greensmaster 1000 walk-behind mower.

## **Effects on Turfgrass Color**

NFAR treatments produced significant main effect differences on nearly all collection dates during both years of study. No significant interactions were observed.

The vast majority of dates produced results indicating that with each increase in fertilizer rate, turfgrass color also increases (Table 13 and 14). Early dates in the second year of the study (not shown in the available tables) were either insignificant or did not detect the separation at each level that was typical of most other dates. This could be the result of a pre-plant application of Polyon (a slow-release fertilizer) being washed out by a heavy rain early in the establishment process for that year. The fertilizer was applied on September 4, 2015, and the washout occurred between the evening of September 7 and the morning of September 8, 2015, when more than 5 cm of rain fell. Pellets that washed away and gathered in small areas were collected and redistributed evenly across areas lacking fertilizer. This process was performed with the most precision possible, but it would have been impossible to remove and replace the exact amounts of fertilizer to their respective areas. As the growing season progressed, separation at each level of fertilizer was once again observed, leading to the conclusion that each level of increase in NFAR in this study corresponded with an increase in turfgrass color quality.

Effects from brushing treatments on turfgrass color were insignificant with the exception of one collection date, August 12, 2015 (Table 13). On that date, plots receiving no brushing treatments had significantly higher color quality than plots receiving either brushing treatment. The overall insignificance of these treatments indicates that brushing had no effect on turfgrass color in this study.

Table 19. Effects of nitrogen fertilizer, brushing, and wetting agents on turfgrass color<sup>z</sup> of an establishing creeping bentgrass putting green. East Lansing, MI. 2015.

| Treatment                                | Application Rate | NDVI <sup>y</sup>    |         |         |         |          |
|------------------------------------------|------------------|----------------------|---------|---------|---------|----------|
|                                          |                  | May 14               | June 4  | July 1  | July 23 | Aug. 12  |
| Nitrogen Fertilizer                      | 12.23            | 0.639 a <sup>u</sup> | 0.719 a | 0.773 a | 0.734 a | 0.776 a  |
| Application Rate                         | 9.78             | 0.623 b              | 0.697 b | 0.719 b | 0.720 b | 0.762 b  |
| (F) <sup>x</sup>                         | 7.34             | 0.601 c              | 0.661 c | 0.686 c | 0.686 c | 0.737 c  |
| LSD (P=0.05)                             |                  | 0.016                | 0.015   | 0.010   | 0.009   | 0.007    |
| Brush Treatment (B) <sup>w</sup>         | None             | 0.622                | 0.697   | 0.715   | 0.719   | 0.763 a  |
|                                          | Transformer      | 0.628                | 0.696   | 0.716   | 0.713   | 0.755 b  |
|                                          | Toro             | 0.614                | 0.684   | 0.707   | 0.709   | 0.757 ab |
| LSD (P=0.05)                             |                  | NS <sup>t</sup>      | NS      | NS      | NS      | 0.007    |
| Wetting Agent Treatment (W) <sup>v</sup> | None             | 0.626                | 0.700   | 0.717   | 0.716   | 0.761 a  |
|                                          | 7.96             | 0.625                | 0.687   | 0.707   | 0.708   | 0.752 b  |
|                                          | 15.93            | 0.613                | 0.690   | 0.714   | 0.717   | 0.761 a  |
| LSD (P=0.05)                             |                  | NS                   | NS      | NS      | NS      | 0.007    |
| F x B                                    |                  | NS                   | NS      | NS      | NS      | NS       |
| F x W                                    |                  | NS                   | NS      | NS      | NS      | NS       |
| B x W                                    |                  | NS                   | NS      | NS      | NS      | NS       |
| F x B x W                                |                  | NS                   | NS      | NS      | NS      | NS       |

<sup>z</sup> Chlorophyll content measured by a FieldScout® TCM 500 Turf Color Meter.

<sup>y</sup> Turfgrass color based on reflected light on a scale from 0.000 to 1.000.

<sup>x</sup> Nitrogen source used was urea (46-0-0) applied weekly (kg N ha<sup>-1</sup>).

<sup>w</sup> Brushing treatments were performed five times per week with a push broom mounted in front of a Toro Greensmaster 1000 walk-behind mower.

<sup>v</sup> Wetting agent treatments were made with Symphony from Harrell's at a low rate (7.96 L ha<sup>-1</sup>) every 15-d or a full rate (15.93 L ha<sup>-1</sup>) every 30-d.

<sup>u</sup> Columns with the same letter are not significantly different according to Fisher's LSD at P=0.05.

<sup>t</sup> NS = significant at the P=0.05 level of probability.

Table 20. Effects of nitrogen fertilizer, brushing, and wetting agents on turfgrass color<sup>z</sup> of an establishing creeping bentgrass putting green. East Lansing, MI. 2016.

| Treatment                                | Application Rate | NDVI <sup>y</sup>    |          |         |         |         |
|------------------------------------------|------------------|----------------------|----------|---------|---------|---------|
|                                          |                  | May 24               | June 15  | July 6  | July 19 | Aug. 11 |
| Nitrogen Fertilizer                      | 12.23            | 0.658 a <sup>u</sup> | 0.690 a  | 0.709 a | 0.719 a | 0.753 a |
| Application Rate                         | 9.78             | 0.646 b              | 0.667 b  | 0.682 b | 0.700 b | 0.744 b |
| (F) <sup>x</sup>                         | 7.34             | 0.601 c              | 0.642 c  | 0.665 c | 0.688 c | 0.734 c |
| LSD (P=0.05)                             |                  | 0.013                | 0.010    | 0.012   | 0.009   | 0.009   |
| Brush Treatment (B) <sup>w</sup>         | None             | 0.641                | 0.668    | 0.689   | 0.705   | 0.743   |
|                                          | Transformer      | 0.635                | 0.662    | 0.683   | 0.699   | 0.747   |
|                                          | Toro             | 0.629                | 0.669    | 0.685   | 0.703   | 0.742   |
| LSD (P=0.05)                             |                  | NS <sup>t</sup>      | NS       | NS      | NS      | NS      |
| Wetting Agent Treatment (W) <sup>v</sup> | None             | 0.642                | 0.675 a  | 0.690   | 0.702   | 0.746   |
|                                          | 7.96             | 0.632                | 0.665 ab | 0.685   | 0.705   | 0.744   |
|                                          | 15.93            | 0.631                | 0.659 b  | 0.682   | 0.699   | 0.740   |
| LSD (P=0.05)                             |                  | NS                   | 0.010    | NS      | NS      | NS      |
| F x B                                    |                  | NS                   | NS       | NS      | NS      | NS      |
| F x W                                    |                  | NS                   | NS       | NS      | NS      | NS      |
| B x W                                    |                  | NS                   | NS       | NS      | NS      | NS      |
| F x B x W                                |                  | NS                   | NS       | NS      | NS      | NS      |

<sup>z</sup> Chlorophyll content measured by a FieldScout® TCM 500 Turf Color Meter.

<sup>y</sup> Turfgrass color based on reflected light on a scale from 0.000 to 1.000.

<sup>x</sup> Nitrogen source used was urea (46-0-0) applied weekly (kg N ha<sup>-1</sup>).

<sup>w</sup> Brushing treatments were performed five times per week with a push broom mounted in front of a Toro Greensmaster 1000 walk-behind mower.

<sup>v</sup> Wetting agent treatments were made with Symphony from Harrell's at a low rate (7.96 L ha<sup>-1</sup>) every 15-d or a full rate (15.93 L ha<sup>-1</sup>) every 30-d.

<sup>u</sup> Columns with the same letter are not significantly different according to Fisher's LSD at P=0.05.

<sup>t</sup> NS = not significant at the P=0.05 level of probability.

Wetting agent treatments were significant on five dates throughout the entirety of the experiment (Table 13 and 14). The results on significant dates indicated that applying wetting agents (especially at a 15-d interval) may produce a slight decrease in turf color quality. In all cases of significance, the 15-d interval plots were either the lowest rated or equal to the lowest rated plots. However, since the vast majority of dates resulted in no differences between treatments in this study, it can be concluded that wetting agents do not often contribute to a change in turfgrass color when applied at a 15- or 30-d interval.

No significant interactions were observed for turfgrass color quality during either year of the study.

## **Effects on Visual Percent Ground Cover**

Percentage turfgrass ground cover data were based on a visual estimate of green tissue covering the soil surface. Data were collected on nearly every week during the first year of the study, and only on three occasions during the second year. The reason that data were not collected as often during the second year of the study was partially due to the aforementioned heavy rain event and subsequent fertilizer movement. This made it difficult to collect percentage turfgrass cover on early (fall) dates of the second year of the study.

Results for percentage turfgrass cover from the first year of this study show that during the first few collection dates after seeding, plots receiving higher NFAR treatments established more rapidly than plots receiving less nitrogen at each level (Table 15). As the study progressed, however, there was a leveling off at  $9.78 \text{ kg N ha}^{-1}$ , at which point the addition of more nitrogen no longer correlated with an increased percentage of turfgrass cover. Plots receiving the lowest N application rate ( $7.34 \text{ kg N ha}^{-1}$ ) always rated as having the least amount of cover. During the second year of the study, no significant differences were observed between treatments. Neither the brushing or wetting agent treatments, nor any interactions, were significant for this data collection method at any point during the study.

Table 21. Effects of nitrogen fertilizer, brushing, and wetting agents on visual percent turfgrass cover<sup>z</sup> of an establishing creeping bentgrass putting green. East Lansing, MI. 2015.

| Treatment                                             | Application Rate | Percent Turfgrass Cover <sup>y</sup> |                 |        |         |         |
|-------------------------------------------------------|------------------|--------------------------------------|-----------------|--------|---------|---------|
|                                                       |                  | Oct. 17                              | May 7           | May 21 | June 10 | June 25 |
| Nitrogen Fertilizer Application Rate (F) <sup>x</sup> | 12.23            | 84.3 a <sup>u</sup>                  | 89.6 a          | 95.1 a | 96.7 a  | 97.4 a  |
|                                                       | 9.78             | 78.2 b                               | 87.4 a          | 93.3 a | 94.7 a  | 95.1 a  |
|                                                       | 7.34             | 72.5 c                               | 81.0 b          | 88.7 b | 89.0 b  | 90.3 b  |
| LSD (P=0.05)                                          |                  | 5.2                                  | 4.3             | 3.3    | 3.8     | 3.0     |
| Brush Treatment (B) <sup>w</sup>                      | None             | 80.7 a                               | 87.6            | 93.6   | 95.0    | 95.6    |
|                                                       | Transformer      | 80.6 a                               | 86.1            | 92.1   | 94.0    | 95.0    |
|                                                       | Toro             | 73.7 b                               | 84.2            | 91.5   | 91.4    | 92.2    |
| LSD (P=0.05)                                          |                  | 5.2 <sup>t</sup>                     | NS <sup>s</sup> | NS     | NS      | NS      |
| Wetting Agent Treatment (W) <sup>v</sup>              | None             | 78.2                                 | 85.7            | 92.4   | 92.9    | 94.2    |
|                                                       | 7.96             | 79.4                                 | 86.4            | 92.9   | 94.2    | 95.4    |
|                                                       | 15.93            | 77.4                                 | 85.8            | 91.9   | 93.3    | 93.2    |
| LSD (P=0.05)                                          |                  | NS                                   | NS              | NS     | NS      | NS      |
| F x B                                                 |                  | NS                                   | NS              | NS     | NS      | NS      |
| F x W                                                 |                  | NS                                   | NS              | NS     | NS      | NS      |
| B x W                                                 |                  | NS                                   | NS              | NS     | NS      | NS      |
| F x B x W                                             |                  | NS                                   | NS              | NS     | NS      | NS      |

<sup>z</sup> Percent turfgrass cover is based on a visual estimate using the NTEP protocol.

<sup>y</sup> Percent turfgrass cover is given as a percent from 0-100.

<sup>x</sup> Nitrogen source used was urea (46-0-0) applied weekly (kg N ha<sup>-1</sup>).

<sup>w</sup> Brushing treatments were performed five times per week with a push broom mounted in front of a Toro Greensmaster 1000 walk-behind mower.

<sup>v</sup> Wetting agent treatments were made with Symphony from Harrell's at a low rate (7.96 L ha<sup>-1</sup>) every 15-d or a full rate (15.93 L ha<sup>-1</sup>) every 30-d.

<sup>u</sup> Columns with the same letter are not significantly different according to Fisher's LSD at P=0.05.

<sup>t</sup> Although significant, brushing treatments were not initiated until April 20, 2016. This significance is a statistical anomaly.

<sup>s</sup> NS = not significant at the P=0.05 level of probability.



Table 22. Effects of nitrogen fertilizer, brushing, and wetting agents on visual percent turfgrass cover<sup>z</sup> of an establishing creeping bentgrass putting green. East Lansing, MI. 2016.

| Treatment                                | Application Rate | Percent Turfgrass Cover <sup>y</sup> |        |        |
|------------------------------------------|------------------|--------------------------------------|--------|--------|
|                                          |                  | May 3                                | May 11 | May 17 |
| Nitrogen Fertilizer                      | 12.23            | 86.1                                 | 89.0   | 92.8   |
| Application Rate                         | 9.78             | 86.6                                 | 89.0   | 91.6   |
| (F) <sup>x</sup>                         | 7.34             | 84.8                                 | 87.5   | 91.6   |
| LSD (P=0.05)                             |                  | NS                                   | NS     | NS     |
| Brush Treatment (B) <sup>w</sup>         | None             | 86.0                                 | 87.5   | 91.2   |
|                                          | Transformer      | 83.9                                 | 87.4   | 91.0   |
|                                          | Toro             | 87.6                                 | 90.7   | 93.8   |
| LSD (P=0.05)                             |                  | NS                                   | NS     | NS     |
| Wetting Agent Treatment (W) <sup>v</sup> | None             | 86.5                                 | 88.9   | 93.1   |
|                                          | 7.96             | 85.6                                 | 89.3   | 91.2   |
|                                          | 15.93            | 85.5                                 | 87.4   | 91.6   |
| LSD (P=0.05)                             |                  | NS                                   | NS     | NS     |
| F x B                                    |                  | NS                                   | NS     | NS     |
| F x W                                    |                  | NS                                   | NS     | NS     |
| B x W                                    |                  | NS                                   | NS     | NS     |
| F x B x W                                |                  | NS                                   | NS     | NS     |

<sup>z</sup> Percent turfgrass cover is based on a visual estimate using the NTEP protocol.

<sup>y</sup> Percent turfgrass cover is given as a percent from 0-100.

<sup>x</sup> Nitrogen source used was urea (46-0-0) applied weekly (kg N ha<sup>-1</sup>).

<sup>w</sup> Brushing treatments were performed five times per week with a push broom mounted in front of a Toro Greensmaster 1000 walk-behind mower.

<sup>v</sup> Wetting agent treatments were made with Symphony from Harrell's at a low rate (7.96 L ha<sup>-1</sup>) every 15-d or a full rate (15.93 L ha<sup>-1</sup>) every 30-d.

<sup>u</sup> NS = not significant at the P=0.05 level of probability.

## Effects on Volumetric Water Content

Volumetric water contents were taken periodically throughout the growing seasons using a FieldScout® TDR 300 Soil Moisture Meter at depths of 3.81 and 7.62 cm. Significant main effects were observed during both years of study. No interactions were observed at either depth of data collection during either year. The shorter tines (3.81 cm depth) recorded more significant differences than the longer tines (7.62 cm) during both years of the study.

The shorter tines recorded significant NFAR treatment results on most dates throughout both years of the study (Table 17 and 19). On significant collection dates, minimal separation was observed between the middle and high levels of fertilizer (9.78 and 12.23 kg N ha<sup>-1</sup>). On fewer of these dates, there was also no separation seen between the lowest and middle rates (7.34 and 9.78 kg N ha<sup>-1</sup>). The majority of dates seem to indicate that there is a plateau at 9.78 kg N ha<sup>-1</sup> per week, after which point the addition of more nitrogen does not lead to more water retention. The longer tines (7.62 cm) produced only one significant separation of means (June 15, 2016; date is not present in the tables below). On this date, the middle rate was not different from either the high or low rates, but the high rate recorded higher volumetric water contents than the low rate.

On July 23, 2015, the brushing treatments were significantly different from one another according to the short tine data collected (Table 17). On this date, both the control plots and plots receiving the Transformer brushing treatments had higher volumetric water contents than plots receiving the Toro brushing treatments. Due to the overall insignificance of this factor, it can be concluded that brushing (in this study) does not have an effect on volumetric water contents.

Table 23. Effects of nitrogen fertilizer, brushing, and wetting agents on volumetric water content<sup>z</sup> at a 3.81 cm depth of an establishing creeping bentgrass putting green. East Lansing, MI. 2015.

| Treatment                                | Application Rate | TDR <sup>y</sup>   |         |         |         |
|------------------------------------------|------------------|--------------------|---------|---------|---------|
|                                          |                  | June 17            | July 15 | July 23 | Aug. 12 |
| Nitrogen Fertilizer                      | 12.23            | 7.9 a <sup>u</sup> | 5.4 a   | 10.6 a  | 7.9 a   |
| Application Rate                         | 9.78             | 7.5 a              | 5.7 a   | 10.5 a  | 7.8 a   |
| (F) <sup>x</sup>                         | 7.34             | 6.9 b              | 5.0 b   | 9.6 b   | 7.0 b   |
| LSD (P=0.05)                             |                  | 0.6                | 0.4     | 0.5     | 0.4     |
| Brush Treatment (B) <sup>w</sup>         | None             | 7.4                | 5.5     | 10.5 a  | 7.7     |
|                                          | Transformer      | 7.4                | 5.3     | 10.3 ab | 7.5     |
|                                          | Toro             | 7.4                | 5.3     | 9.9 b   | 7.6     |
| LSD (P=0.05)                             |                  | NS <sup>t</sup>    | NS      | 0.5     | NS      |
| Wetting Agent Treatment (W) <sup>v</sup> | None             | 7.8                | 5.8 a   | 10.6 a  | 8.3 a   |
|                                          | 7.96             | 7.4                | 5.1 b   | 9.7 b   | 7.0 c   |
|                                          | 15.93            | 7.1                | 5.2 b   | 10.4 a  | 7.4 b   |
| LSD (P=0.05)                             |                  | NS                 | 0.4     | 0.5     | 0.4     |
| F x B                                    |                  | NS                 | NS      | NS      | NS      |
| F x W                                    |                  | NS                 | NS      | NS      | NS      |
| B x W                                    |                  | NS                 | NS      | NS      | NS      |
| F x B x W                                |                  | NS                 | NS      | NS      | NS      |

<sup>z</sup> Volumetric water contents measured by a FieldScout TDR 300 Soil Moisture Meter.

<sup>y</sup> Results are given in percent soil moisture content.

<sup>x</sup> Nitrogen source used was urea (46-0-0) applied weekly (kg N ha<sup>-1</sup>).

<sup>w</sup> Brushing treatments were performed five times per week with a push broom mounted in front of a Toro Greensmaster 1000 walk-behind mower.

<sup>v</sup> Wetting agent treatments were made with Symphony from Harrell's at a low rate (7.96 L ha<sup>-1</sup>) every 15-d or a full rate (15.93 L ha<sup>-1</sup>) every 30-d.

<sup>u</sup> Columns with the same letter are not significantly different according to Fisher's LSD at P=0.05.

<sup>t</sup> NS = not significant at the P=0.05 level of probability.

Table 24. Effects of nitrogen fertilizer, brushing, and wetting agents on volumetric water contents<sup>z</sup> at a 7.62 cm depth of an establishing creeping bentgrass putting green. East Lansing, MI. 2015.

| Treatment                                | Application Rate | TDR <sup>y</sup> |         |         |                     |
|------------------------------------------|------------------|------------------|---------|---------|---------------------|
|                                          |                  | June 25          | July 15 | July 23 | Aug. 12             |
| Nitrogen Fertilizer                      | 12.23            | 11.1             | 11.3    | 18.5    | 15.6                |
| Application Rate (F) <sup>x</sup>        | 9.78             | 11.4             | 11.8    | 18.4    | 15.8                |
|                                          | 7.34             | 10.8             | 11.2    | 17.9    | 14.8                |
| LSD (P=0.05)                             |                  | NS <sup>u</sup>  | NS      | NS      | NS                  |
| Brush Treatment (B) <sup>w</sup>         | None             | 10.9             | 11.3    | 18.1    | 15.5                |
|                                          | Transformer      | 11.0             | 11.5    | 18.6    | 15.1                |
|                                          | Toro             | 11.4             | 11.5    | 18.1    | 15.6                |
| LSD (P=0.05)                             |                  | NS               | NS      | NS      | NS                  |
| Wetting Agent Treatment (W) <sup>v</sup> | None             | 11.3             | 11.8    | 18.1    | 16.3 a <sup>t</sup> |
|                                          | 7.96             | 11.2             | 11.4    | 18.2    | 14.9 b              |
|                                          | 15.93            | 10.9             | 11.1    | 18.5    | 15.0 b              |
| LSD (P=0.05)                             |                  | NS               | NS      | NS      | 0.9                 |
| F x B                                    |                  | NS               | NS      | NS      | NS                  |
| F x W                                    |                  | NS               | NS      | NS      | NS                  |
| B x W                                    |                  | NS               | NS      | NS      | NS                  |
| F x B x W                                |                  | NS               | NS      | NS      | NS                  |

<sup>z</sup> Volumetric water contents measured by a FieldScout TDR 300 Soil Moisture Meter.

<sup>y</sup> Results are given in percent soil moisture content.

<sup>x</sup> Nitrogen source used was urea (46-0-0) applied weekly (kg N ha<sup>-1</sup>).

<sup>w</sup> Brushing treatments were performed five times per week with a push broom mounted in front of a Toro Greensmaster 1000 walk-behind mower.

<sup>v</sup> Wetting agent treatments were made with Symphony from Harrell's at a low rate (7.96 L ha<sup>-1</sup>) every 15-d or a full rate (15.93 L ha<sup>-1</sup>) every 30-d.

<sup>u</sup> NS = not significant at the P=0.05 level of probability.

<sup>t</sup> Columns with the same letter are not significantly different according to Fisher's LSD at P=0.05.

Table 26. Effects of nitrogen fertilizer, brushing, and wetting agents on volumetric water contents<sup>z</sup> at a 3.81 cm depth of an establishing creeping bentgrass putting green. East Lansing, MI. 2016.

| Treatment                                | Application Rate | TDR <sup>y</sup>    |         |        |         |         |
|------------------------------------------|------------------|---------------------|---------|--------|---------|---------|
|                                          |                  | May 24              | June 15 | July 6 | July 26 | Aug. 11 |
| Nitrogen Fertilizer                      | 12.23            | 10.5 a <sup>u</sup> | 12.5 a  | 10.7   | 10.7    | 11.7 a  |
| Application Rate (F) <sup>x</sup>        | 9.78             | 10.2 ab             | 11.7 b  | 10.3   | 10.5    | 11.2 ab |
|                                          | 7.34             | 9.6 b               | 11.1 b  | 10.5   | 9.9     | 10.8 b  |
| LSD (P=0.05)                             |                  | 0.6                 | 0.7     | NS     | NS      | 0.6     |
| Brush Treatment (B) <sup>w</sup>         | None             | 10.2                | 11.9    | 10.3   | 10.6    | 11.3    |
|                                          | Transformer      | 9.9                 | 11.6    | 10.6   | 10.4    | 11.2    |
|                                          | Toro             | 10.3                | 11.7    | 10.7   | 10.2    | 11.1    |
| LSD (P=0.05) <sup>t</sup>                |                  | NS                  | NS      | NS     | NS      | NS      |
| Wetting Agent Treatment (W) <sup>v</sup> | None             | 10.2                | 11.7    | 10.8   | 10.6    | 11.5    |
|                                          | 7.96             | 10.2                | 11.9    | 10.9   | 10.3    | 11.1    |
|                                          | 15.93            | 9.9                 | 11.6    | 9.9    | 10.3    | 11.1    |
| LSD (P=0.05)                             |                  | NS                  | NS      | NS     | NS      | NS      |
| F x B                                    |                  | NS                  | NS      | NS     | NS      | NS      |
| F x W                                    |                  | NS                  | NS      | NS     | NS      | NS      |
| B x W                                    |                  | NS                  | NS      | NS     | NS      | NS      |
| F x B x W                                |                  | NS                  | NS      | NS     | NS      | NS      |

<sup>z</sup> Volumetric water contents measured by a FieldScout TDR 300 Soil Moisture Meter.

<sup>y</sup> Results are given in percent soil moisture content.

<sup>x</sup> Nitrogen source used was urea (46-0-0) applied weekly (kg N ha<sup>-1</sup>).

<sup>w</sup> Brushing treatments were performed five times per week with a push broom mounted in front of a Toro Greensmaster 1000 walk-behind mower.

<sup>v</sup> Wetting agent treatments were made with Symphony from Harrell's at a low rate (7.96 L ha<sup>-1</sup>) every 15-d or a full rate (15.93 L ha<sup>-1</sup>) every 30-d.

<sup>u</sup> Columns with the same letter are not significantly different according to Fisher's LSD at P=0.05.

<sup>t</sup> NS = not significant at the P=0.05 level of probability.

Table 27. Effects of nitrogen fertilizer, brushing, and wetting agents on volumetric water contents<sup>z</sup> at a 7.62 cm depth of an establishing creeping bentgrass putting green. East Lansing, MI. 2016.

| Treatment                                | Application Rate | TDR <sup>y</sup> |                     |        |         |         |
|------------------------------------------|------------------|------------------|---------------------|--------|---------|---------|
|                                          |                  | May 24           | June 15             | July 6 | July 26 | Aug. 11 |
| Nitrogen Fertilizer                      | 12.23            | 15.8             | 15.2 a <sup>t</sup> | 18.0   | 14.6    | 18.0    |
| Application Rate                         | 9.78             | 15.5             | 15.0 ab             | 17.3   | 14.6    | 17.8    |
| (F) <sup>x</sup>                         | 7.34             | 14.9             | 14.0 b              | 17.3   | 14.1    | 17.4    |
| LSD (P=0.05)                             |                  | NS <sup>u</sup>  | 1.0                 | NS     | NS      | NS      |
| Brush Treatment (B) <sup>w</sup>         | None             | 15.6             | 14.9                | 17.5   | 14.8    | 18.0    |
|                                          | Transformer      | 15.2             | 14.7                | 17.4   | 14.4    | 17.7    |
|                                          | Toro             | 15.3             | 14.6                | 17.7   | 14.1    | 17.4    |
| LSD (P=0.05)                             |                  | NS               | NS                  | NS     | NS      | NS      |
| Wetting Agent Treatment (W) <sup>v</sup> | None             | 15.4             | 14.5                | 17.7   | 14.6    | 17.9    |
|                                          | 7.96             | 15.6             | 15.1                | 17.6   | 14.4    | 17.4    |
|                                          | 15.93            | 15.2             | 14.5                | 17.3   | 14.3    | 17.9    |
| LSD (P=0.05)                             |                  | NS               | NS                  | NS     | NS      | NS      |
| F x B                                    |                  | NS               | NS                  | NS     | NS      | NS      |
| F x W                                    |                  | NS               | NS                  | NS     | NS      | NS      |
| B x W                                    |                  | NS               | NS                  | NS     | NS      | NS      |
| F x B x W                                |                  | NS               | NS                  | NS     | NS      | NS      |

<sup>z</sup> Volumetric water contents measured by a FieldScout TDR 300 Soil Moisture Meter.

<sup>y</sup> Results are given in percent soil moisture content.

<sup>x</sup> Nitrogen source used was urea (46-0-0) applied weekly (kg N ha<sup>-1</sup>).

<sup>w</sup> Brushing treatments were performed five times per week with a push broom mounted in front of a Toro Greensmaster 1000 walk-behind mower.

<sup>v</sup> Wetting agent treatments were made with Symphony from Harrell's at a low rate (7.96 L ha<sup>-1</sup>) every 15-d or a full rate (15.93 L ha<sup>-1</sup>) every 30-d.

<sup>u</sup> NS = not significant at the P=0.05 level of probability.

<sup>t</sup> Columns with the same letter are not significantly different according to Fisher's LSD at P=0.05.

During the first year of study, significant differences were observed regarding wetting agent treatments (Table 17 and 18). For that year, at the 3.81 cm depth, wetting agent treatments often had detrimental effects on water retention. In most cases, the more frequent applications (14-d) led to lower retention than the 30-d applications, which then had less retention than control plots. This could be due, as mentioned above, to the record amount of rainfall that East Lansing received during the summer of 2015. In 2016 (Table 19 and 20), no differences between wetting agent treatments were observed. These results indicate that wetting agent treatments, when applied frequently to newly (less than one year old) established creeping bentgrass putting greens, do not benefit plants by helping to retain water and may in fact hinder that capability when frequent irrigation (or rainfall events) occur.

### **Effects on Turfgrass Stability**

Turfgrass stability, measured by shear strength, did not produce any significant main effects or interactions in either year of the study (Table 21). The results indicate that turfgrass stability in this study plateaued at 7.34 kg N ha<sup>-1</sup> per week, after which point the addition of more nitrogen fertilizer did not contribute to more stable turf. Brushing plots does not seem to affect turf stability and neither does the use of wetting agents.



Table 28. Effects of nitrogen fertilizer, brushing, and wetting agents on turfgrass stability<sup>z</sup> of an establishing creeping bentgrass putting green. East Lansing, MI. 2015/2016.

| Treatment                                             | Application Rate | Turfgrass Stability <sup>y</sup> |                 |
|-------------------------------------------------------|------------------|----------------------------------|-----------------|
|                                                       |                  | August 14, 2015                  | August 11, 2016 |
| Nitrogen Fertilizer Application Rate (F) <sup>x</sup> | 12.23            | 10.3                             | 12.3            |
|                                                       | 9.78             | 10.8                             | 12.3            |
|                                                       | 7.34             | 10.5                             | 11.6            |
| LSD (P=0.05)                                          |                  | NS <sup>u</sup>                  | NS              |
| Brush Treatment (B) <sup>w</sup>                      | None             | 10.8                             | 12.3            |
|                                                       | Transformer      | 10.5                             | 11.8            |
|                                                       | Toro             | 10.3                             | 12.1            |
| LSD (P=0.05)                                          |                  | NS                               | NS              |
| Wetting Agent Treatment (W) <sup>v</sup>              | None             | 10.8                             | 12.2            |
|                                                       | 7.96             | 10.5                             | 11.9            |
|                                                       | 15.93            | 10.3                             | 12.2            |
| LSD (P=0.05)                                          |                  | NS                               | NS              |
| F x B                                                 |                  | NS                               | NS              |
| F x W                                                 |                  | NS                               | NS              |
| B x W                                                 |                  | NS                               | NS              |
| F x B x W                                             |                  | NS                               | NS              |

<sup>z</sup> Turfgrass stability measured by a Turf-Tec Shear Strength Tester.

<sup>y</sup> Turfgrass stability is reported in Newton Meters of force required to shear the turf from its surroundings.

<sup>x</sup> Nitrogen source used was urea (46-0-0) applied weekly (kg N ha<sup>-1</sup>).

<sup>w</sup> Brushing treatments were performed five times per week with a push broom mounted in front of a Toro Greensmaster 1000 walk-behind mower.

<sup>v</sup> Wetting agent treatments were made with Symphony from Harrell's at a low rate (7.96 L ha<sup>-1</sup>) every 15-d or a full rate (15.93 L ha<sup>-1</sup>) every 30-d.

<sup>u</sup> NS = significant and not significant at the P=0.05 level of probability, respectively.

## CONCLUSIONS

In this study, NFAR treatments produced unique, significant results based on data collection method. For chlorophyll content index and turfgrass color quality, higher rates of nitrogen (with very few exceptions) improved turf quality. However, for visual percent turfgrass cover and volumetric water content it appears that there is a plateau at the middle rate of nitrogen used in this study ( $9.78 \text{ kg N ha}^{-1}$ ), after which point no benefits were observed. Another distinct result was seen with the turf shear strength tester, which produced no differences between any NFAR treatments. Combined, these results demonstrate that there is no exact amount of nitrogen that can be applied to every newly seeded green to produce perfect results. If a turf manager desires a stand that is of the highest visual quality, they may want to consider a rate of at least  $12.23 \text{ kg N ha}^{-1}$  weekly. If, however, the preferred program involves saving money and resources while still providing a stable surface that covers ground at the highest rate observed in this study, lower amounts (around  $9.78 \text{ kg N ha}^{-1}$ ) may produce the desired results. Previous studies suggested that rates of between  $12.1$  and  $19 \text{ kg N ha}^{-1}$  weekly provided better quality and percent cover results than lower rates and were statistically similar to higher rates (Pease et al., 2011; Watson et al., 2012) at establishment. This study confirms that for the best combination of characteristics, a rate of around  $12 \text{ kg N ha}^{-1}$  per week seems to be a good target, but qualities such as percent cover and turf stability can be achieved at a slightly lower rate. According to these results, rates higher than  $12.23 \text{ kg N ha}^{-1}$  per week would seem to be excessive, but that should be investigated further before any conclusions are made.

Brushing treatments in this study were mostly insignificant. The effects that did occur on a few select dates mostly involved chlorophyll content. Results were not always consistent, but the general trend in the conditions of this study indicated brushes had an overall detrimental

effect. At the very best, there was no difference between the control plots and the brushes, but no positive effects from brushing the turf in the early stages of establishment was seen. Data presented by Gu (2016) produced somewhat inconsistent results, but they seemed to come to a similar conclusion: At best, brushing neither helped nor hurt turf, and at worst it did some damage. The insignificance of brushing in this study could be partially due to size restrictions, since plots could only be brushed in two directions (East to West and West to East) and not the desired method of multiple directions. It is also possible that brushing has no effect on turfgrass establishment characteristics, but further studies would need to be performed to determine any effects or lack thereof.

Wetting agent treatments were more often significant during the first year of the study, but the same results were seen in both years. Wetting agent treatments, especially the more frequent treatments that occurred every 15-d, decreased turf chlorophyll content index and volumetric water content. These results were almost exclusively detected at 3.81 cm below the turf surface, suggesting that most of the wetting agent was held in the upper portion of the soil profile and therefore had the most effect in that area. As discussed earlier, it is hypothesized that these results were seen more frequently in the first year of the study due to the heavy rainfall in 2015 that left conditions on the plot area more saturated than what would be considered desirable. Previous studies performed by Anda (1975) and Henderson (2000) on Kentucky bluegrass either saw no benefit to applying wetting agents or detrimental effects from their application. While wetting agents clearly have a purpose and benefit to mature turf stands, it seems that they provide no such benefits when attempting to establish a new turf stand.

In conclusion, the outcome of this study suggests that some plant benefits were seen from using NFAR treatments of up to 12.23 kg N ha<sup>-1</sup> per week, but there was also a plateau that was

observed at 9.78 kg regarding turf strength and percent visual ground cover. The brushing factor produced almost no effect on any of the factors. The wetting agent treatments, in general, had a detrimental effect on overall turf quality. Recommendations based on these factors are that turf managers use at least 9.78 kg N ha<sup>-1</sup> weekly and do not apply wetting agents at less than a 30-d interval on a regular basis (unless extenuating circumstances provide for this to be beneficial) when establishing a new creeping bentgrass putting green from seed. Brushing did not benefit or hinder the establishment process in this study, therefore further research needs to be conducted before a definitive conclusion can be made about its potential benefits.

## **APPENDIX**

Table 29. Analysis of Variance results for the effects of nitrogen fertilizer application rate, brushing, and wetting agent use on chlorophyll content<sup>z</sup>. East Lansing, MI. 2014/2015.

|                | 10-<br>10 | 10-<br>17 | 10-<br>23 | 4-<br>14 | 5-<br>7 | 5-<br>14 | 5-<br>21 | 5-<br>29 | 6-<br>4 | 6-<br>10 | 6-<br>17 | 6-<br>25 | 7-<br>1 | 7-<br>9 | 7-<br>15 | 7-<br>23 | 7-<br>30 | 8-<br>4 | 8-<br>12 |
|----------------|-----------|-----------|-----------|----------|---------|----------|----------|----------|---------|----------|----------|----------|---------|---------|----------|----------|----------|---------|----------|
| F <sup>y</sup> | ***       | ***       | ***       | ***      | ***     | ***      | ***      | ***      | ***     | ***      | ***      | ***      | ***     | ***     | ***      | ***      | ***      | ***     | ***      |
| B              | --        | --        | --        | --       | --      | NS       | NS       | NS       | *       | NS       | NS       | NS       | NS      | NS      | NS       | NS       | NS       | NS      | *        |
| F*B            | --        | --        | --        | --       | --      | NS       | NS       | NS       | NS      | NS       | NS       | NS       | NS      | NS      | NS       | NS       | NS       | NS      | NS       |
| W              | --        | --        | --        | --       | --      | NS       | NS       | NS       | NS      | NS       | NS       | NS       | *       | **      | *        | **       | *        | *       | **       |
| F*W            | --        | --        | --        | --       | --      | NS       | NS       | NS       | NS      | NS       | NS       | NS       | NS      | NS      | NS       | NS       | NS       | NS      | NS       |
| B*W            | --        | --        | --        | --       | --      | NS       | NS       | NS       | NS      | NS       | NS       | NS       | NS      | NS      | NS       | NS       | NS       | NS      | NS       |
| F*B*W          | --        | --        | --        | --       | --      | NS       | NS       | NS       | NS      | NS       | NS       | NS       | NS      | NS      | NS       | NS       | *        | NS      | NS       |

\*, \*\*, \*\*\* represent significance at the P<0.05, 0.01, and 0.0001 level of probability.

-- represent dates on which data was not collected because the selected treatments had not yet been initiated.

<sup>z</sup> Chlorophyll content measured by a FieldScout® CM 1000 Chlorophyll Meter.

<sup>y</sup> F, B, and W represent nitrogen fertilizer application rate, brushing, and wetting agent treatments, respectively.

Table 30. Analysis of Variance results for the effects of nitrogen fertilizer application rate, brushing, and wetting agent use on visual percent cover<sup>z</sup>. East Lansing, MI. 2014/2015.

|                | 10-<br>10 | 10-<br>17 | 10-<br>23 | 4-<br>14 | 5-<br>7 | 5-<br>14 | 5-<br>21 | 5-<br>29 | 6-<br>4 | 6-<br>10 | 6-<br>17 | 6-<br>25 |
|----------------|-----------|-----------|-----------|----------|---------|----------|----------|----------|---------|----------|----------|----------|
| F <sup>y</sup> | --        | **        | **        | --       | **      | **       | **       | **       | --      | **       | ***      | ***      |
| B              | --        | --        | --        | --       | --      | NS       | NS       | NS       | --      | NS       | NS       | NS       |
| F*B            | --        | --        | --        | --       | --      | NS       | NS       | NS       | --      | NS       | NS       | NS       |
| W              | --        | --        | --        | --       | --      | NS       | NS       | NS       | --      | NS       | NS       | NS       |
| F*W            | --        | --        | --        | --       | --      | NS       | NS       | NS       | --      | NS       | NS       | NS       |
| B*W            | --        | --        | --        | --       | --      | NS       | NS       | NS       | --      | NS       | NS       | NS       |
| F*B*W          | --        | --        | --        | --       | --      | NS       | NS       | NS       | --      | NS       | NS       | NS       |

\*, \*\*, \*\*\* represent significance at the P<0.05, 0.01, and 0.0001 level of probability.

-- represent dates on which data was not collected because the selected treatments had not yet been initiated.

<sup>z</sup> Percent turfgrass cover is based on a visual estimate using the NTEP protocol.

<sup>y</sup> F, B, and W represent nitrogen fertilizer application rate, brushing, and wetting agent treatments, respectively.

Table 31. Analysis of Variance results for the effects of nitrogen fertilizer application rate, brushing, and wetting agent use on chlorophyll content<sup>z</sup>. East Lansing, MI. 2015/2016.

|                | 10-<br>1 | 10-<br>9 | 10-<br>20 | 4-<br>20 | 4-<br>27 | 5-<br>3 | 5-<br>11 | 5-<br>17 | 5-<br>24 | 6-<br>1 | 6-<br>6 | 6-<br>15 | 6-<br>28 | 7-<br>6 | 7-<br>12 | 7-<br>19 | 7-<br>26 | 8-<br>1 | 8-<br>11 |
|----------------|----------|----------|-----------|----------|----------|---------|----------|----------|----------|---------|---------|----------|----------|---------|----------|----------|----------|---------|----------|
| F <sup>y</sup> | NS       | NS       | NS        | NS       | NS       | *       | ***      | ***      | ***      | NS      | ***     | ***      | ***      | ***     | ***      | ***      | --       | ***     | ***      |
| B              | --       | --       | --        | NS       | NS       | NS      | NS       | NS       | NS       | NS      | NS      | NS       | NS       | NS      | NS       | NS       | --       | NS      | NS       |
| F*B            | --       | --       | --        | NS       | NS       | NS      | NS       | NS       | NS       | NS      | NS      | *        | *        | NS      | NS       | NS       | --       | NS      | NS       |
| W              | --       | --       | --        | --       | --       | --      | --       | NS       | NS       | NS      | *       | *        | NS       | NS      | NS       | NS       | --       | NS      | NS       |
| F*W            | --       | --       | --        | --       | --       | --      | --       | NS       | NS       | NS      | NS      | NS       | NS       | NS      | NS       | NS       | --       | NS      | NS       |
| B*W            | --       | --       | --        | --       | --       | --      | --       | NS       | NS       | NS      | NS      | NS       | NS       | NS      | NS       | NS       | --       | NS      | NS       |
| F*B*W          | --       | --       | --        | --       | --       | --      | --       | NS       | NS       | NS      | NS      | NS       | NS       | NS      | NS       | NS       | --       | NS      | NS       |

\*, \*\*, \*\*\* represent significance at the P<0.05, 0.01, and 0.0001 level of probability.

-- represent dates on which data was not collected because the selected treatments had not yet been initiated.

<sup>z</sup> Chlorophyll content measured by a FieldScout® CM 1000 Chlorophyll Meter.

<sup>y</sup> F, B, and W represent nitrogen fertilizer application rate, brushing, and wetting agent treatments, respectively.



Table 32. Analysis of Variance results for the effects of nitrogen fertilizer application rate, brushing, and wetting agent use on turfgrass color quality<sup>z</sup>. East Lansing, MI. 2015/2016.

|                | 10-<br>1 | 10-<br>9 | 10-<br>20 | 4-<br>20 | 4-<br>27 | 5-<br>3 | 5-<br>11 | 5-<br>17 | 5-<br>24 | 6-<br>1 | 6-<br>6 | 6-<br>15 | 6-<br>28 | 7-<br>6 | 7-<br>12 | 7-<br>19 | 7-<br>26 | 8-<br>1 | 8-<br>11 |
|----------------|----------|----------|-----------|----------|----------|---------|----------|----------|----------|---------|---------|----------|----------|---------|----------|----------|----------|---------|----------|
| F <sup>y</sup> | NS       | NS       | NS        | NS       | *        | *       | ***      | ***      | ***      | NS      | ***     | ***      | ***      | ***     | ***      | ***      | NS       | ***     | **       |
| B              | --       | --       | --        | NS       | NS       | NS      | NS       | NS       | NS       | NS      | NS      | NS       | NS       | NS      | NS       | NS       | NS       | NS      | NS       |
| F*B            | --       | --       | --        | NS       | NS       | NS      | NS       | NS       | NS       | NS      | NS      | NS       | NS       | NS      | NS       | NS       | NS       | NS      | NS       |
| W              | --       | --       | --        | --       | --       | --      | --       | *        | NS       | NS      | NS      | *        | NS       | NS      | NS       | NS       | NS       | NS      | NS       |
| F*W            | --       | --       | --        | --       | --       | --      | --       | NS       | NS       | NS      | NS      | NS       | NS       | NS      | NS       | NS       | NS       | NS      | NS       |
| B*W            | --       | --       | --        | --       | --       | --      | --       | NS       | NS       | NS      | NS      | NS       | NS       | NS      | NS       | NS       | NS       | NS      | NS       |
| F*B*W          | --       | --       | --        | --       | --       | --      | --       | NS       | NS       | NS      | NS      | NS       | NS       | NS      | NS       | NS       | NS       | NS      | NS       |

\*, \*\*, \*\*\* represent significance at the P<0.05, 0.01, and 0.0001 level of probability.

-- represent dates on which data was not collected because the selected treatments had not yet been initiated.

<sup>z</sup> Turfgrass color quality is based on results from a FieldScout® TCM 500 NDVI Turf Color Meter.

<sup>y</sup> F, B, and W represent nitrogen fertilizer application rate, brushing, and wetting agent treatments, respectively.

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