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# Winter Desiccation Prevention and Recovery in Turfgrass

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# WINTER DESICCATION PREVENTION AND RECOVERY IN TURFGRASS

by

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WINTER DESICCATION PREVENTION AND RECOVERY IN TURFGRASS

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Desiccating winters in the Northern Great Plains can lead to widespread turf death. This loss of turf results in poor aesthetics and can be financially burdensome. Financial implications include the cost of re-establishing turf and the loss of potential revenue from poor playing conditions in the spring which can both be devastating for financial success. The winter of 2013-2014 was particularly devastating, leaving many golf course superintendents re-evaluating their desiccation prevention management plans. There are many prevention practices available to turf managers that vary greatly in affordability, effectiveness, and labor. These prevention practices aim to prevent excessive water loss and keep plant tissue hydrated. Specifically, the survival of the turf crown, or growing point of the plant, is critical for rapid recovery in the spring. Desiccation prevention treatments include physical protection products such as protective covers and sand topdressing. Additionally, several spray-applied products have potential to reduce desiccation, including anti-transpirants, horticultural spray oils, turf colorants, and wetting agents. Current recommendations for winter desiccation prevention are based on anecdotal observations, rather than scientific explanation. The first objective of this study is to quantify the effectiveness of desiccation prevention treatments in terms of crown moisture content and spring recovery. A second objective is to evaluate commonly practiced re-establishment techniques which maximize turf re-establishment following winter desiccation to guide future recommendations.

The results from this study indicate that protective covers and sand topdressing can sustain crown moisture content in desiccating environments, and these treatments often lead to more rapid spring recovery. Crown moisture contents observed in March ranged from as high 0.764 g $H_2O$ $g^{-1}$ fresh weight from an impermeable cover treatment to as low as 0.251 g $H_2O$ $g^{-1}$ fresh weight from the control treatment. Protective covers and sand topdressing consistently sustained crown moisture and recovered in the spring. Results from the winterkill recovery study showed that many of the practices which accelerate recovery may not be as effective as previously believed. Protective covers and aggressive fertilization did not maximize re-establishment in this study; these results may attributed to low solar radiation accumulation typical to the early spring and pre-existing nutrients sources  providing adequate fertility.

I dedicate this thesis to my friends and family

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## LITERATURE REVIEW

Turf covers the greatest amount of land of irrigated crops in the United States, with an estimated 40.5 million acres, or four times the land used for maize production (Milesi et al., 2005). Currently, there are approximately 16,000 golf courses in the United States with an average of 150 acres per course and approximately 67% of those acres being maintained (Golf Course Superintendents Association of America, 2007). The Golf Course Superintendents Association of America's environmental profile (2007) also estimates that the average golf course has 30 acres of fairways, three acres of greens, and three acres of tees. Combined, this estimate yields a total of 576,324 acres of highly maintained golf course turf. While less than 1.5% of all turf in the United States is considered highly maintained, this turf has high economic value and is an important system to study.

Creeping bentgrass (*Agrostis stolonifera* L.) is a cool-season turf species commonly used for golf course fairways, greens, and tees throughout much of the United States (140,740 acres total; GCSAA, 2007). Creeping bentgrass spreads by stolons and has excellent tolerance to traffic, low mowing height, and cold temperatures (Beard, 1973). The "North Central" United States contains over 61,000 acres of creeping bentgrass (GCSAA, 2007). While most creeping bentgrass typically survives the winters of this region, various environmental conditions can lead to turf death during the winter.

The survival of a creeping bentgrass crown, or growing point of the plant, is essential for winter survival as its viability will ensure rapid recovery in the spring. The

crown of a bentgrass plant typically remains at or below the soil level. However, it not uncommon for the crown to migrate above the soil surface which makes it more susceptible to stress. Applying a thin layer of sand into the turf canopy is frequently done to ensure bentgrass crowns remain buried. Creeping bentgrass typically goes dormant during the winter months in the North Central United States. Dormant turf is unable to recover from damage until growth resumes in the spring, making winter management difficult.

Physical and physiological changes occur in order for turfgrasses to survive the winter. Low light intensity and cool but non-freezing air temperatures, typical to the fall, interact together to induce plant responses that improve freezing tolerance (Vasil'yev, 1961) in a process called cold-acclimation. During the cold-acclimation process, the moisture content of bentgrass crowns decreases from near 77% to 60%, leading inversely to an increase in cold hardiness (Beard, 1973). Following cold-acclimation in the field, creeping bentgrass can survive temperatures as low as -35°C (Lethal Temperature$_{50}$; $LT_{50}$) (Gusta et al., 1980) compared to non-acclimated creeping bentgrass having an $LT_{50}$ of -8°C (Hoffman et al., 2014). Exposure of dormant turf to warm periods during winter can initiate pre-mature deacclimation, resulting in a decreased cold hardiness (Hoffman et al., 2014).

There are four primary causes of turf death during the winter; winter-borne fungi, ice encasement, direct low temperature kill, and desiccation. Winter-bourne fungi commonly infect turf in the north central United States during winter months. The two most commonly-studied diseases are pink snow mold (*Microdochium nivale*) which is typically non-lethal, and gray snow mold (*Typhula incarnate* Fr.), which can be lethal.

Gray snow mold development favors canopy temperatures near 35°F, above freezing soil temperatures, and prolonged snow cover (Smiley et al., 2005). Snow mold fungi can be treated preventatively in the late fall, however conditions favoring the development favoring this disease are not common in the Great Plains region.

Ice encasement is the process of turf death resulting from prolonged periods of ice covering the turf. Two primary theories exist explaining turf death from ice encasement; toxic gas accumulation (Sprague and Graber, 1943), or more commonly believed, anoxic conditions (Castonguay et al., 2009). Creeping bentgrass ice encasement injury is rare as it can survive long periods of encasement (>120) compared to annual bluegrass (*Poa annua* L.) which is negatively affected between 45-60 days (Tompkins et al., 2004) days. Ice encasement can typically be prevented by improving surface drainage and disrupting the ice layer upon formation (Beard, 1973).

Direct low temperature kill is commonly caused by large temperature fluctuations; inducing either intercellular or intracellular ice formation and subsequent turf death. Intercellular ice formation is a slower process inducing cellular dehydration in which water is redistributed from within the cell to extracellular spaces as a result of a vapor pressure deficit (Jones, 2014). Intracellular ice formation typically punctures or disrupts cell membranes after rapid ice formation within the plant cell. Intracellular ice formation is less common as it requires an extreme temperature drops for the water to not redistribute to the extracellular spaces (Jones, 2014).

Winter desiccation is the permanent and lethal dehydration of plant material. Regardless of the time of year, desiccation and drought stress cause similar effects to plants at the cellular level. Under mild drought stress many plant physiological processes

are altered. An increase in abscisic acid concentration signals plant-osmoregulation to compensate for the overall decreased water potential (Jones, 2014). Osmoregulation, or regulation of guard cells to reduce water loss, serves as a means for retaining water when photosynthetic efficiency is low. As photosynthetic efficiency continues to decrease under water stress, carbon-assimilation is decreased at the expense of reactive oxygen species production (Jones, 2014). Reactive oxygen species degrade plant membrane and organelles and cause cell and leaf death. This process of leaf death may be beneficial to plant survival as it can be an effective means for reducing evapotranspiration during periods of drought stress (Stier and Fei, 2008). As leaf tissue dies, survival of the plant is shifted to the crown (Jones, 2014). It is also plausible that dead leaf tissue serves as a means of reducing photo-oxidative stress in the crowns by reducing direct light exposure (Jones, 2014). While plants have mechanisms to avoid short term-drought, many species lack an ability to recover from extreme drought (Jones, 2014).

As water is lost during prolonged periods of drought stress, cell membranes and organelles become permanently dehydrated and lose function (Stier and Fei, 2008). The first observation under extreme water loss is a drastic reduction in cell volume (Farrant, 2000). A process called plasmolysis then occurs in which the plasma membrane contracts from the cell wall, eventually causing the collapsing and folding of cell walls (Vicrè et al., 2004), preventing recovery. Under this permanent dehydration, all cellular function is lost and cell death occurs (Stier and Fei, 2008).

Winter desiccation can severally impact winter sewn crops, as well as perennial systems such as turf and evergreen trees throughout much of the North Central United States. Winter desiccation is primarily caused by a lack of plant available water. When

transpiration exceeds plant water uptake for an extended period of time, it can induce a lethal dehydration. This lethal drying of plant material can be caused by inaccessible frozen soil-water or a lack of soil-water. Desiccation pressure is the greatest on elevated sites that typically do not sustain snow cover (Beard, 1973). Desiccation pressure also increases when high wind speeds and above freezing air temperatures occur while soils remain frozen. The Intergovernmental Panel on Climate Change (2001) projects climate warming in the foreseeable future which may have implications for increasing frequency and severity of winter desiccation occurrences.

Many environmental factors during the winter interact with the plant and impact turf survival. While winter desiccation is primarily believed to be solely influenced by water-limiting stress, it is likely more complex. Crown hydration, for example, is another form of winterkill which requires two factors to cause turf death; excessive or premature uptake of water, and freezing temperatures following water uptake. Tompkins et al., (2000) developed a predictive model to estimate cold hardiness based on observed soil temperatures and crown moisture content. This model evaluated crown moisture contents between 59-77% in the early-spring when supra-optimal crown moisture contents are a concern from snow melts. Crown moisture contents low enough to represent water-limiting stress were not evaluated.

The most complete understanding between crown moisture and cold tolerance has been studied over a wide range of crown moisture contents in winter wheat (*Triticum aestivum*) and barley (*Hordeum vulgare* L.; Metcalf et al., 1970). An ideal range of crown moisture contents exists for each species that maximized cold tolerance. For example, the barley variety 'Dicktoo' had a maximum cold hardiness of -18°C ($LT_{50}$) when the crown

moisture content was at 64%. As crown moisture content decreased to 55%, cold hardiness was reduced to -13°C. Additionally as crown moisture content was increased to 75%, cold hardiness was again reduced with an $LT_{50}$ of -11°C. While the relationship between crown moisture content and cold hardiness has not been evaluated for turf under sub-optimal crown moistures, the temperatures to which the turf is exposed likely influence survival.

*Prevention of Winter Desiccation*

Throughout much of Nebraska and South Dakota, the winter of 2013-2014 was one of the most problematic winters in terms of winter injury in recent history (20+ years). Below average precipitation, large temperature swings, and high wind speeds led to the turf death of even the most winter hardy turf species, rough bluegrass (*Poa trivialis* L.), and creeping bentgrass (Kreuser, 2014b; Beard, 1973). The golf course industry in the North Central region of the United States has significant value, estimated to be greater than $1.6 billion (Haydu et al., 2002), and the winter of 2013-2014 impacted many throughout this region. The widespread turf death throughout this region left many superintendents re-evaluating their management strategies and their winter desiccation plans.

The prevention of winter desiccation is based on protection of growing points and preserving soil and crown moisture. In winter wheat, recommendations focus on planting depth as a primary practice to preserve crown moisture. In evergreen tree production, the use of burlap bags to prevent wind exposure as well as winter watering have been suggested anecdotally as methods for preventing desiccation. Recommendations are similar in turf settings: sand topdressing to bury crowns, wind fences to accumulate

snow/decrease wind exposure, winter-watering, and the use of protective covers/tarps. Watering during warm periods of the winter can be an effective way to re-hydrate crowns but it is difficult to quantify and determine timing.

Physical protection of the turf is commonly practiced to sustain crown moisture. Physical protection practices include sand topdressing, protective covers, and other practices can serve as a buffer from the environment. Sand topdressing involves applying a thin layer of sand on top of the turf canopy. This practice helps to dilute the accumulation of turf thatch (Lewis et al., 2010), which is comprised of dead plant material. The sand buries the crowns for increased protection, and smooths the playing surface during the growing season. Sand topdressing can also be applied at a heavier rate once the turf has stopped growing in the fall to provide physical protection to the crowns and reduce plant tissue exposure to environmental stress during the winter. Elevated crowns within the turf canopy are most likely to experience winter desiccation. Sand topdressing has been shown to improve turf green-up in the early spring and increase clipping yield compared to turf not top-dressed with sand (Bigelow et al., 2005). For many turf managers, sand topdressing is an affordable practice and relatively easy to employ as it is a practice routinely used. However, some managers choose not to sand topdress as it can cause mower reels to become dull and ineffective.

Some golf courses utilize protective covers as a means of sustaining crown moisture throughout the winter. Roberts (1986) determined that covers on putting greens increased soil and leaf moisture content, and ultimately accelerated regrowth in the spring. Protective covers vary greatly in color, thickness, and permeability. The use of protective covers is usually limited to putting greens because they are labor-intensive to

employ, and generally not cost effective for large areas. Covers also vary greatly in their ability to transmit photosynthetically-active radiation (PAR) which greatly affects turf even while dormant. Covers which exclude a large portion of PAR can result in necrotic and etiolated turf and should be removed earlier in the spring to prevent this stress (Watson and Wickland, 1962). Covers can also reduce direct light exposure that could have implications on limiting photooxidative stresses and may be a factor in earlier spring green up. Impermeable covers typically transmit less PAR than permeable covers, however, this is highly dependent on color and thickness. While impermeable covers are more effective at sustaining soil moisture in extreme desiccating environments they do inhibit free exchange of $CO_2$ and $O_2$ which can be detrimental.

Several sprayable products have been marketed as tools for reducing desiccation. These products offer a convenient means of application at a relatively affordable cost compared to protective covers. Examples of these products include anti-transpirants, horticultural spray oil with green pigment, turf colorants containing green pigments, and soil wetting agents. Anti-transpirants tested in cotton (*Gossypium hirsutum* L.) resulted in reduced water loss during chilling stress by up to 40% in some instances (Christiansen and Ashworth, 1978). Horticultural spray oils can reduce transpiration rates and block stomata in turf leaves (Kreuser, 2014a). Recently, there has been an increased use of turf colorants and pigment-containing products applied in the late fall as a means of improving visual appearance of dormant turf, increasing soil temperatures, and possibly reducing the production of harmful reactive oxygen species. Wetting agents are often used to improve soil moisture uniformity, and some have been shown to persist throughout winter months (Cavanaugh et al., 2015). Sustaining uniform soil moisture in

desiccating environments could reduce desiccation pressure. While some evidence suggests many of these products have potential in reducing desiccation, no results have been published to validate their role in desiccation prevention of turfgrass.

*Recovery from Winterkill*

Recovering from winterkill is a difficult task as winterkill occurs in sporadic and unpredictable ways. Often, the degree of winterkill is not fully understood until turf growth resumes in the spring. Timely re-establishment of turf is critical in golf course settings to minimize facility downtime, time with poor playing conditions, and prevent encroachment from undesirable turf and weed species. Replacing winterkilled turf with sod may be a viable re-establishment method for some managers, but is highly dependent on sod availability, soil compatibility, work force, and cost.

Compared to sodding winterkilled turf, seeding is typically viewed as the more cost effective means of recovery. Additionally, seed is generally more available, and the process can be less invasive. Early spring seeding is often difficult as soil temperatures fluctuate and often remain cool and sub-optimal for germination. Optimal germination temperatures for creeping bentgrass, the most commonly used turf species for putting greens, ranges from 55-86°F (Beard, 1973). Temperatures in the North Central United States commonly fluctuate in and out of this range during the spring.

Aggressive fertilization practices are often recommended when establishing sand-based putting greens which includes frequent applications at above typical maintenance rates. The United States Golf Association (2002) recommends that a total of 2-4 lbs N, 1-2 lbs P, and 1-2 lbs K be applied into many split applications at the turf manager’s discretion during establishment. However, no recommendations have been developed for

re-establishing turf following winterkill, as nutrients from organic matter mineralization and prior fertilizations may provide a significant portion of plant nutrients.

Soil amendments and covers have been used for over 50 years to increase the success of germination and establishment. These practices can increase soil temperatures and reduce water requirements during seedling establishment. Straw, wood shavings, and sawdust were the first amendments used to improve establishment, which conserved soil water and improved establishment in home lawns (Barkley et al., 1965). The use of plastic-based covers, or tarps have replaced these amendments as germination aids as they are easier to employ, do not disrupt the playing surface, and provide a more uniform effect. These plastic-based covers vary greatly in thickness, permeability, color, and ability to transmit light. In 2010, Patton et al. evaluated 12 different covers to determine their effect on germination and establishment of warm-season turf species. The authors found that polyethylene sheeting (4 mil) consistently provided the greatest amount of soil warming but only improved establishment for three of the five species tested. The ability of these establishment aids to improve winterkill recovery remains poorly understood.

*Thesis Objectives*

Winter desiccation injury in the North Central United States can lead to widespread turf death and can be economically devastating. There is currently a lack of desiccation research to guide science-based recommendations, leaving superintendents and turf managers unsure of the decisions they are making regarding their high-value turf. The research conducted in this thesis will answer many unknowns in the scientific literature and provide the scientific-backing many golf course superintendents are seeking. Specifically, this will be attained through two primary goals: i) determine the

impact desiccation prevention treatments have on sustaining crown moisture content in desiccating environments and elucidate the impact they have on spring survival and ii) evaluate commonly practiced re-establishment methods to determine which methods maximize re-establishment in the early spring.

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# CHAPTER TWO: SAND TOPDRESSING AND PROTECTIVE COVERS SUSTAIN BENTGRASS CROWN MOISTURE DURING WINTER DESICCATION

## ABSTRACT

Winter desiccation injury can severely impact golf courses in the northern Great Plains; however, little is known about its prevention. While anecdotal evidence suggests numerous prevention options are available to practitioners, the impacts these prevention practices have on turfgrass survival remain unclear. The objective of this two-year study was to evaluate the effectiveness of winter desiccation prevention treatments on turfgrass survival across multiple locations in Nebraska. To assess treatment effectiveness, crown moisture content was measured monthly from December to March at Mead, NE and in March at Axtell, NE. Visual turf quality was rated in the field at Mead, and in the greenhouse from Axtell to monitor survival and rate of spring green-up. Late fall treatments included heavy sand topdressing, a permeable or impermeable cover, anti-transpirant, turf colorant, horticultural spray oil, and wetting agent. The results from this study indicate that both protective cover treatments and sand topdressing were the best performing treatments at both Mead and Axtell. The crown moisture content under these treatments was as high as 0.764 g $H_2O$ $g^{-1}$ FW at Mead, compared to the lethally low 0.251 g $H_2O$ $g^{-1}$ FW observed in the control at Axtell. Treatments that sustained crown moisture content levels throughout the winter resulted in a higher turf quality in the spring and recovered faster at both sites. Sprayable products performed less consistently and rarely provided any added benefit. These results suggest that heavy sand topdressing

and protective covers applied late in the fall can reduce desiccation in high-risk areas by sustaining crown moisture contents and improving turf survival, reducing the likelihood of turf death from winter desiccation.

# INTRODUCTION

Infrequent snow cover, high wind speeds, and abrupt temperature fluctuations during winter make growing perennial plant systems as well as winter-sown cereal crops difficult in the northern Great Plains. These challenging conditions often lead to lethal dehydration, or desiccation. Factors such as elevated sites, which are exposed to high wind speeds and prone to runoff, and temperatures above freezing can increase desiccation potential (Beard, 1973). Winter desiccation occurs when water that is lost from the soil cannot be replaced because of a lack of, or an unavailable form of water. Desiccation is the most common form of turfgrass death in northern central United States (Watson and Wickland, 1962). Desiccation injury is problematic to golf courses because it reduces the playability of turf, is visually displeasing, and requires re-establishment during cool, unpredictable, spring weather. The plant's crown, or growing point, is the primary focus of research on turf stress physiology as it is often the last plant tissue to die during extreme stress while its continued viability ensures the plant can recover.

Preventative products for desiccation are readily available to turf managers but vary in effectiveness, cost, and ease-of-use. Traditional preventative practices include the use of protective turf covers and heavy rates of topdressing in the fall. Protective covers are commonly used on golf course putting greens and typically increase soil and leaf moisture content in the spring, promoting spring regrowth (Roberts, 1986). While protective covers are effective, they are labor-intensive to employ, costly, and often not feasible for large-scale application. Covers that allow for transmission of photosynthetically-active radiation are preferable because light-excluding covers result in

necrotic and etiolated turf in the spring (Watson and Wickland, 1962). In the instance that light-excluding covers are used, they must be removed from turf early in spring (Roberts, 1986). Permeable covers allow for the exchange of $CO_2$ and $O_2$ and allow precipitation to reach the soil. However, in prolonged drought, an impermeable cover that inhibits water loss would be preferred.

Sand topdressing is another traditional practice often used to reduce desiccation. It is believed that sand provides a physical barrier from the environment by burying the crowns and thatch. Often, elevated crowns within the turf canopy are most likely to experience winter desiccation (Kreuser, 2014). Additionally, sand topdressing can improve spring green-up and increase clipping yield (Bigelow et al., 2005).

Several sprayable products have been marketed as tools for reducing desiccation. These products offer a convenient means of application at a relatively affordable cost compared to protective covers. These products include a horticultural spray oil with green pigment, turf colorants, wetting agent, and anti-transpirants. However, no results have been published to validate their role in desiccation prevention.

Though turf managers commonly use desiccation-prevention treatments, the effectiveness and physiological impact of these practices has not been described in the literature. Thus, the research objectives of this study were to evaluate commonly-used desiccation prevention treatments and quantify the impact they have on turfgrass crowns. By monitoring the crown moisture content, survival, and spring recovery, this research will help establish a scientific background for management decisions.

# MATERIALS AND METHODS

*Site Characteristics*

A two-year field study was conducted at the John Seaton Anderson Turfgrass Research Facility in Mead, NE during the winters of 2014-2015 and 2015-2016. The plot space consisted of a mature stand of 'L-93' creeping bentgrass (*Agrostis stolonifera*) managed as a golf course fairway, with the root zone constructed following the recommendations of the United States Golf Association (2004). Prior to initiation of the study, plots were irrigated three times weekly to replace 80% of potential evapotranspiration. A preventative snow mold application was made with Banner Maxx$^{TM}$ (Syngenta, Greensboro, NC) at the maximum labeled rate for snow mold on bentgrass on 11 November, 2014 and 7 November, 2015. Treatments were applied on 21 November, 2014 and 24 November, 2015 while the turf was still green, but no longer actively growing. To increase the likelihood of winter desiccation injury, precipitation was withheld throughout the winter by covering the plots with a 3.5 mil clear impermeable plastic cover prior to precipitation events. Snow and covers were removed within 24 hours after the precipitation events to minimize any potential soil warming effects. The study concluded on 22 April, 2015 and 15 April, 2016.

A similar field study was conducted on a native sand soil (Valentine-Els loamy fine sands; Web Soil Survey, 2016), mature creeping bentgrass 'T-1' fairway with moderate layer of thatch at Awarii Dunes Golf Course in Axtell, NE. The site has no tree cover, and is surrounded by rolling hills covered with native prairie grass. The site was blocked to account for northern winds on a north-facing slope. The study was initiated on

20 November, 2014 and 11 November, 2015 while the turf was still green, but no longer actively growing. Unlike the study conducted at Mead, NE, natural precipitation was not withheld from these plots. The study was concluded on 26 March, 2015 and 29 March, 2016. There were also replications at the Sand Hill Golf Club in Mullen, NE, and Monument Shadows Golf in Gering, NE but results were excluded from this study because desiccation injury was not present.

*Experimental Treatments*

In the Mead study, both traditional desiccation prevention treatments and spray-applied treatments were evaluated (Table 2.1). Traditional desiccation treatments commonly used by turf managers included a GreenJacket™ white woven permeable cover (GreenJacket™, Genoa City, WI), a clear 3.5 mil clear impermeable cover, and sand topdressing at a thickness of 0.5 cm which buried all of the turf except the tips of the leaves. Spray-applied treatments included a combination of the horticultural spray oil, Civitas™, mixed with the turf colorant Harmonizer™ (Petro-Canada, Mississauga, ON, Canada), Tournament Ready™ wetting agent (KALO, Overland Park, KS), Foursome™ turf colorant (Quali-Pro, Pasadena, TX), and Transfilm™ anti-transpirant (PBI-Gordon, Kansas City, MO). These treatments were applied using a $CO_2$-powered backpack sprayer with three Teejet AL 8005 nozzles at 234 kPa, calibrated to deliver a spray volume of 828 L $ha^{-1}$.

A similar study was conducted in Axtell, NE except the clear 3.5 mil impermeable cover was substituted with a GreenJacket™ white impermeable cover. Treatments were applied in a similar fashion as Mead (Table 2.1).

*Measurements*

*Mead, NE*

Crown moisture content (CMC) was measured monthly by taking a representative 13 $cm^2$ plug from each plot and isolating 25 crowns per plug. At higher levels of CMC (>0.60 g $H_2O$ $g^{-1}$ FW), crowns can be identified by their bulb like structure but as CMC declines (<0.60 g $H_2O$ $g^{-1}$ FW), the bulb-like structure is less distinguishable. A definition was applied for all samples where a crown was defined as the portion of the plant where the stem and roots joined (approximately 5 mm long). Crowns were immediately weighed to determine their fresh weight (FW). Crowns were then oven-dried at 70°C for 24 hr and re-weighed. Crown moisture content was calculated as the difference between the fresh and dry weight divided by the fresh weight of the plant material for each plot and reported in g $H_2O$ $g^{-1}$ FW.

To assess spring green-up and turf survival, visual turf quality was monitored weekly on a 1-9 scale, where 1 represented dead or brown turf, 9 represented dense, green, uniform turf, and 6 was minimally acceptable for a golf course fairway. Measurements were taken by the same observer for all ratings. These measurements were initiated when three of four replications of a single treatment had broken dormancy and exhibited signs of spring regrowth. This occurred on 14 March, 2015 and 11 March, 2016. Ratings were taken weekly from the time of spring regrowth to the conclusion of the study which was 29 April, 2015 and 22 April, 2016.

*Axtell, NE*

Crown moisture content was measured once in the spring on 13 March, 2015 and on 13 March, 2016 with the same methods as were used at Mead. To evaluate spring

recovery, representative plugs of turf were collected at the time of CMC sampling and potted in a greenhouse that was maintained at 29°C day/25°C night temperature with supplemental light from 0600-0830 and 1600-2200. Potted plugs were saturated with water every other day, and visual turf quality was rated every other day for a total of 6 ratings to evaluate recuperative capacity.

*Statistical Analysis*

Individual plots (1.5 m x 2.7 m) were arranged in a randomized complete block design with four replications per treatment. Data were subjected to Analysis of Variance (ANOVA) and treatment means were separated using Fisher's Protected Least Significant Difference and the Student's t-test at the 0.05 probability level. Repeated measures analysis was conducted for visual turf quality to account for plot variability.

## RESULTS

*Weather*

In year one of the study, both Mead and Axtell had considerable turf death due to winter desiccation. Snow removal occurred four times at Mead, and generally turf death was less severe overall compared to Axtell which never sustained any snow cover. A weather station nearby (16 km to the NW) to Axtell, NE reported only 1.6 cm of snow fall during year one of the study. In 2015-2016 at Mead, desiccation pressure was slightly less than in the previous year, with snow removal occurring seven times. This resulted in minimal turf death. Axtell received more snow in year two (8.3 cm) than in year one, with several snow events melting and providing a source of moisture to keep turf crowns

hydrated. However, due to the location of the study being on a north facing slope, snow accumulation on the study was always minimal.

*Mead, NE*

*Crown Moisture Content*

For the purpose of determining which treatments were the most effective in sustaining crown moisture, CMC was monitored monthly. From ANOVA (Table 2.2), a three-way interaction was not detected (p=0.790) so the two years of data were pooled by treatment and rating date (Fig. 2.1). While all treatments were similar in both December and January, separation among treatments was first observed during February (Fig. 2.1). Crown moisture contents observed in December and January ranged from 0.57 to 0.64 g $H_2O$ $g^{-1}$ fresh weight for all treatments which is consistent with Beard's (1966) findings for cold-acclimated creeping bentgrass (0.54 to 0.66 g $H_2O$ $g^{-1}$ FW). In February, crown moisture contents still fell within Beard's reported range but still remained with the defined ranges. The largest differences were observed during the month of March with crown moisture contents ranging from 0.455 – 0.764 $H_20$ $g^{-1}$ FW.

The highest CMC in March occurred in plots with the 3.5 mil clear impermeable cover (0.764 g $H_20$ $g^{-1}$ FW), followed by the white permeable cover (0.700 g $H_20$ $g^{-1}$ FW) and sand topdressing (0.660 g $H_20$ $g^{-1}$ FW) compared to 0.508 g $H_20$ $g^{-1}$ FW for the non-treated control. The 3.5 mil clear impermeable cover and the white permeable cover both exhibited significant increases in CMC when compared to the January rating date. The sand topdressing showed a slight increase in CMC but was non-significant when compared to other rating dates.

Several treatments were affected by winter desiccation and exhibited large reductions in CMC over the course of the study. The largest reduction in CMC was with the wetting agent (16%), followed by the non-treated control (10%), horticultural spray oil (8%), and anti-transpirant (7%).

*Turfgrass Quality*

To determine the effect of CMC on spring recovery, turf quality ratings were taken weekly in the spring to quantify the impact they have on turf survival following the winter. Covers were removed on 17 March, 2015 and 11 March, 2016, when spring growth was first observed and forecasted high temperatures were near 18°C for several days. A three-way interaction was detected ($p<0.001$; Table 2.2) so the data for the two years are reported separately (Fig. 2.2). Repeated measures analysis accounted for 38% of variability in the statistical model.

In 2014-2015, at the time of cover removal, the clear impermeable cover was the best performing treatment with a quality of 8.25 as plots were dark green in color with no damage from winter (Fig. 2.2). By comparison, the non-treated control had a visual quality of 1.4, a bleached brown color, and turf leaves were crushed when trafficked by foot. The white impermeable cover had the second highest quality with a quality of 3.9 as spring regrowth was just initiating. All other treatments had turf quality ratings below 3. The worst-performing treatment at the beginning of spring recovery was the sand topdressing with a quality of 1.25, but this was attributed to the plots still being nearly completely covered with the sand.

Turf quality generally increased as spring progressed except the plots which contained the 3.5 mil clear impermeable cover. These plots had an initial quality of 8.25,

but quality dropped to 4.1 on 26 March and 2.8 on 2 April as a result of rapid freezing event which caused damage as a result of premature crown hydration. The turf with the 3.5 mil clear impermeable cover recovered over the next 4 weeks to a quality of 7.3. On the last rating date, the highest performing statistical group contained both protective covers with a quality of 8.5 for the white permeable cover and 7.3 for the 3.5 mil clear impermeable cover. Sand topdressing was the only other treatment in which the turf was able to recover above the minimally acceptable turf quality of 6 with a rating of 6.5. The non-treated control had a quality of 5 on the last rating date. All spray-applied treatments were similar to the control on the last rating date.

Similar to year one, in 2015-2016, the turf under the 3.5 mil clear impermeable was the best performing treatment when covers were removed with a quality of 8.9 compared to 1.7 in the non-treated control. The white permeable cover had the next highest quality of 7.9. All other treatments had a turf quality below 4. The worst-performing treatment was the non-treated control with a quality of 1.7. Turf quality generally rose throughout the spring and the highest turf quality ratings were typically observed on the last rating date. All treatments were statistically similar on the final rating date. Unlike 2014-2015, there was not a rapid freezing event during the recovery period.

*Axtell, NE*

*Crown Moisture Content*

From ANOVA (Table 2.2), a two-way interaction was detected ($p<0.001$) so the data were reported separately (Fig. 2.3). In 2014-2015, both protective covers and sand topdressing were similar to each other, and had greater CMC levels than the untreated

control (Fig. 2.3). The highest CMC that was observed was the white impermeable cover with 0.606 g $H_20$ $g^{-1}$ FW, followed by sand topdressing (0.567 g $H_20$ $g^{-1}$ FW), and the white permeable cover (0.516 g $H_20$ $g^{-1}$ FW). All other treatments had a substantially lower CMC and were statistically similar to the non-treated control with CMCs ranging from 0.218 – 0.364 g $H_20$ $g^{-1}$ FW.

In 2015-2016, the white impermeable cover had the highest CMC with 0.755 g $H_20$ $g^{-1}$ FW compared to a CMC of 0.547 g $H_20$ $g^{-1}$ FW for the non-treated control (Fig. 2.3). The white impermeable cover also had a statistically greater CMC than all other treatments except the sand topdressing with a CMC of 0.641 g $H_20$ $g^{-1}$ FW. However, sand topdressing was statistically similar to all other treatments. The lowest CMC observed was with the horticultural spray oil with a CMC of 0.529 g $H_20$ $g^{-1}$ FW.

*Turfgrass Quality*

To determine the effect of the treatments on spring recovery, turf quality ratings were taken every two days in the greenhouse to quantify the impact they have on turf survival following the winter. Covers were removed on 13 March, 2015 and 2016, when spring growth was first observed and forecasted high temperatures were near 18°C for several days. A two-way interaction was detected ($p<0.001$; Table 2.2.) so the data for the two years are reported separately (Fig. 2.4). Repeated measures analysis accounted for 28% of variability in the statistical model.

In year one of this study, similar trends were observed at the Axtell site compared to the Mead site in 2014-2015 in that the best performing treatments were the covers and the sand topdressing (Fig. 2.4). Turf qualities were generally poor at the time of cover removal on 13 March as no treatment had a turf quality greater than five. The white

impermeable cover, which had the highest CMC of 0.606 g $H_2O$ $g^{-1}$ FW, had the best turf quality but was still deemed unacceptable. Sand topdressing and the white permeable cover had turf qualities less than three, but had similar CMC's (0.597 and 0.520 g $H_2O$ $g^{-1}$ FW, respectively) to the white impermeable cover. Both protective cover treatments, as well as sand topdressing, all recovered above the minimally acceptable turf quality of six by the final rating date. The white impermeable cover was consistently the best-performing treatment as it had a greater mean turf quality than all other treatments for all rating dates with a turf quality of nine on 26 March. The white permeable cover as well as the sand topdressing initially had poor turf qualities but recovered quickly with turf qualities of 7.5 for the white impermeable cover and 6.8 for the sand topdressing. Collectively, the spray-applied treatments as well as the untreated control never recovered above a turf quality of three and exhibited significant turf death. The spray applied treatments and the non-treated control had low CMCs with no treatment having a greater CMC than 0.364 g $H_2O$ $g^{-1}$ FW (wetting agent).

In year two of the study, on 13 March, visual turf qualities varied greatly but had small differences in CMC. The white permeable cover was again the best performing treatment with a quality of 7.5 and a CMC of 0.757 g $H_2O$ $g^{-1}$ FW, compared the non-treated control which had a quality of 2.0 and a CMC of 0.574 g $H_2O$ $g^{-1}$ FW. The anti-transpirant was the only other treatment which had an acceptable turf quality on the initial rating date with a quality of 6.0 and a CMC of 0.581 g $H_2O$ $g^{-1}$ FW. By the end of the rating period, all treatments recovered to levels above minimally acceptable, with the control having the lowest turf quality among all treatments with a mean of 8.4.

# DISCUSSION

At both locations, sustained CMC was observed for both protective covers, as well as sand topdressing that allowed the turf to recover in the spring (Figs. 2.2, 2.4). While sand topdressing typically did not recover as fast as the protective covers, and this was likely due to the turf having to grow through the topdressing sand. These results are consistent with previously published work indicating that turf survival can be improved with sand topdressing (Bigelow et al., 2005).

While the 3.5 mil clear impermeable cover used at Mead and the GreenJacket$^{TM}$ white impermeable cover used at Axtell were different between the sites, the effects were similar in that both had the highest CMC content (Figs. 2.1, 2.3). These data suggest that the color of the cover did not affect its ability to sustain crown moisture. However, in year one of the study at Mead, the 3.5 mil clear impermeable cover sustained a crown moisture content which resulted in a significant reduction in quality when exposed to freezing temperatures a week after removal. This did not happen in year two at Mead or either year at Axtell, which makes it difficult to determine whether CMC or light transmission reduced the turf's ability to tolerate freezing temperatures. The white permeable cover which was able to sustain similar CMCs, allowed for rapid spring recovery, and did not predispose the turf to freezing injury.

In contrast to lethally low levels of crown moisture, an excessively high level of crown moisture content was harmful in this study as it increased the risk of freezing damage. While little is known about the direct relationship between crown moisture content and relative cold hardiness in turfgrass, Beard (1966) suggests that they are

related. Crown moisture content increases are typically observed during early spring when deacclimation starts to occur, or when the turf starts to break dormancy. Premature deacclimation is a concern because it reduces the turf's ability to tolerate freezing temperatures typically experienced in the spring. Factors such as air temperature and duration, soil temperature, and crown moisture content accelerate deacclimation and reduce the turf's ability to tolerate cold temperatures (Hoffman et al. 2014 ; Tomkins et al., 2000). A predictive model has been formulated to estimate Lethal Temperature$_{50}$ ($LT_{50}$) based on soil temperature and crown moisture content (Tompkins et al., 2000). However, this research did not evaluate turf under severely water-stressed conditions.

To date, the most detailed understanding between crown moisture content and freezing tolerance (Metcalf et al., 1970) was described in various varieties of wheat (*Triticum aestivum* L.) and barley (*Hordeum vulgare* L.). In this study, cold hardiness was maximized at a particular crown moisture content for each species and increases or decreases from that crown moisture content resulted in a loss of cold hardiness. Because there is a lack of understanding between the relationship between crown moisture content and freezing tolerance in creeping bentgrass, it remains difficult to determine at what crown moisture content turf death can be expected in the field because of the temperature variability during the winter.

While the impermeable and permeable covers were expected to sustain CMC (Roberts, 1986), sand topdressing was surprising in its effectiveness in sustaining CMC, and adequately recovered in the spring. These results suggests that sand topdressing would be the ideal treatment selection for reducing winter desiccation. However, protective turf covers may still be used on higher value turf such as putting greens. The

difficulty of installing covers on a large scale limits their practical use, whereas sand topdressing is easier to perform, costs less, and has the added benefit of burying thatch.

Several of the spray applied treatments performed less consistently in providing benefit. The horticultural spray oil mixed with the green turf colorant and the turf colorant alone similarly followed the CMC trends of the non-treated control. While the speed to recovery results were never statistically greater than the non-treated control, the green color these products provide could play a role in improving golfer relations masking the bleached-brown leaves. In this study the wetting agent provided no added benefit. While wetting agents may not directly be related to reducing winter desiccation pressure, entering the winter months with uniform soil moisture and adequately hydrated plants should not be understated. The anti-transpirant was not effective in reducing winter desiccation pressure in the harsher year one of the study. In year two of the study, the turf treated with the anti-transpirant had an acceptable turf quality of six and was second in highest turf quality following only the permeable cover. This suggests that anti-transpirants may be beneficial in improving turf survival and speed of green-up during moderate desiccation pressure. Collectively, the spray applied treatments have a limited role in preventing desiccation likely because they provide minimal physical protection from desiccating winds.

Winter desiccation in the northern Great Plains region makes growing high maintenance turfgrass difficult in the winter. The results of this study provide a physiological basis to improve understanding of the impacts of commonly used desiccation treatments. In historically problematic areas experiencing winter desiccation,

using protective covers or applying heavy sand topdressing rates can sustain crown moisture contents and improve turf survival.

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Table 2.1. Desiccation prevention treatments applied to fairway turf at Mead and/or Axtell NE in fall of 2014 and fall of 2015.

| Treatment | Mead, NE | Axtell, NE | Thickness or Rate |
|---|---|---|---|
| Untreated/uncovered control | X | X | - |
| Traditional desiccation prevention | | | |
| 3.5 mil clear plastic cover | X | | 3.5 mil |
| GreenJacket™ white permeable cover† | X | X | 763 g $m^{-1}$ |
| GreenJacket™ white impermeable cover† | | X | 6 mil |
| Sand topdressing | X | X | 0.5 cm |
| Spray-based treatments | | | |
| Civitas™ + Harmonizer, horticultural spray oil | X | X | 51 + 3.2 L $ha^{-1}$ |
| Foursome™, turf colorant | X | X | 4.4 L $ha^{-1}$ |
| Tournament Ready™, wetting agent | X | X | 25.5 L $ha^{-1}$ |
| Transfilm™, anti-transpirant | X | X | 25.5 L $ha^{-1}$ |

† Variable thicknesses are not offered by manufacturer

Table 2.2. ANOVA table including p-values of statistical model effects for both Mead and Axtell.

| | Mead | | Axtell | |
|---|---|---|---|---|
| Effect | Crown Moisture Content | Visual Turf Quality | Crown Moisture Content | Visual Turf Quality |
| Treatment (T) | *** | *** | *** | *** |
| Date (D) | * | *** | - | *** |
| Year (Y) | *** | *** | *** | *** |
| T x D | *** | *** | - | ns |
| T x Y | ns | ns | *** | *** |
| D x Y | *** | *** | - | *** |
| T x D x Y | ns | *** | - | *** |

* Significant at the 0.05 probability level
** Significant at the 0.01 probability level
*** Significant at the 0.001 probability level
ns, non-significant
-, not applicable

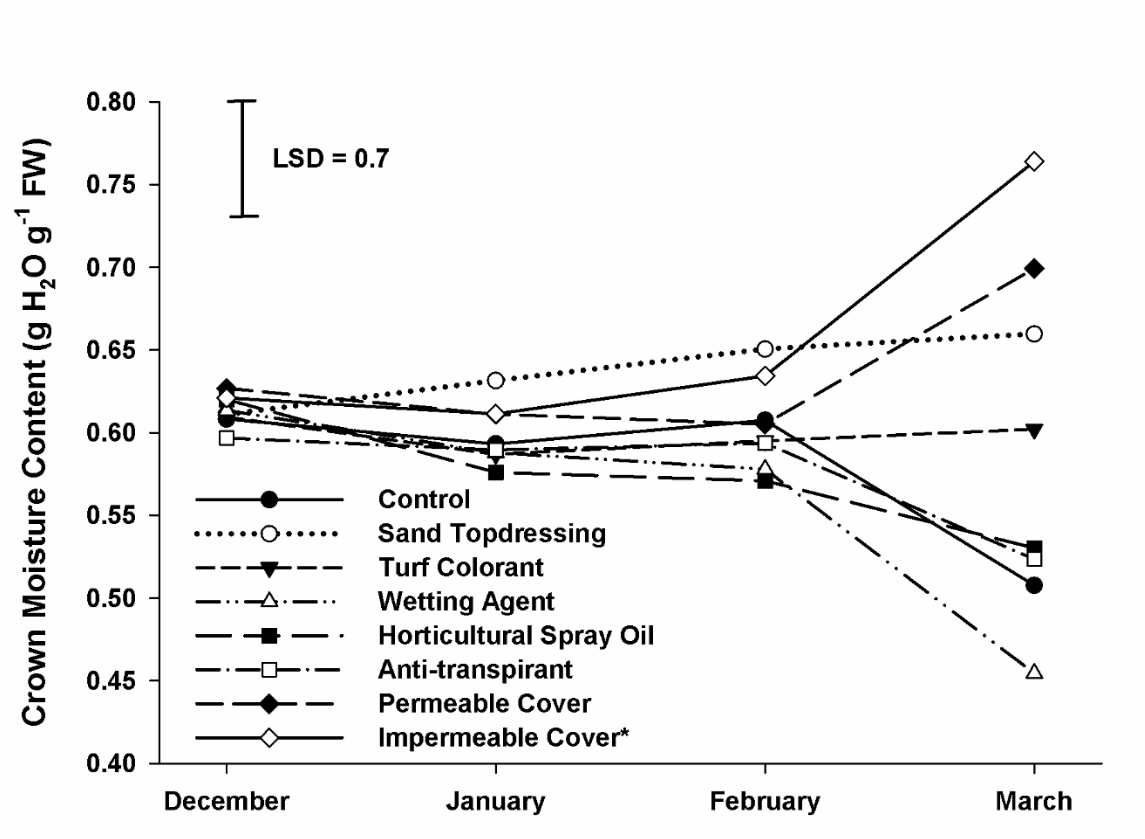


Figure 2.1. Crown moisture content as affected by spray-applied and cover treatments in Mead, NE. Data were pooled across 2014-15 and 2015-16 studies ($p<0.001$). *3.5 mil clear impermeable cover

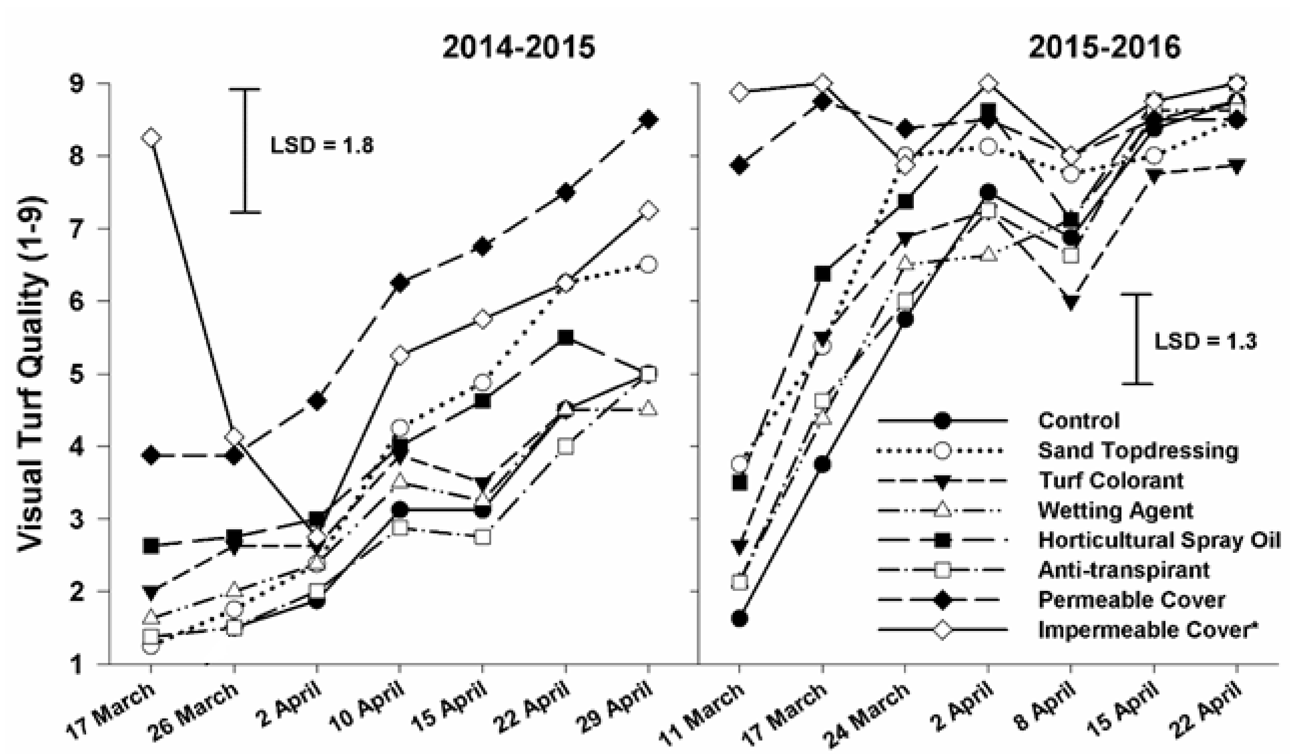


Figure 2.2. Visual turf quality as affected by spray-applied and cover treatments after removal of covers in Mead, NE (p<0.001). *3.5 mil clear impermeable cover

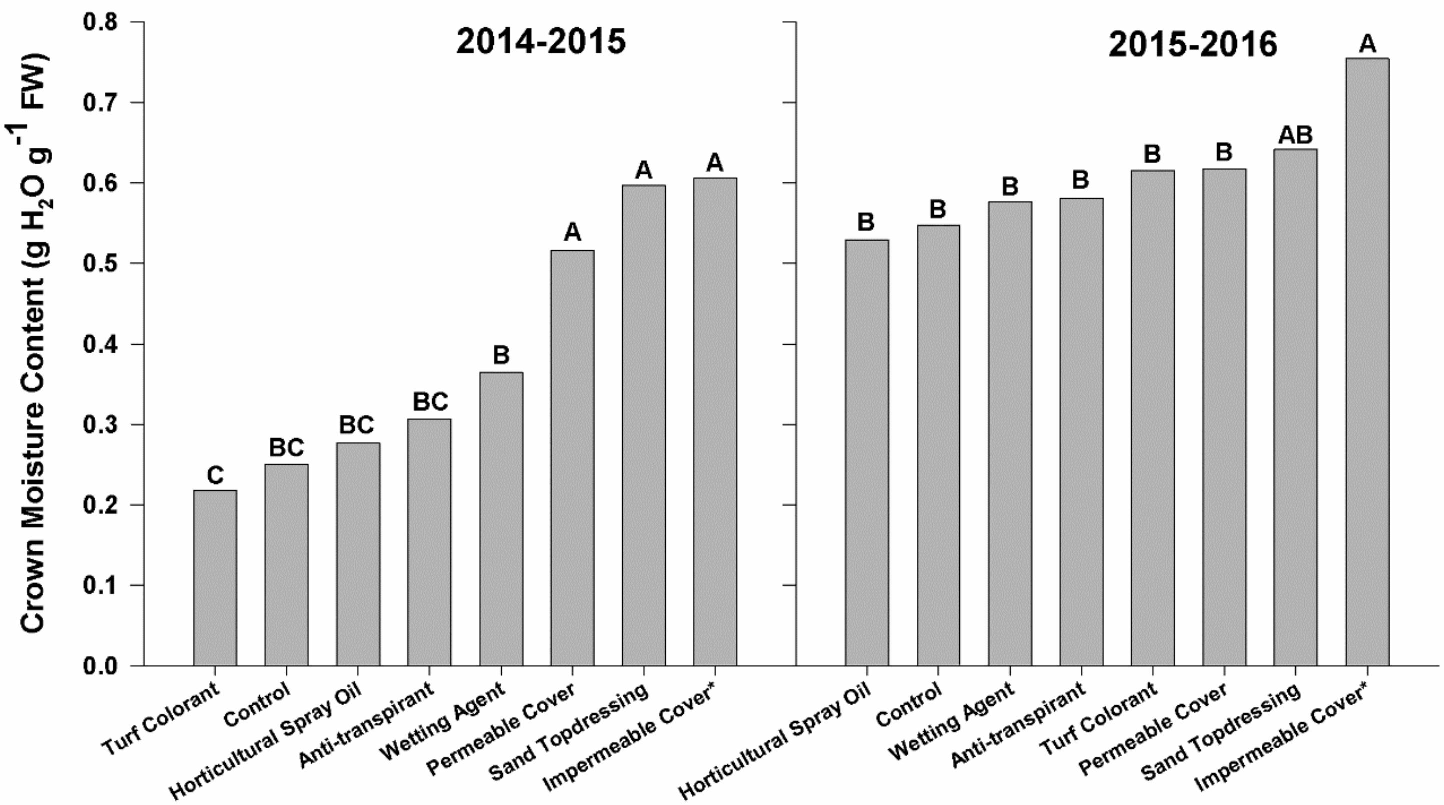


Figure 2.3. Crown moisture content as affected by spray-applied and cover treatments in Axtell, NE 13 March, 2015 and 2016 (p<0.001). Different letters above bars within a year denote a statistical difference at the 0.05 probability level. *White impermeable cover

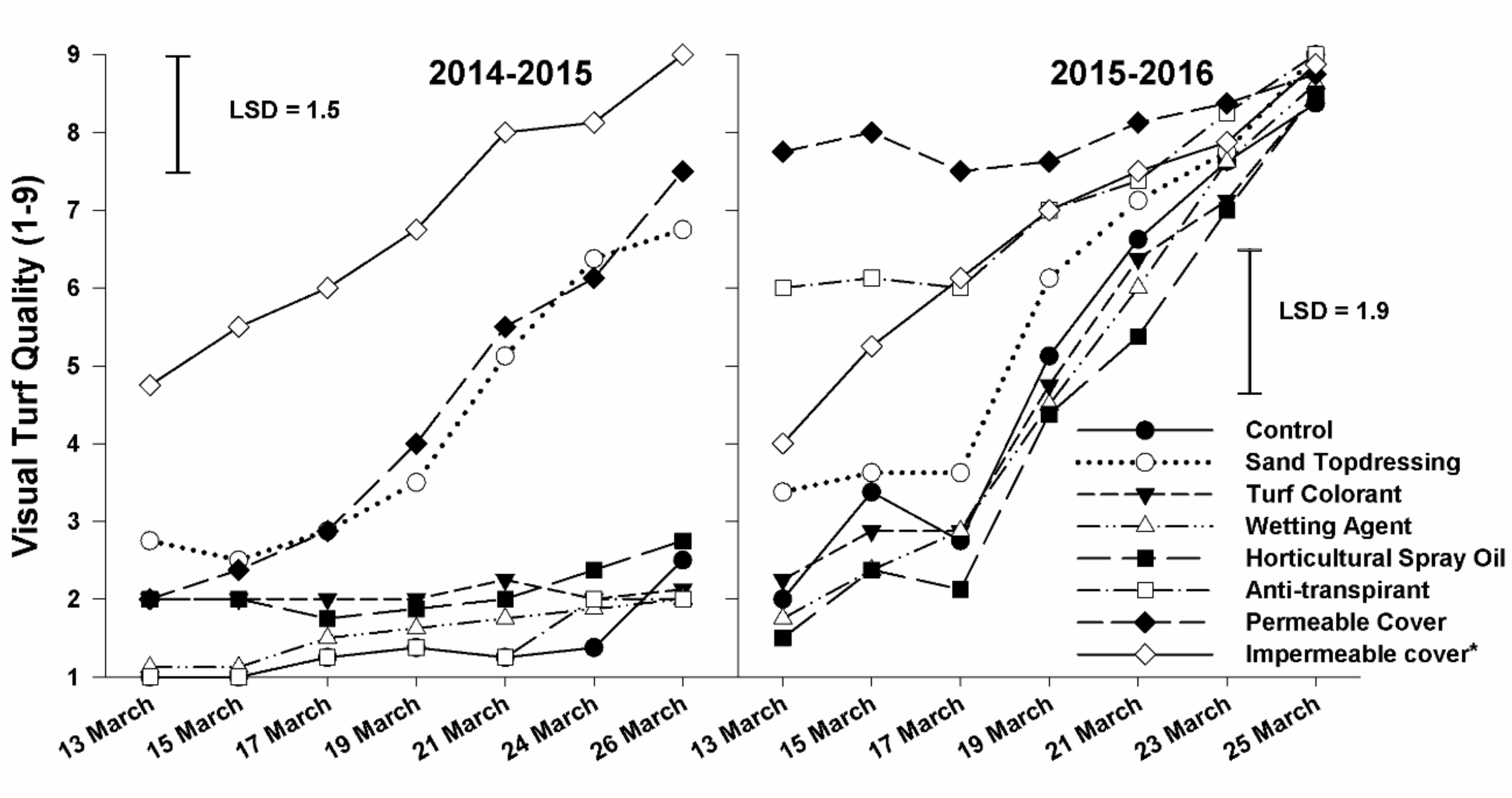


Figure 2.4. Visual turf quality as affected by spray-applied and cover treatments in Axtell, NE after removal of covers. Samples were evaluated in the greenhouse for recuperative capacity and rate of green-up (p<0.001). *White impermeable cover

# CHAPTER THREE: MAXIMIZING RE-ESTABLISHMENT OF CREEPING BENTGRASS (*Agrostis stolonifera*) PUTTING GREENS IN THE EARLY SPRING

## ABSTRACT

The winter of 2013-2014 left many golf course superintendents in the Great Plains region looking for re-establishment solutions following widespread winterkill. The objectives of this research were to evaluate the effects of protective covers/pigments and nitrogen fertilization on rate of re-establishment of a creeping bentgrass (*Agrostis stolonifera* L.) putting green in the early spring. A three-year study was conducted on a 'L-93' creeping bentgrass putting green. In year one of the study, natural winterkill resulted in greater than 90% turf death; winterkill was simulated the following two years with non-selective herbicides. The study was conducted as a strip-split plot design with three replicates. Whole plot treatments consisted of cover/pigment treatments which included a non-covered control, a white woven permeable cover, 3.5 mil clear plastic sheeting which was modified by manually punching holes on approximately 1 inch centers, black landscape fabric, and a green turf colorant applied at a rate of 4 fl. oz./1000 $ft^2$. Whole plots were stripped with 'L-93' creeping bentgrass or not seeded to measure natural bentgrass recovery and regrowth. Sub-plots were then split with three rates of N; 0.0, 0.1 or 0.5 lbs N/1000 $ft^2$ from urea (46-0-0), applied at seeding and following emergence every other week. Upon emergence, covers were removed and percent turfgrass cover was evaluated weekly for ten weeks using digital image analysis. Data were analyzed using a repeated measures approach. In this study, the use of covers or turf

colorants did not result in improved turfgrass cover at any point in the study, and black landscape fabric actually reduced turfgrass coverage for most of the rating dates. Various fertilizer rates had no effect on improving turf coverage for any rating date. These results suggest that many practices thought to be beneficial for rapid turf re-establishment may not be as effective as previously believed.

# INTRODUCTION

The winter of 2013-2014 provided significant challenges for growing turfgrass throughout North America. Dry desiccating weather was observed in the Great Plains (Kreuser, 2014), cold temperatures in the South, and ice around the Great Lakes lead to widespread winterkill (Smith, 2014). Many golf course superintendents were forced to re-establish turfgrass on greens, tees, and fairways during cool, unpredictable, spring weather. Rapid re-establishment is critical to prevent facility downtime, prevent encroachment of undesirable turf and weed species, and minimize time with poor playing conditions. Despite the broad impact of winterkill on the turfgrass industry, there is limited research on methods to promote rapid re-establishment during early the early spring.

Creeping bentgrass (*Agrostis stolonifera* L.) is a cool-season turfgrass that is widely regarded for its excellent cold tolerance and tolerance to low mowing heights (Beard, 1973), which makes it an excellent choice for putting greens. Annual bluegrass (*Poa annua* L.) also tolerates low mowing heights and often encroaches into creeping bentgrass putting greens as they age (Beard, 1973. Seeding in the spring is often difficult due to sub-optimal soil temperatures. Optimal germination temperatures for creeping bentgrass, the most commonly used turf species for putting greens, ranges from 55-86°F (Beard, 1973). Timing seeding remains a challenging task as soil temperatures often remain sub-optimal for much of early spring.

A common establishment practice, the use of protective covers, has been proven in many instances to improve turfgrass establishment. As early as 1965, it was found that

establishing turf with straw, wood shavings, or sawdust over the seedbed improved both turf establishment and helped conserve soil water moisture compared to establishing turf without these amendments (Barkley et al., 1965). While these methods improved establishment for home lawns, there are limitations with each treatment which make them impractical for putting greens; weed seed presence in the straw, sawdust eroding under heavy rainfall, and wood cellulose fibers would create an undesirable putting surface.

More recently, the use of plastic-based covers, or tarps, have been used to induce similar effects of mulches without the limitations. To the turf manager, covers also add flexibility during the establishment process, affording them the opportunity to add or remove them at their discretion. Protective covers vary in thickness, permeability, color, and ability to transmit light. Patton et al. (2010) evaluated 12 different covers/mulches on turfgrass establishment, on five different warm-season species. The authors found that polyethylene (4 mil) consistently provided the greatest soil warming when compared to the other treatments. The polyethylene cover did reduce turfgrass coverage for two of the five species tested. The authors cited excessive heat accumulation likely caused seedling death, thus complicating cover selection.

Another establishment practice for sand-based putting greens, is frequent and aggressive fertilization. The United States Golf Association (2002,) currently recommends 2-4 lbs N, 1-2 lbs P, and 1-2 lbs K split into frequent applications during the establishment phase of a putting green to maximize establishment and minimize leaching risk. However, when re-establishing the turf following winterkill, fertilizer requirements of seedlings are less defined as nutrients could be potentially supplied from organic matter mineralization or prior fertilization.

While the use of covers and fertilization are commonly used practices by many turf managers when re-establishing turf in the spring, it remains unclear which practices should be utilized to maximize re-establishment speed. The objective of this research was to evaluate the effects of protective covers and nitrogen fertilization on re-establishment speed of a creeping bentgrass putting green in the early spring by monitoring percent turfgrass cover following emergence.

## MATERIALS AND METHODS

### *Site Characteristics*

A three-year field study was conducted on a research putting green at the John Seaton Anderson Turfgrass Research Center near Mead, NE in the springs of 2014-2016. The plot space consisted of a mature 'L-93' creeping bentgrass putting green, with the root zone constructed following the recommendations of the United States Golf Association (2004). The studies were conducted adjacent to each other on the same putting green over the three years. Prior to the study in 2014, an irrigation water quality lab test reported 20 ppm $NO_3^-$ - N. The winter of 2013-2014 resulted in significant winterkill of the putting green (>90%), which was evaluated prior to spring green-up by harvesting 20, 4 $in^2$ plugs and evaluating regrowth in a greenhouse (data not shown). The greenhouse was maintained at 87/80 °F day/night temperature with supplemental lighting from 0600-0830 and 1600-2200 local time. To simulate winterkill in 2015 and 2016, the putting green was sprayed with non-selective herbicides both in the fall and early in the spring (prior to initiation of the study). In 2015, the plot space was sprayed with

Glufosinate-ammonium (Finale, Bayer; Research Park Triangle, NC, USA) at 4.5 oz/1000 $ft^2$ on 25 November while the turf was still green. A second application was made a week prior to seeding on 10 March. In the third year, applications were made on 11 November in 2015 while the turf was still green and twice prior to seeding on 1 April and 11 April in 2016.

*Experimental Treatments*

The study was initiated on 4 April in 2014, 17 March in 2015, and 18 April in 2016. Timing for initiation was based on visual observation of early spring green up in surrounding turf not impacted by winterkill or sprayed with non-selective herbicides. The study was conducted as a strip-split plot design with three replicates. Whole plot treatments consisted of cover/pigment treatments which included a non-covered control, a white woven permeable cover (Green Jacket; Genoa City, WI, USA), 3.5 mil clear plastic sheeting (HDX; Atlanta, GA, USA) which was modified with manually punched small holes punched on approximately 1 inch centers, black landscape fabric (Vigoro; Atlanta, GA, USA), and a green turf colorant (Foursome; Quali-Pro, Pasadena, TX, USA) applied at a rate of 4 fl. oz./1000 $ft^2$. Whole plots were stripped with 'L-93' creeping bentgrass or not seeded to measure natural bentgrass recovery and regrowth. Seeding was conducted with a Turfco TriWave overseeder (Turfco; Blaine, MN, USA) to a depth of approximately 3/8 in. and calibrated to deliver seed at a rate of 1.5 lbs PLS/1000 $ft^2$ in one pass. Seeded plots were hand-brushed with coarse-bristled brooms and rolled with a pull-behind drum to improve seed-to-soil contact. Sub-plots were then split with three rates of N; 0.0, 0.1 or 0.5 lbs N/1000 $ft^2$ from urea (46-0-0), applied at seeding and bi-weekly following emergence. Individual plots measured 3 ft. x 5 ft. prior to

covers/pigments being applied, all plots received 1.0 lb $P_2O_5$/1000 ft$^2$ from monopotassium phosphate (0-52-34). All fertilizer was applied with a $CO_2$-powered backpack sprayer with three Teejet AL 8005 nozzles at 34 psi, calibrated to deliver a spray volume of 2 gal/1000 ft$^2$. Plots were irrigated to promote germination with approximately 0.2 inches of water split into four applications daily. In all three years, emergence from covers/pigments occurred simultaneously within a week. Once emergence occurred, irrigation frequency and quantity were subsequently decreased. Plots were monitored for emergence three times weekly. When emergence (seedlings > 1 cm tall) from all three replications of a cover/pigment treatment was observed, the cover treatments were removed and initial ratings were taken starting the following week. Mowing was conducted three times weekly, first occurring two weeks after emergence at 0.250". At five weeks after emergence, the height of cut was reduced to 0.180", and subsequently reduced to 0.160" at eight weeks after emergence for the remainder of the study.

*Data Collection and Analysis*

Percent turfgrass cover was measured weekly for ten weeks, starting the week following emergence. Percent turfgrass cover was quantified by using the digital image analysis software ImageJ (Rasband, 1997). Images were taken with an 8 megapixel camera from a height of 5' with the camera facing nearly horizontal (downward) to the turf. Images were then cropped to only contain plot space within the image. Percent turfgrass color was calculated as the number of green pixels present divided by the total number of pixels in an image. Due to the green hue of the turf treated with the colorant, images treated with the turf colorant required additional attention to focus the desired

range of green pixels to correctly identify only the turf and exclude turf colorant. Daily cumulative solar radiation and average daily air temperatures were recorded for the duration of the study from a nearby weather station (appx. 3 miles away) surrounded by turf. Turfgrass coverage data were analyzed using JMP (SAS, Cary, NC, USA) and subjected to analysis of variance (ANOVA). Treatment means were separated using Fisher's Protected Least Significant Difference (LSD) when appropriate. Data were analyzed using repeated measures by nesting treatment parameters within PLOT and attributing a random term to the statement to account for the correlation of means over time. Year effect was treated as a random term to isolate treatment effects.

## RESULTS

Repeated measures analysis accounted for a small portion of model variance (12%). The term Year accounted for 18% of the total model variance. Analysis of variance results resulted in multiple significant two-way interactions (Table 3.1). Days to emergence greatly varied from year to year as in 2014 emergence occurred in six days, 22 days in 2015, and 11 days in 2016 (Fig. 3.1). In 2014, the average air temperature was 50°F compared to 48°F in 2015 and 58°F in 2016. In 2014, daily average solar radiation was the greatest among all three years with an average of 204 W $m^{-2}$ $d^{-1}$. In 2015, daily average solar radiation was considerably lower at 164 W $m^{-2}$ $d^{-1}$. In 2016, daily average solar radiation was 188 W $m^{-2}$ $d^{-1}$. Interestingly, the greater the average daily cumulative solar radiation, the quicker emergence occurred.

There was a significant Cover/Pigment*Week interaction (Table 3.1; $p < 0.001$) in which various covers performed differently over time (Fig. 3.2). By the end of the 10 week evaluation period for all three years, turf which was covered with cover/pigment treatments recovered to 90% (± 2.5%) with one exception, the black landscape fabric at 81%, the lowest turf coverage. The turf treated with the white permeable cover, the 3.5 mil punctured plastic, as well as the turf colorant all performed similarly to the control not receiving the cover/pigment treatment throughout the entire study. The black landscape fabric negatively impacted turfgrass coverage as turf often declined in quality upon removal of the cover and appeared yellow and necrotic. It was visually observed that the turf treated with the black landscape fabric lead to significant seedling death in the weeks following cover removal. At one week after emergence, the turf treated with the black landscape fabric had a coverage of 18.8% but was reduced to 8.6% the following week. Throughout the majority of the study the turf treated with the black landscape fabric resulted in approximately a 10% turfgrass coverage reduction compared to the control for a given rating date.

There was also a Seed*Week interaction (Table 3.1; $p < 0.001$). Seeded treatments recovered to 92.4% turfgrass coverage whereas the non-seeded turf recovered to 84.7% ten weeks after emergence (Fig. 3.3). Both seeding treatments performed similarly for the first six weeks of the study. Starting the seventh week after emergence, seeding provided 6-11% added coverage when compared to not seeding for the remainder of the study.

The effect was fertilizer was non-significant in this study. Regardless of the rate, the application of fertilizer did not improve turfgrass coverage any rating date.

# DISCUSSION

Conventional wisdom would suggest that a winterkilled turf stand or a turf stand sprayed multiple times with non-selective herbicides would ensure complete turf death. However, that was not the instance in this study as the non-seeded controls recovered to 84.7% whereas the seeded turf established to a turf coverage 92.4% after 10 weeks after emergence. At seeding in years two and three, when the turf was treated with a non-selective herbicide, it appeared the herbicide was effective as turf surrounding the study not included in the plot space was starting spring green-up. While the methods for killing the pre-existing turf stand in this study varied from the first year to the following two, natural winterkill and non-selective herbicides provided similar levels of bentgrass death. It is clearly apparent that bentgrass is difficult to completely kill as the resiliency of stolons and crowns of bentgrass allowed for significant recovery. It wasn't until week seven in which seeding improved turf coverage over not seeding. While turf managers should not rely on natural regeneration of bentgrass following winterkill, some natural regeneration of bentgrass may be expected as turf breaks a deep dormancy. Simulating winterkill with herbicides did result in effective control of the turf crowns but did not effectively control regrowth from stolons. This method did create a uniform plot space for evaluation and similarly represented natural recovery from winterkill.

The results from this study indicate that many of the practices commonly used for turf establishment may not be as effective when re-establishing turf stands. The use of protective covers and a turf colorant during the germination period did not result in an increased turfgrass coverage compared to the control for any rating date. This finding was

contrary to reports Patton et al. (2010) found where they showed that covers often improved establishment. They showed that the use of covers can increase soil temperatures at the depth of seeding improving germination and accelerating growth. While soil temperatures were not measured in this study, emergence was not improved and accelerated re-establishment was not observed. Bogle (2009) found that using covers when nighttime temperatures were below 10°C can result is quicker re-establishment of putting greens in the early spring but results were often highly variable. A possible explanation for the lack of improved turf coverage with covers in our study might be attributed to the short day lengths and low sun angle in the early spring which potentially limits the impacts solar radiation might have on increasing soil temperatures (Fig. 3.1). Additionally, irrigation was applied frequently during germination to keep the soil profile moist. This increased supply of water likely moderated soil temperatures compared to air temperatures and reduced any soil heating from our cover/pigment treatments.

Seed blankets and covers also reduce the evaporation demand of the seed bed and maintain soil volumetric water content (Barkley et al., 1965; Patton et al., 2010). However, placement of bentgrass seed with the Turfco Triwave was ideal as the slicing action of the blade located the seed below the thatch level and offered protection. The previously existing turf provided protection to losing excess water by decreasing exposure to winds and direct sunlight. It is possible that the previously existing turf stand and protective covers provided similar effects on reducing water loss.

Turf managers seeking a proactive approach to maximizing re-establishment should consider turf colorants as a viable option. While colorants did not accelerate re-

establishment in this study, turf treated with a colorant is more visually appealing than winterkilled turf, allows for play to resume, is cost effective, and is easy to employ.

Fertilizer added no benefit in this study (Table 3.1). These results were contradictory to the results found by Bogle (2009) in which they found that higher fertilizer rates contributed to a more rapid re-establishment of a putting green. High $NO_3^-$-N concentrations in the irrigation water, coupled with frequent irrigation timings, may have been adequate for rapid turfgrass re-establishment. Nitrogen supplied from irrigation water was estimated for each year through back-calculating estimated water applied during the study. Cumulative water applied was estimated by assuming the plots received 0.2 inch daily of irrigation water from date of seeding through 14 days after emergence. Following the two week period after emergence to the end of the study, plots were estimated to be irrigated to replace 80% potential evapotranspiration (pET) calculated using the Penman-Montieth (Monteith, 1964) equation collected from the nearby weather station. Days in which rainfall exceeded pET were excluded in the back-calculations.

In year one of the study, it was estimated that 10.7 inches of irrigation water were applied during the duration of the study which supplied 1.1 lbs N/1000 $ft^2$. During year two of the study, emergence was delayed significantly when compared to year one and, thus, irrigated more. It was calculated that 12.94 inches of irrigation were applied during the course of the study which supplied 1.4 lbs N/1000 $ft^2$. Year three of the study had significantly less natural precipitation and was irrigated more than either year one or two receiving and estimated 39.9 inches of irrigation water which supplied 4.2 lbs N/1000 $ft^2$.

Another source of nutrients could have been supplied from plant decomposition, mineralization and from prior fertilizer applications. While it remains difficult to speculate on fertilizer impacts early in the study when irrigation was frequent, as irrigation frequency and quantity were significantly deceased, the absence of fertilizer impact later in the study indicates that plant material breakdown, and organic matter mineralization likely contributed to a significant portion of nutrients supplied to the non-fertilized controls. The authors still recommend fertilizing young turf stands despite these data suggesting that a significant portion of nutrients necessary for rapid recovery may be supplied from the soil and previously existing turf stand.

While this study provides scientific evidence to turf managers regarding re-establishment of putting greens, there were a few limitations. In this study, the authors were limited to only seeding in one direction with the Triwave with plot space concerns. Ideally, seeding in two directions to create a diamond pattern would have decreased the distance seedlings needed to spread to create a full recovery more rapidly (Fig. 3.4). Additionally, seeding at a rate of 1.5 lbs pure live seed in a single direction increases seedling competition and preventative fungicides needed to be used to prevent stand loss. Sand topdressing was only done once during week five. More frequent applications with light rates may help maximize establishment by providing a medium for seedlings to grow in between rows, while additionally burying the previously existing turf stand. Lastly, because the angle of view when taking images was not completely downward facing, observed coverage values are likely slight over-estimations. The preferred method would capture images directly downward facing to the plot to negate any observational-

angle influence. However, the angle was similar for all images allowing for proper relative comparisons.

## CONCLUSIONS

Re-establishing putting greens in the early spring remains difficult with cool, cloudy weather, and the traffic from play (Frank, 2015). The use of covers to improve seeding emergence and re-establishment is labor intensive, costly, and in this study provided no benefit. Overall, the ineffectiveness of covers in accelerating emergence or re-establishment coupled with increased labor requirements provides evidence that they may not beneficial. Rather weather following seeding may be more influential than cover treatments. Fertilizer impacts on re-establishment of turf remains largely unsolved as, nitrogen supplied from irrigation water was likely sufficient for maximum establishment, in this study. Future work should further examine nitrogen requirements on turf being re-established and the potential of mineralization in the early spring.

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Table 3.1. ANOVA table including degrees of freedom (df) and p-values of treatment effects.

| Effect | df | p-value |
|---|---|---|
| Cover/Pigment (C) | 4 | <0.001 |
| Fertilizer (F) | 2 | 0.833 |
| Seed (S) | 1 | <0.002 |
| Week (W) | 9 | <0.001 |
| C*F | 8 | 0.965 |
| C*S | 4 | 0.299 |
| C*W | 36 | <0.001 |
| F*S | 2 | 0.762 |
| F*W | 18 | 1.000 |
| S*W | 9 | <0.001 |
| C*F*S | 8 | 0.999 |
| C*S*W | 36 | 0.781 |
| C*F*W | 72 | 1.000 |
| F*S*W | 18 | 1.000 |
| C*F*S*W | 72 | 1.000 |

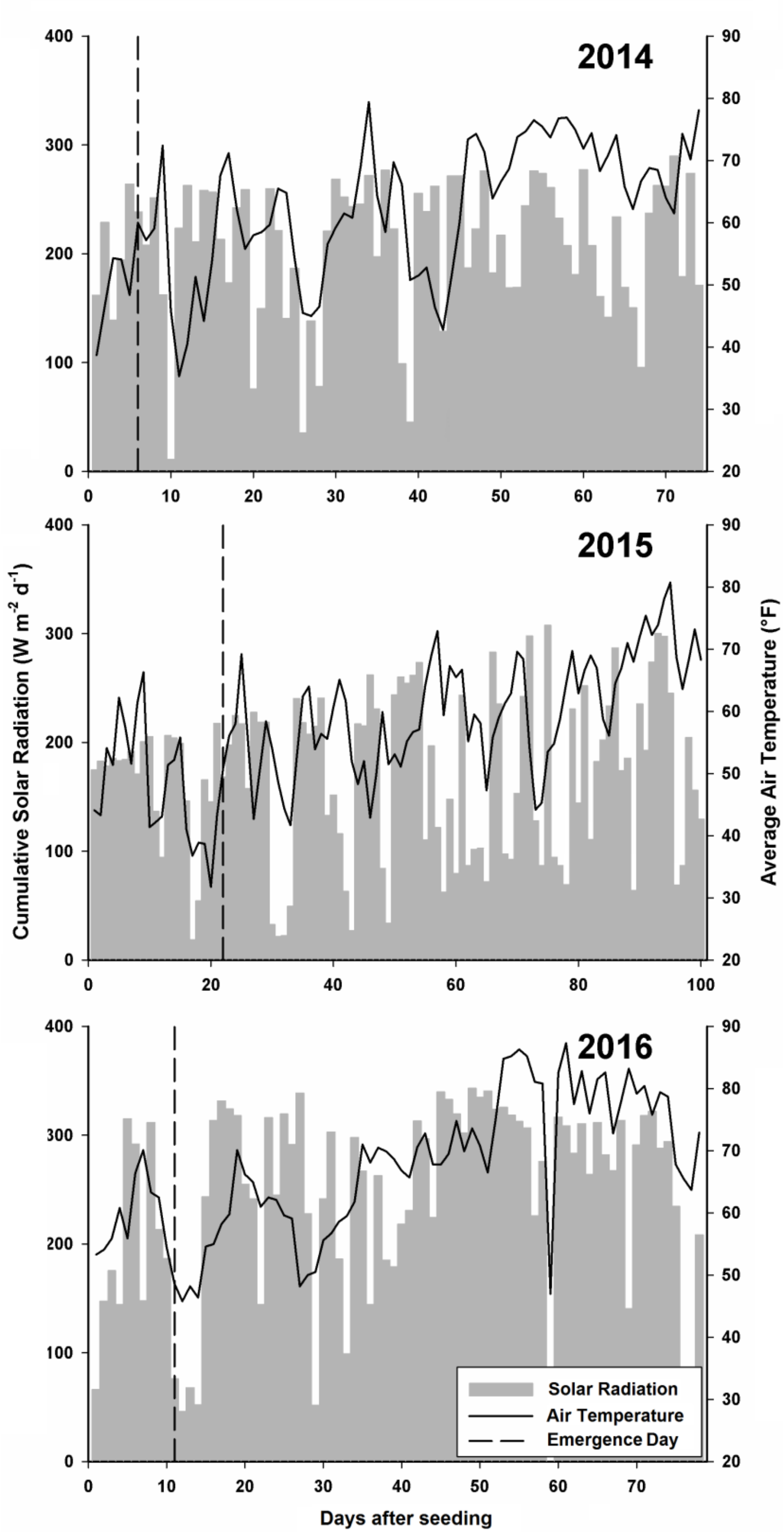


Figure 3.1. Cumulative daily solar radiation and average daily air temperature during year one of the study initiated on 4 April in 2014, 17 March in 2015, and 18 April in 2016.

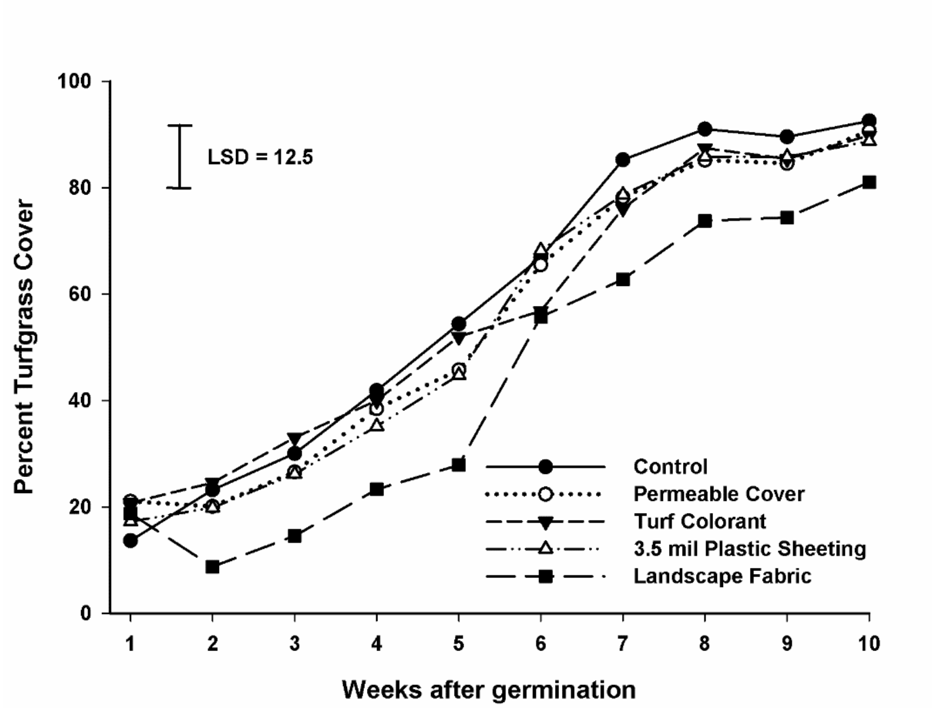


Figure 3.2. Cover/Pigment x weeks after emergence interaction pooling three years of percent turfgrass coverage data ($p<0.001$)

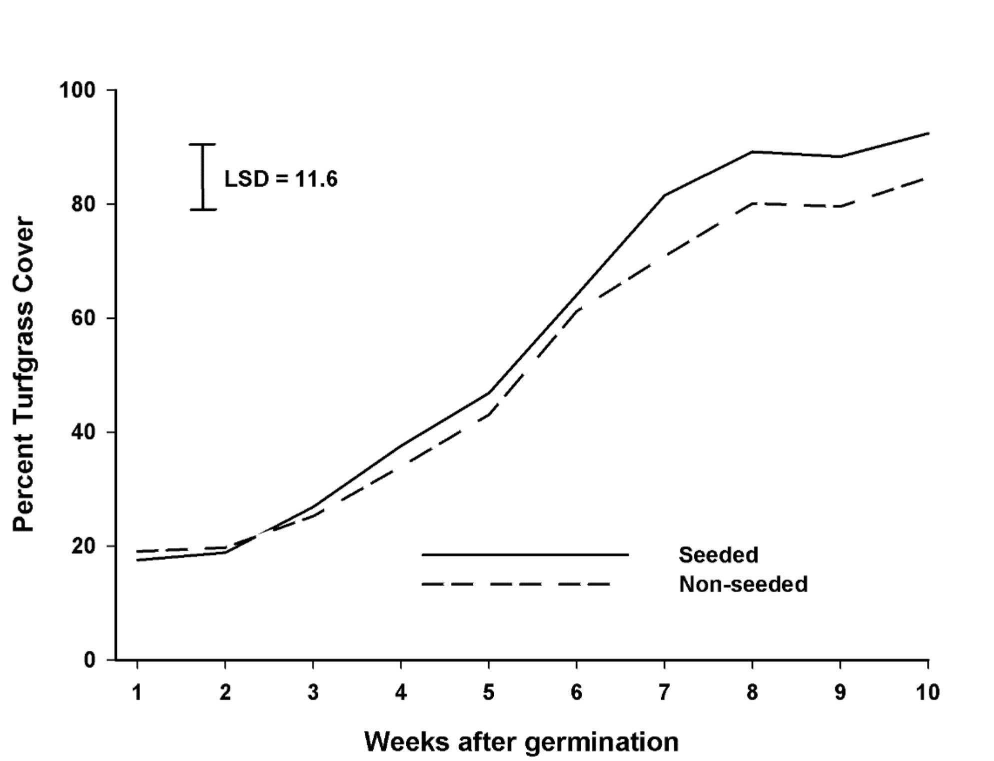


Figure 3.3. Seeding treatment x weeks after emergence interaction pooling three years of percent turfgrass coverage data (p<0.001).


Figure 3.4. A limitation to this study was that seeds were planted on 1.5" spacing. Seeding in multiple directions, or applying light frequent topdressings may accelerate re-establishment.

# CHAPTER FOUR: THESIS SUMMARY AND FUTURE RESEARCH

Winter desiccation injury observed in the northern Great Plains was particularly widespread during the winter of 2013-2014. The loss of turf left many golf course superintendents re-evaluating their winter desiccation prevention plans. However, a scientific backing to support agronomic decision-making regarding desiccation prevention is lacking in the literature. Since winter desiccation injury is likely in the future, it is important to understand how desiccation prevention treatments influence the winter survival of turfgrass by sustaining crown moisture content and improving spring recovery.

While no preventative practices can guarantee complete survival of turf, several of the tested treatments can reduce desiccation pressure and increase the likelihood of survival. The impermeable covers tested in this study consistently provided the greatest level of crown moisture content retention regardless of location. However, the recovery results varied greatly between years at Mead. In 2014-2015 the turf quality declined when freezing temperatures injured the turf following cover removal whereas this was not observed in 2015-2016 where temperatures remained above freezing following cover removal. Both the permeable cover and sand topdressing treatments also effectively sustained crown moisture contents throughout the winter at both sites and both years. The sand topdressing and permeable cover recovered similarly to the impermeable cover by the end of the study, but at a slower rate. Interestingly, the slight reduction in crown moisture content from the impermeable cover did not result in freezing injury following cover removal in 2014-2015. It is very likely that turf under the impermeable cover lost

significant cold hardiness from soil warming and heat accumulation, and pre-maturely deacclimated. The turf under the permeable cover and sand topdressing were less effected by heat accumulation and retained a greater level of cold hardiness.

While the use of both covers typically resulted in quicker recovery in the spring, their labor requirements to employ limit their uses while aggressive sand topdressing provides a labor effective means of sustaining crown moisture content in desiccating conditions for large scale applications. Sprayable products were ineffective at sustaining crown moisture content in harsher desiccating environments. When desiccation pressure was less severe at Axtell in 2015-2016, the use of an anti-transpirant did result in an acceptable turf quality while many other treatments did not.

Since complete survival is highly dependent on the winter environment, a plan must be prepared in the event of turf loss. This thesis evaluated several commonly practiced techniques superintendents implement to ensure rapid recovery such as germination blankets and fertilizer programs. Surprisingly, the results indicate that these practices are not as effective as previously believed. Germination blankets did not result in accelerated emergence or quicker re-establishment. It has been shown that germination blankets can increase soil temperatures and accelerate re-establishment in some instances, but due to the low sun-angle and short day lengths observed in the spring, solar-induced soil heating was likely limited. Aggressive fertilization is also believed to accelerate re-establishment but in this study, the practice did not result in the anticipated results. Pre-existing nutrient sources present in the soil may have supplied adequate fertility for young seedlings.

While the results from this thesis answer many questions regarding the effectiveness of desiccation prevention treatments and maximizing re-establishment of putting greens from superintendents and in the literature, many questions remain. Specifically, future studies investigating the relationship between crown moisture content and cold hardiness of creeping bentgrass (*Agrostis stolonifera* L.) would provide more clarity when selecting desiccation prevention treatments. Understanding the ideal crown moisture content range which maximizes cold hardiness allows superintendents to select desiccation prevention treatments which minimize pressure from both desiccation and freezing temperatures. Since practitioners are lacking the necessary tools to accurately measure crown moisture content, diagnostic tools should be developed to which will allow managers to visually estimate crown moisture content and viability of turf crowns. Additionally, annual bluegrass (*Poa annua* L.) is often considered to be more susceptible to desiccation and freezing temperatures. Identifying crown moisture contents in which desiccation injury occurs in annual bluegrass as well as how annual bluegrass' crown moisture impacts cold hardiness would improve our understanding of how and when turf dies. Similarly, superintendents could formulate winter management plans around ensuring ideal crown moisture contents in which desiccation pressure is reduced while cold hardiness is maximized.