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Using Covers and Wetting Agents to Prevent Winter Injury of Ultradwarf Bermudagrass

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Using Covers and Wetting Agents to Prevent Winter Injury of Ultradwarf Bermudagrass

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by

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ABSTRACT

As ultradwarf bermudagrass (*Cynodon dactylon* (L.) Pers. × *C. transvaalensis* Burtt-Davy) putting green use in the United States moves further north, there is risk of sustaining winter injury from low-temperature exposure and tissue desiccation. Protective covers reduce low-temperature exposure on ultradwarf bermudagrass greens. Desiccation of turf can be caused by hydrophobic soils. Wetting agents are applied to actively growing ultradwarf bermudagrass greens to relieve symptoms of hydrophobic soils. Less is known about the effects late-fall wetting agent applications on dormant bermudagrass putting greens. This research aims to define a predicted low-temperature threshold for covering ultradwarf bermudagrass greens and to quantify the effects of a late-fall wetting agent application on winter survival of ultradwarf bermudagrass. A protective cover and wetting agent trial was conducted on a sand-based putting green with plots of 'Champion', 'MiniVerde', and 'TifEagle' ultradwarf bermudagrass during the winters if 2015-2016 and 2016-2017. Cover treatments were placed at forecasted low-temperature thresholds of -9.4, -7.8, -5.6, and -4.0 °C and were compared to an uncovered control. A single late-fall wetting agent application was applied to each cultivar x cover treatment. An additional wetting agent trial was conducted by comparing a single application of various wetting agent treatments to an untreated control on a sand-based ultradwarf bermudagrass putting green. Spring green-up was monitored by quantifying green turfgrass coverage through digital image analysis. Soil volumetric water content was monitored at a depth of 3.8 cm using time-domain reflectometry. The wetting agent trial included two water drop penetration tests during each season. In both seasons, reducing the cover temperature threshold resulted in significant differences in green turfgrass coverage between treatments, but lower cover temperatures did not delay green-up of turf. 'MiniVerde' and 'TifEagle' greened up

significantly faster compared to ‘Champion’. In 2016, wetting agent treatments greened up significantly faster than the untreated control. Multiple wetting agent treatments significantly reduced water drop penetration times in the top three cm of the soil profile. Our research demonstrates the potential to reduce the forecasted low-temperature for covering ultradwarf bermudagrass without negatively impacting turf health, potentially reducing golf course winter labor costs.

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LITERATURE REVIEW

Transition zone putting greens

Creeping bentgrass (*Agrostis stolonifera L.*) is an ideal grass for use on golf course putting greens as its quality surpasses that of any another cool-season turfgrass (Emmons, 1995). Creeping bentgrass is a perennial, cool-season turfgrass that is adapted to cool, humid environments. Primarily due to climate, maintenance of creeping bentgrass putting greens is difficult in the southern United States and much of the transition zone, a geographic region best suited for neither warm- nor cool-season grasses. During the summer, high daytime temperatures coupled with warm nighttime temperatures create adverse conditions for bentgrass growth (Duble, 1989). High relative humidity during the summer elevates turfgrass disease pressure from fungal pathogens and results in frequent, costly fungicide applications. These stressful summer months can also coincide with the busiest season for play on a transition zone golf course, making bentgrass putting green management in the transition zone, difficult, costly, and time intensive.

Other species of turfgrass, such as hybrid bermudagrass (*Cynodon dactylon* (L.) Pers. × *C. transvaalensis* Burtt-Davy), are better adapted to heat and humidity and are also commonly used as putting surfaces throughout the transition zone and the southern United States. Hybrid bermudagrass is a warm-season turfgrass, which must be vegetatively propagated and can provide a dense, fine-textured, vigorous turf (Emmons, 1995). One of the original hybrid bermudagrasses developed for use as a putting surface was ‘Tifgreen’. Not long after the commercial release of ‘Tifgreen’, off-type grasses began appearing in established stands of ‘Tifgreen’ bermudagrass (Burton and Elsner, 1965). According to Caetano-Anollés et al. (1997), off-type grasses are those with a different morphology and performance when compared to the surrounding, desired cultivar, and may potentially be a result of somatic (vegetative) mutations. ‘Tifdwarf’ was an off-type of ‘Tifgreen’ selected for use as a commercial cultivar and has been widely used on putting greens throughout the southern United States. Resulting from demand for higher-quality putting surfaces, turfgrass breeding efforts and selection of naturally occurring ‘Tifgreen’ and ‘Tifdwarf’ off-types with desirable characteristics have led to a group of hybrid bermudagrasses commonly referred to as ultradwarfs. The term ultradwarf was first coined by Dr. Philip Busey in 1995 and was used to describe hybrid bermudagrass cultivars with more diminutive morphology than ‘Tifgreen’ and ‘Tifdwarf’ (Reasor et al., 2016).

Beginning in the late 1990’s, many golf courses throughout the southern United States and the transition zone began converting existing creeping bentgrass putting greens to ultradwarf bermudagrass. Golf courses have also been upgrading their putting greens from older, lower-quality hybrid bermudagrasses like ‘Tifdwarf’ and ‘Tifgreen’, to newer, better-performing ultradwarf cultivars such as ‘Champion’, ‘TifEagle’, and ‘MiniVerde’. Ultradwarf bermudagrasses tolerate lower mowing heights and provide a superior putting surface compared to their predecessors (USGA Green Section, 2004). Ultradwarf bermudagrasses exhibit excellent traffic tolerance and potentially require fewer inputs (fungicides, fans and syringing) than creeping bentgrass, which often makes ultradwarf bermudagrasses less costly to maintain than bentgrass. When compared to bentgrass, ultradwarf bermudagrass cultivars allow superintendents to focus more on the playability of a putting green and less on its survival during stressful summer months (Hartwiger, 2009).

Low temperature exposure

Winters in the transition zone can be unfavorable to the long-term success of ultradwarf bermudagrass putting greens. Bermudagrass usually stops growing when air temperatures drop below approximately 16 °C and may show discoloration and reduced turf quality when air temperatures fall below 10 °C (Hale and Orcutt, 1987). Winter injury to warm-season turfgrasses is likely to occur when air temperatures drop below -6.7 °C and can be caused by low temperature exposure as well as plant tissue desiccation (Trenholm, 2000). Low-temperature injury can occur due to either direct or indirect low temperature exposure. Indirect low-temperature injury refers to injury that occurs during winter months when plant tissue is acclimated to cold temperatures but is subjected to extended periods of sub-zero temperature exposure. Occurring less commonly, direct low-temperature injury is a result of rapid exposure of non-cold acclimated plant tissue to freezing temperatures (Fry, 1990).

Freeze tolerance refers to a plant’s ability to recover from prolonged exposure to lethal, low temperatures. Anderson et al. (2002), conducted a laboratory-based study to assess relative freeze tolerance levels of several popular ultradwarf bermudagrass cultivars. In that study, cold hardiness was reported as T_{mid}, or the temperature at which 50% of the tested plant population was no longer viable after being subjected to low temperatures for extended periods of time. The reported T_{mid} value for ‘Champion’ of -4.8 °C, was significantly greater than T_{mid} values for ‘MiniVerde’ and ‘TifEagle’, with T_{mid} values of -5.8 °C and -6.0 °C, respectively. Because this research was conducted in a controlled environment, these temperatures may not reflect plants exposed to freezing temperatures under field conditions (Anderson et al., 2002). In northern areas of the transition zone, temperatures can regularly fall below -6.0 °C for extended periods of time during winter months. Protecting sensitive putting green turf from exposure to these damaging low-temperature extremes is essential for turfgrass survival.

Protective covers

The benefits of covering or insulating putting greens during winter months have been well documented. Beckett (1929) reported the positive impact of using a layer of pine straw as winter protection on bermudagrass putting greens in Atlanta, GA. Pine straw, and more commonly today, protective covers, act as insulators and help retard the release of accumulated heat from the soil profile back into the atmosphere. Utilizing protective covers for ultradwarf bermudagrass putting greens to reduce winter injury and hasten spring green-up has become a popular, if not essential, practice (White, 2011). Temperature regulation and heat retention from protective covers may play a factor in limiting turfgrass exposure to low temperature extremes. Various, commercially-available and experimental covers were evaluated by Goatley et al., (2007) for their effects on surface temperature and turfgrass growth on a bermudagrass (*Cynodon magennissii* Hurc.'MS-Express'*)* putting green at the Mississippi State University Golf Course over the winter months of a three-year period. Applying any form of cover on a temporary basis prior to predicted temperatures of less than -4.0 °C resulted in increased mean minimum surface temperatures compared to an uncovered control. Goatley et al. (2007) also determined that using doubled layers of commercially available polypropylene covers had marginal impact on increasing mean daily minimum surface temperatures. In a study investigating predicted low-temperature thresholds for covering hybrid bermudagrass [*Cynodon dactylon* (L.) Pers. X *C. transvaalensis* Burtt-Davy cv. Tifway] maintained at 20 mm, Goatley et al. (2005) reported no additional protective benefit when utilizing protective covers at predicted nightly low-temperatures of 15 and 9.5 °C compared to 4 °C. Plots covered at a predicted low-temperature of 4 °C achieved complete turf green-up four to six weeks faster than uncovered control plots.

Protective covers are also used on cool-season turfgrasses, which typically do not enter a period of full dormancy during the winter like warm-season turfgrasses. Research on the effects of tarp color was conducted on ‘Midnight’ Kentucky bluegrass (*Poa pratensis* L.) in Ames, Iowa (Minner et al., 2001). Replicated treatments included an uncovered control, Enkamat, normally used to protect turf or prevent erosion, and tarps of the following colors: red, yellow, light-green, purple, dark-green, gray/white, and white. Cover treatments were placed at the end of November and removed just prior to normal spring green up of uncovered turf. Turf color was visually rated while covers were in place and until 100% green up was achieved. Minner et al. (2001) concluded, cover colors which transmitted the largest levels of photosynthetically active radiation generally showed enhanced turf quality in the spring.

In addition to temperature regulation, protective covers may also play a role in reducing desiccation of turfgrass crowns. Because the crown is the center of meristematic activity in the grass plant, crown survival is essential for turf recovery in the spring. Roberts (1986) experimented with the influence of protective covers on reducing winter desiccation of turf. The study, performed on creeping bentgrass (*Agrostis palustris* Huds. ‘Emerald’), included treatments of spun bonded polyester and polypropylene blankets, sewage sludge, and pine needles. Roberts (1986) concluded that, when compared to an uncovered control, using spun bonded polyester blankets for winter protection, resulted in 10 to 20% greater spring leaf moisture, up to 24% more root length, 80% more clippings, and up to 10 °C higher soil temperature. These changes increased spring turf green-up by 5 to 12 days.

According to Shashikumar and Nus (1993), the effect that protective covers have on the moderation of low temperature extremes is important for bermudagrass winter survival, but survival of dormant bermudagrass crowns and rapid spring green-up is also dependent upon adequate crown moisture. A three-year field study in Manhattan, KS, examined winter cover effects on cold acclimation and crown moisture content of eight different bermudagrass cultivars. Covers were placed in mid-December and removed in May of the following spring. Crown moisture content was recorded in two-week intervals from the time of cover placement to the beginning of April. Research concluded that crown moisture contents were higher than the control for every cultivar at each sampling, with the most pronounced differences occurring from early January through mid-February. It was concluded that spun bonded covers on bermudagrasses increased their capacity to cold acclimate and conserve crown moisture content (Shashikumar and Nus, 1993). However, leaving protective covers in place throughout the entire winter may not be an option for a golf course superintendent managing hybrid bermudagrass in the transition zone.

Understanding the specific low-temperature at which it is necessary to cover putting greens is important for golf course superintendents who may not have the luxury of installing covers and leaving them in place until the turf exits dormancy the following spring. Because winters in the transition zone are not as harsh as the North, most courses are expected to be open for play throughout the winter, when the weather permits, meaning covers may have to be installed and removed numerous times throughout the winter. A golf course superintendent in North Carolina, tracking labor hours for multiple winter seasons of installing and removing protective covers, has determined the average cost of one covering and cover removal event to be $742. Records over seven years indicated total seasonal labor costs associated with covering ranged from as little as $2,900 to as much as $24,500 (Jared Nemitz, The Peninsula Club, Cornelius NC, personal communication). Although winter weather conditions and labor hours ultimately influence seasonal costs for covering putting greens, the costs of purchasing protective covers and the ongoing cost in labor to install or remove them for play are significant and must be considered. The current recommendation for protecting ultradwarf bermudagrass putting greens is to apply covers when the low temperature is forecasted to reach -4.0 °C or lower (O’Brien and Hartwiger, 2013). If the target low-temperature at which greens are covered can be decreased from -4.0 °C without a drastic increase in winter injury, labor costs could be reduced, and revenue potential expanded by increasing days open for golf during the winter months.

Hydrophobic soils

Another factor that may be contributing to winter injury of ultradwarf bermudagrass putting greens is desiccation caused by hydrophobic soils. Soil hydrophobicity often occurs in sandy soils. Jamison (1946) described sandy surface soils in citrus groves located in central Florida that resisted wetting from irrigation and precipitation even during the summer rainy season. Hydrophobicity has also been documented in watersheds of burned forest land in southern California (DeBano et al., 1970). Sandy soils are preferred for use as putting green rootzones due to their resistance to compaction and rapid water drainage potential (Lunt, 1956). The sandy rootzone mixture of a putting green constructed to USGA specifications (United States Golf Association, 2004) can make soil hydrophobicity a major problem. As hydrophobicity pertains to golf course putting greens, areas that become water repellent are most commonly near the upper region of the root zone and the crowns of the plant. This repellency is likely caused by individual sand particles that have become coated with an organic compound exhibiting hydrophobic properties (Miller and Wilkinson, 1977; Henry and Paul, 1978). Localized dry spot (LDS) is a term used in the golf course industry to define irregularly shaped areas of desiccated, brown turf resulting from soil that has become resistant to wetting from both irrigation and rainfall (Beard and Beard, 2005). This is a major issue during summer months on putting greens when uniform moisture distribution throughout the root zone is a necessity for both the playability and the aesthetic property of an intensely managed putting surface.

Wetting agents have become a popular and reliable way to mitigate damage caused by LDS and are utilized for other purposes as well. Wetting agents belong to a chemical group called surfactants or “Surface Active Agents”. Surfactants effectively reduce the surface tension of water by lowering its cohesive properties, allowing water to penetrate the surface of a hydrophobic soil (Karnok et al., 2004), however, the underlying cause of the hydrophobicity may still be present in the rootzone. Studying the efficacy of wetting agents to relieve symptoms of hydrophobicity in the field can be difficult. The ability to predict the formation of hydrophobic soil is not realistic due to many uncontrollable environmental factors responsible for hydrophobic soil formation. In a study on the effects of wetting agents on sand based rootzone hydrophobicity, ten commercially available wetting agents were applied to creeping bentgrass on a ninety-six percent sand based rootzone. Leinauer et al. (2007) demonstrated that wetting agents could relieve hydrophobicity at depths of .5 and 1.5 cm and, as expected, the most hydrophobic soils exhibited the lowest turf stand quality.

Testing various wetting agents in a controlled setting, Song et al., (2014) showed laboratory constructed hydrophobic sand root zones treated with various wetting agents had increased water infiltration rates when compared to the untreated controls. Soil rewettability, the capacity of a soil to absorb water after a period of drying, was also enhanced by wetting agent application, although results were not consistent across all products tested. Karnok and Tucker (2001) performed a study to determine the impact of a soil wetting agent on soil hydrophobicity, as well as root growth and shoot quality of ‘Penncross’ creeping bentgrass. The study was conducted using root observation chambers at the University of Georgia Rhizotron in Athens, GA. Observation chamber root zones were constructed according to USGA Green Section specifications and the top 10.1 cm of the root zone consisted of a hydrophobic soil. The wetting agent used in the study reduced soil hydrophobicity for up to 12 weeks after application. Turfgrass color and quality, as well as root length, were also found to be superior in wetting agent treatments compared to the control. Because only one specific wetting agent was used, the authors could not speculate if these effects would be observed using other wetting agent products (Karnok and Tucker, 2001).

In the field, beneficial effects from wetting agents can be short-lived. Wetting agents are commonly applied to putting greens many times throughout the spring and summer months. Because wetting agents do not cure the cause of soil hydrophobicity, soils may remain hydrophobic during the winter, resulting in turfgrass desiccation due to soil water repellency, even though symptoms (LDS) may not be evident due to the dormant state of the turf.

Research is currently lacking examining the effects of late-season wetting agent applications to dormant putting green turf for the purpose of combating winter turfgrass desiccation. Research regarding specific temperatures at which placing covers on ultradwarf bermudagrass putting greens becomes critical is also lacking. Therefore, the objectives of this study were to 1) examine the effects of several predicted low-temperature thresholds used for placing protective covers on three different cultivars of ultradwarf bermudagrass putting greens, 2) investigate the effects of a late-fall wetting agent application on soil moisture and winter survival of ultradwarf bermudagrass, 3) evaluate the effects of a late-fall application of three commercially available wetting agents on winter survival, soil moisture, and soil water repellency.

It was hypothesized that reducing the predicted low-temperature for covering ultradwarf bermudagrass putting greens would not significantly increase the severity of winter injury sustained by the putting green. Also, it was predicted that a late-fall wetting agent application would reduce winter injury, increase soil volumetric water content, and reduce soil water repellency.

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Reducing ultradwarf bermudagrass putting green winter injury with covers and wetting agents

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Abbreviations: DIA, digital image analysis; DOY, day of year; LDS, localized dry spot; N, nitrogen; WA, wetting agent.

ABSTRACT

As ultradwarf bermudagrass (*Cynodon dactylon* (L.) Pers. × *C. transvaalensis* Burtt-Davy) putting green use in the United States moves further north, there is increased risk of sustaining winter injury from desiccation and low-temperature exposure. Protective covers are an essential tool for reducing winter injury of ultradwarf bermudagrass greens. Installation and removal of covers to allow for golf during periods of favorable weather is costly and labor intensive. This research aims to define a predicted low-temperature threshold when covering an ultradwarf putting green becomes necessary, and to quantify the effects of a late-fall wetting agent application on winter survival and spring green-up. Research was conducted in Fayetteville, AR during the winters of 2015-2016 and 2016-2017 on a sand-based putting green with replicated plots of ‘Champion’, ‘MiniVerde’, and ‘TifEagle’ bermudagrass. Covering treatments were placed on the green at forecasted low-temperature thresholds of -9.4, -7.8, -5.6 and -4.0 °C and were compared to an uncovered control. A single late-fall wetting agent application was applied as a split plot to each cultivar x cover treatment. Plots receiving cover treatments, regardless of temperature, achieved significantly faster spring green-up than the control. During both seasons, significant differences in green turfgrass coverage between cover treatments were recorded on multiple dates, although differences were not indicative of a drastic increase in winter injury from lower cover temperature thresholds. Throughout both seasons, ‘MiniVerde’ and ‘TifEagle’ had significantly faster spring green-up compared to ‘Champion’ but did not differ from each other. Plots receiving a wetting agent application achieved significantly faster spring green-up compared to the control during 2015-2016. Therefore, it may be possible to reduce the predicted low temperature threshold for covering greens without a significant

increase in winter injury severity. This temperature reduction can reduce golf course labor costs and increase revenue with more days open for play.

BACKGROUND

Beginning in the late 1990's, many golf courses throughout the southern United States and the transition zone began converting existing creeping bentgrass (*Agrostis stolonifera L.*) putting greens to ultradwarf bermudagrass (*Cynodon dactylon* (L.) Pers. × *C. transvaalensis* Burtt-Davy) (Hartwiger, 2009). Golf courses have also been upgrading their putting greens from older hybrid bermudagrasses like 'Tifdwarf' and 'Tifgreen', to newer, better-performing ultradwarf cultivars such as 'Champion', 'TifEagle', and 'MiniVerde'. Ultradwarf bermudagrasses tolerate lowering mowing heights and provide a superior putting surface compared to their predecessors (USGA Green Section, 2004). Ultradwarf bermudagrasses also exhibit excellent traffic tolerance and potentially require fewer inputs (fungicides, fans and syringing) than creeping bentgrass, which can make ultradwarf bermudagrasses less costly to maintain than bentgrass. When compared to bentgrass, ultradwarf cultivars allow superintendents to focus more on the playability of a putting green and less on its survival during stressful summer months (Hartwiger, 2009).

Winters in the transition zone can be unfavorable to the long-term success of ultradwarf bermudagrass putting greens. Bermudagrass usually stops growing when air temperatures drop below approximately 16 °C and can show discoloration and reduced turf quality when air temperatures fall below 10 °C (Hale and Orcutt, 1987). Winter injury to warm-season turfgrasses is likely to occur when air temperatures drop below -6.7 °C and can be caused by low temperature exposure as well as plant tissue desiccation (Trenholm, 2000). Low-temperature injury can occur on warm-season turfgrasses due to either direct or indirect low temperature exposure. Indirect low-temperature injury refers to injury that occurs during winter months when plant tissue is acclimated to cold temperatures but is subjected to extended periods of exposure to temperatures below 0 °C. Occurring less commonly, direct low-temperature injury is a result of rapid exposure of non-cold acclimated plant tissue to freezing temperatures (Fry, 1990).

Freeze tolerance refers to a plant's ability to recover from prolonged exposure to lethal, low temperatures. Anderson et al. (2002), conducted a laboratory-based study to assess relative freeze tolerance of several popular ultradwarf bermudagrass cultivars. In their study, cold hardiness was reported as T_{mid}, or the temperature at which 50% of the tested plant population was no longer viable after being subjected to freezing temperatures. The reported T_{mid} value for 'Champion' was -4.8 °C, which was significantly greater than T_{mid} values for 'MiniVerde' and 'TifEagle', (T_{mid} values of -5.8 °C and -6.0 °C, respectively). Because this research was conducted in a controlled environment, these temperatures may not accurately reflect plants exposed to freezing temperatures under field conditions (Anderson et al., 2002). However, it does suggest that genetic selections may differ in their ability to survive direct low-temperature kill. In northern areas of the transition zone, temperatures can regularly fall below -6.0 °C for extended periods of time during winter months. Protecting sensitive putting green turf from exposure to these damaging low temperature extremes is essential for turfgrass survival.

The benefits of covering or insulating putting greens during winter months have been well documented. The positive impact of using a layer of pine straw as winter protection on bermudagrass putting greens in Atlanta, GA was first reported in the 1920s (Beckett, 1929). Pine straw, and more commonly today, protective covers, act as insulators and help retard the release of accumulated heat from the soil profile back into the atmosphere. Utilizing protective covers for ultradwarf bermudagrass putting greens to reduce winter injury and hasten spring green-up has become a popular, if not essential, practice (White, 2011). Temperature regulation and heat retention from protective covers may play a factor in limiting turfgrass exposure to low temperature extremes. Various commercially available and experimental covers were evaluated for their effects on surface temperature and turfgrass growth on a bermudagrass (*Cynodon magennissii* Hurc. 'MS-Express'*)* putting green at the Mississippi State University Golf Course over the winter months of a three-year period (Goatley et al., 2007). Applying any form of cover on a temporary basis prior to predicted temperatures of less than -4.0 °C resulted in increased mean minimum surface temperatures compared to an uncovered control. Goatley et al. (2007) also determined using doubled layers of commercially available polypropylene covers had marginal impact on increasing mean daily minimum surface temperatures. In a study investigating predicted low-temperature thresholds for covering hybrid bermudagrass [*Cynodon dactylon* (L.) Pers. X *C. transvaalensis* Burtt-Davy cv. Tifway] maintained at 20 mm, Goatley et al. (2005) reported no additional protective benefit when utilizing protective covers at predicted nightly low-temperatures of 15 and 9.5 °C compared to 4 °C. Plots covered at a predicted low-temperature of 4 °C achieved complete turf green-up four to six weeks faster than uncovered control plots.

Protective covers have been successfully used on cool season turfgrasses, which typically do not enter a period of full dormancy during the winter like warm season turfgrasses. Research on the effects of tarp color was conducted on 'Midnight' Kentucky Bluegrass (*Poa pratensis* L.) in Ames, Iowa (Minner et al., 2001). Treatments included an uncovered control, Enkamat, normally used to protect turf or prevent erosion, and tarps of the following colors, red, yellow, light-green, purple, dark-green, gray/white, and white. Cover treatments were placed at the end of November and removed just prior to normal spring green up of uncovered turf. Turf color was visually rated while covers were in place and until 100% green up was achieved. Minner et al.

(2001) concluded, cover colors which transmitted the largest levels of photosynthetically active radiation generally showed enhanced turf quality in the spring.

In addition to temperature regulation, protective covers may also play a role in reducing desiccation of turfgrass crowns. Because the crown is the center of meristematic activity in the grass plant, crown survival is essential for turf recovery in the spring. Roberts (1986) experimented with the influence of protective covers on reducing winter desiccation of turf. The study, performed on creeping bentgrass (*Agrostis palustris* Huds. ‘Emerald’), included treatments of spun bonded polyester and polypropylene blankets, sewage sludge, and pine needles. Roberts (1986) concluded that, when compared to an uncovered control, using spun bonded polyester blankets for winter protection, resulted in 10 to 20% greater spring leaf moisture, up to 24% more root length, 80% more clippings, and up to 10 °C higher soil temperature. These factors increased spring green-up by 5 to 12 days.

According to Shashikumar and Nus (1993), the effect that protective covers have on the moderation of low temperature extremes is important for bermudagrass winter survival, but survival of dormant bermudagrass crowns and rapid spring green-up is also dependent upon adequate crown moisture. A three-year field study in Manhattan, KS, examined winter cover effects on cold acclimation and crown moisture content of eight different bermudagrass cultivars. Covers were placed in mid-December and removed in May of the following spring. Crown moisture content was recorded in two-week intervals from the time of cover placement to the beginning of April. Research concluded that crown moisture contents were higher than the control for every cultivar at each sampling, with the most pronounced differences occurring from early January through mid-February. It was concluded that spun bonded covers on bermudagrasses increased their capacity to cold acclimate and conserve crown moisture content

(Shashikumar and Nus, 1993). However, leaving protective covers in place throughout the entire winter will not be an option for most golf course superintendents managing hybrid bermudagrass in the transition zone.

Understanding the specific low temperature at which it is necessary to cover putting greens is important for golf course superintendents who may not have the luxury of installing covers and leaving them in place until the turf exits dormancy during the following spring. Because winters in the transition zone are not as harsh as the North, most courses are expected to be open for play throughout the winter, when the weather permits, meaning covers may have to be installed and removed numerous times throughout the winter. A golf course superintendent in North Carolina, tracking labor hours for multiple winter seasons of installing and removing protective covers, has determined the average labor cost of one covering and cover removal event to be $742. Records over seven seasons indicated total seasonal labor costs ranged from as little as $2,900 to as much as $24,500 (Jared Nemitz, The Peninsula Club, Cornelius NC, personal communication). Although winter weather conditions and labor hours ultimately influence seasonal costs for covering putting greens, the costs of purchasing protective covers and the ongoing cost in labor to install or remove them for play are significant and must be considered. The current recommendation for protecting ultradwarf putting greens is to apply covers when the low temperature is forecasted to reach -4.0 °C or lower (O’Brien and Hartwiger, 2013). If the target low temperature at which greens are covered can be decreased below -4.0 °C without a drastic increase in winter injury, labor costs could be reduced, and revenue potential expanded by increasing days open for golf during the winter months.

Sandy soils are preferred for use as putting green rootzones due to their resistance to compaction and rapid water drainage potential (Lunt, 1956). The sandy rootzone mixture of a putting green constructed to USGA specifications (United States Golf Association, 2004) can make soil hydrophobicity a major problem. As hydrophobicity pertains to golf course putting greens, areas that become water repellent are most commonly near the upper region of the root zone and the crowns of the plant. Repellency is likely caused by individual sand particles that have become coated with an organic compound exhibiting hydrophobic properties (Miller and Wilkinson, 1977; Henry and Paul, 1978). Localized dry spot (LDS) is a term used in the golf course industry to define irregularly shaped areas of desiccated, brown turf resulting from soil that has become resistant to wetting from both irrigation and rainfall (Beard and Beard, 2005). This is a major issue during summer months on putting greens when uniform moisture distribution throughout the root zone is a necessity for both the playability and the aesthetic property of an intensely managed putting surface.

Wetting agents have become a popular and reliable way to mitigate damage caused by LDS and are utilized for other purposes as well. Wetting agents belong to a chemical group called surfactants or “Surface Active Agents”. Surfactants effectively reduce the surface tension of water by lowering its cohesive properties, allowing water to penetrate the surface of a hydrophobic soil (Karnok et al., 2004), however, the underlying cause of the hydrophobicity may still be present in the rootzone. In the field, beneficial effects from wetting agents can be short-lived. Wetting agents are commonly applied to putting greens many times throughout the spring and summer months. Because wetting agents do not cure the cause of soil hydrophobicity, soils may remain hydrophobic during the winter, resulting in turfgrass desiccation due to soil water repellency, even though symptoms (LDS) may not be evident due to the dormant state of the turf.

Research is currently lacking examining the effects of late-season wetting agent applications to dormant putting green turf for the purpose of combating winter turfgrass desiccation. Research regarding specific temperatures at which placing covers on ultradwarf bermudagrass putting greens becomes critical is also lacking. It was hypothesized that reducing the predicted low-temperature for covering ultradwarf bermudagrass putting greens would not significantly increase the severity of winter injury sustained by the putting green. It was also hypothesized that a late-fall wetting agent application would reduce winter injury, increase soil volumetric water content, and reduce soil water repellency. Therefore, the main objective of this study was to investigate the effect of four predicted low-temperature thresholds used for placing covers on winter injury and spring green-up of three cultivars of ultradwarf bermudagrass. This study also investigated the effects of a single, late-fall wetting agent application on winter injury and spring green-up of three ultradwarf bermudagrass cultivars.

MATERIALS AND METHODS

A two-year field study was conducted at the University of Arkansas Agricultural Research and Extension Center in Fayetteville, Arkansas (36.10° N, 94.17° W) during the winters of 2015-2016 and 2016-2017. Four replicate experimental plots of ‘Champion’, ‘MiniVerde’, and ‘TifEagle’ ultradwarf bermudagrass, 4.0 by 12.0 m (Fig. 1) were established in 2013 on a sand-based putting green (United States Golf Association, 2004). Core aerification and use of plant growth regulators were conducted according to typical putting green management practices for the region. Mowing during the growing season was performed 6 d wk^{-1} at a 3.2-mm bench setting height of cut using a Jacobsen Eclipse 322 (Jacobsen, A Textron Company, Charlotte, NC). Approximately one month prior to the onset of winter dormancy, the bench setting height of cut was raised to 3.6 mm. During the growing season, nitrogen (N) was applied every two weeks at a rate of 24 kg N ha^{-1}, alternating between applications of Contec DG 18-9-

18 (The Andersons, Maumee, OH) and Thrive 46-0-0 spray-grade urea (Mears Fertilizer Inc., El Dorado, KS). Phosphorous, potassium, and micronutrients were applied according to annual soil testing. Irrigation was withheld during the winter months but was applied to replace 100% of reference evapotranspiration throughout the growing season. Sand topdressing applications of 0.3 mm were made at two-week intervals during the growing season.

Four different forecasted low-temperature thresholds were used to determine when protective cover treatments were to be placed on the experimental area. The four predicted low-temperature minimums examined were -9.4, -7.8, -5.6 and -4.0 °C and were compared to an uncovered control. All information regarding forecasted temperatures and potential frost events were obtained for Fayetteville, Arkansas, using the National Oceanic and Atmospheric Administration website (www.noaa.gov). Cover treatments were applied as strip plots across all three cultivars (Fig. 1). The protective covers, custom made by Xton (Xton, Inc. Florence, AL), were composed of black, woven polypropylene and measured 2.4 by 12.0 m. After a threshold temperature was forecast and the protective covers associated with that low temperature were placed on the green, covers remained in place until favorable weather would potentially allow a golf course to open for play, typically when the daily high temperature for the following day was predicted to exceed 7.2 °C. This strategy of cover placement and removal was designed to simulate a golf course that would remove covers to allow for play on warmer winter days (> 7.2 °C). After the onset of green-up during spring 2016, protective covers were not placed on the putting green unless one of the four predicted low-temperature thresholds was forecast, leaving experimental plots exposed to frost events. Reductions in spring green-up due to several frost events occurred on all plots during spring 2016. As such, beginning in Mar. 2017, covers were placed on all treatments, excluding uncovered control plots, for any predicted frost event once green-up had initiated in the plot area.

An application of the wetting agent Revolution (Aquatrols, Paulsboro, NJ) was made as a split plot to the cover strip plots at a rate of 19 L ha^{-1} and was compared to an untreated control. Wetting agent plots were 1.2 x 4.0 m (Fig. 1). The wetting agent was applied using a 3-nozzle, CO_2-pressurized plot sprayer with flat fan nozzles (8005VS; TeeJet, Springfield, IL) delivering 701 L ha^{-1} of spray volume. Applications were made on 7 Dec 2015 and 6 Dec 2016. This application timing was designed to be a one-time, late-fall wetting agent application occurring prior to the first putting green covering event. During the growing season, routine wetting agent applications were made to the entire experimental area from May through August, but no wetting agents were applied after September 1 in each growing season.

Data collection

From late November through early March, soil temperature was continuously monitored at a soil depth of 2.5 cm in two replications of each protective-cover treatment using external soil temperature sensors and WatchDog 1000 series micro station data loggers (Spectrum Technologies, Aurora, IL). Sensors were placed to a depth of 2.5 cm to record soil temperatures to which the turfgrass crowns were exposed. Twelve, randomly spaced soil volumetric water content measurements per plot were recorded monthly during the winter of 2015-2016 and then every two weeks during the winter of 2016-2017. Volumetric water content measurements were obtained using time domain reflectometry (TDR) with a FieldScout TDR 300 Soil Moisture Meter (Spectrum Technologies, Aurora, IL). The standard deviation of volumetric water content values, within plots, was used as an indicator of plot soil moisture uniformity. Digital image analysis (DIA) was used to determine percent green turfgrass coverage (Richardson et al., 2001) during the spring green-up period from Mar. through May. Four pictures per plot were taken weekly from February through May using a digital camera (Canon PowerShot G12, Canon Inc., Melville, NY) mounted to a 0.9- by 0.9-m metal box equipped with four light bulbs, providing a consistent light source to collect comparable images. Images collected were then analyzed using SigmaScan (SigmaScan Pro, SPSS Inc., Chicago, IL). Green pixels were selected based on a hue range of 45 to 125 and a saturation range from 10 to 100. The total number of green pixels was divided by the total number of pixels present in the image to calculate percent green turfgrass coverage present in the image.

Experimental design

The experimental design was three-factor, strip-split, randomized complete block with four replications. All data were analyzed separately each year due to inconsistencies in evaluation dates between the two years. Repeated measures analysis of variance using PROC MIXED (SAS v 9.4, SAS Institute, Cary, NC) was used to evaluate the effects of cultivar, cover temperature, wetting agent, and their interactions on green turfgrass coverage, volumetric water content, and standard deviation of within-plot volumetric water content values. Within-plot standard deviation was used as an indicator of soil moisture uniformity. For all data, slicing was performed in PROC MIXED to identify evaluation dates when treatment effects were significant. Treatment means were separated using Fisher's protected LSD ($\alpha = 0.05$). A statistical analysis of soil temperature variation under different cover treatments was not performed due to failure of some sensors and incomplete data collection.

RESULTS

Soil temperature

During 2016, the covered treatments had numerically greater average weekly minimum temperatures compared to the uncovered treatment. During 2016, average weekly minimum temperatures for the uncovered treatment fell below 0 °C, while covered treatments maintained average weekly minimum temperatures above freezing (Fig. 2). During both years of the trial, all covered treatments maintained a minimum 2.5-cm depth temperature above 0 °C, while that in the uncovered treatment fell below 0 °C on multiple dates (Fig. 2).

Green turfgrass coverage

In 2016, the main effects of day of year (DOY) and wetting agent (WA) both significantly affected green turfgrass coverage (Table 1). The higher order interactions of cultivar x DOY, cover temperature x DOY, WA x DOY, and cultivar x cover temperature x WA also significantly affected green turfgrass coverage during 2016.

In 2016, green turfgrass coverage did not differ among cover temperatures on 7 of 12 sampling dates (Fig. 3). On 9, 16, and 21 May 2016, the uncovered treatment had significantly less green turfgrass coverage compared to at least two of the four cover temperature treatments. The largest difference between any two treatments was observed on 21 May 2016, when the -4.0 °C cover treatment had 13% more green turfgrass coverage compared to the uncovered treatment (Fig. 3).

In 2016, green turfgrass coverage differed on 8 of the 12 total sampling dates (Fig. 4). On 20 Mar. 2016, ‘Champion’ had a significantly greater percentage of green turfgrass coverage compared to ‘TifEagle’ and ‘MiniVerde’, but this was the only date of occurrence throughout the data collection period. ‘TifEagle’ and ‘MiniVerde’ had significantly greater green turfgrass coverage compared to ‘Champion’ for the other seven sampling events occurring from 17 Apr. through 21 May 2016. On the last sampling date, 21 May 2016, ‘MiniVerde’ had 67% green turfgrass coverage, the largest percentage of any cultivar during 2016. By the end of the data collection period, ‘Champion’ had yet to achieve more than 50% green turfgrass coverage (Fig. 4).

In 2016, the WA treatment significantly increased green turfgrass coverage on 8 of 12 sampling dates (Fig. 5). On the seven sampling dates from 18 Apr. through the end of data collection, the WA treatment consistently had approximately 10% greater green turfgrass coverage compared to the untreated control, with the largest difference occurring on 21 May 2016. When investigating the highest order interaction of cultivar x cover temperature x WA during 2016, the WA treatment significantly increased green turfgrass coverage in all cover temperature treatments of ‘Champion’ (Fig. 6). In ‘TifEagle’, the WA treatment only significantly increased green turfgrass coverage in the -4.0 °C cover temperature treatment, while the WA treatment increased green turfgrass coverage in cover treatments of -5.6, -7.8, and -9.4 °C in ‘MiniVerde’. In the uncovered treatment with ‘TifEagle’ and ‘MiniVerde’, the WA treatment also significantly increased green turfgrass coverage compared to the treatment with no WA (Fig. 6). The uncovered ‘Champion’ treatment did not show an increase in green turfgrass coverage from the WA treatment.

In 2017, the main effects of DOY, cultivar, and cover temperature significantly affected green turfgrass coverage (Table 1). Higher order interactions of cultivar x DOY, cover temperature x DOY, and cultivar x cover temperature x DOY also significantly affected green turfgrass coverage during 2017. Unlike 2016, the WA treatment did not significantly affect green turfgrass coverage during 2017 (Table 1).

In 2017, green turfgrass coverage did not differ among cultivar x cover temperature treatments on the first five sampling dates from 28 Feb. to 23 Mar. 2017 (Fig. 7). On 31 Mar. 2017, ‘TifEagle’ with cover temperature treatments of -4.0, -5.6, and -7.8 °C were the only treatments that had greater percentages of green turfgrass coverage compared to the uncovered treatment. From 18 Apr. through the last sampling date on 23 May 2017, all cover treatments within each cultivar had significantly greater percentages of green turf grass coverage compared to the uncovered treatment (Fig. 7). From 2 May through 23 May 2017, all covered ‘TifEagle’ and ‘MiniVerde’ treatments had significantly greater green turfgrass coverage compared to the same covered ‘Champion’ treatments. ‘MiniVerde’ treatments covered at -5.6 °C had significantly greater green turfgrass coverage compared to ‘MiniVerde’ treatments covered at all other temperatures on all six sampling dates from 18 Apr. through 23 May 2017. On 23 May 2017, ‘MiniVerde’ treatments covered at -5.6 °C had 20% more green turfgrass coverage compared to ‘MiniVerde’ treatments covered at -4.0 °C (Fig. 7). The uncovered treatment from all cultivars had negligible amounts of green turfgrass coverage throughout the entire 2017 sampling period, never having more than 6% green turfgrass coverage on any sampling date. ‘TifEagle’ treatments covered at -4.0 and -5.6 °C and ‘MiniVerde’ treatments covered at -5.6 °C were the only treatments with at least 80% green turfgrass coverage by the end of the data collection period.

Soil volumetric water content

In 2016, the main effects of month and WA, as well as the higher order interactions of cover temperature x month, and WA x month significantly affected soil volumetric water content

(Table 2). Standard deviation of volumetric water content was significantly affected by the main effects of cultivar and month and by the higher order interactions of cultivar x month and WA x month (Table 2).

In 2016, the WA treatment significantly affected soil volumetric water content on two sampling dates in 2016 (Fig. 8). The WA treatment had significantly greater volumetric water content compared to the untreated control for the Feb. and Apr. sampling dates. The WA treatment increased soil volumetric water content from 8.3% in the untreated control, to 10.3% at the Feb. sampling date. The untreated control had a soil volumetric water content of 6.3% at the Apr. sampling date compared to 7.5% in the WA treatment (Fig. 8). Volumetric water contents ranged from a low of 6.3% to a high of 10.2% during the 2016 data collection period.

In 2016, cover temperature significantly affected volumetric water content on 2 sampling dates (Fig. 9). The Feb. sampling date revealed the -9.4 °C cover temperature treatment contained 8.7% soil volumetric water content, this was significantly less than the uncovered treatment, which contained 9.7% soil volumetric water content but was not significantly less than other cover temperature treatments. On the Mar. sampling date, the -9.4 °C cover treatment had significantly less volumetric water content compared to all other cover treatments, but did not differ from the uncovered treatment.

The standard deviation of soil volumetric water content was significantly affected by cultivar on 4 sampling dates, in 2016 (Table 3). ‘Champion’ had a significantly greater standard deviation of soil volumetric water content than both ‘TifEagle’ and ‘MiniVerde’ at every sampling date, excluding the Apr. sampling date. Standard deviations were never significantly different between ‘TifEagle’ and ‘MiniVerde’ during the 2016 data collection period. Standard deviation was significantly affected on two sampling dates by the WA treatment (Table 4). The untreated control had a significantly lower standard deviation for the Feb. and Apr. sampling date compared to the WA treatment.

In 2017, the main effects of cover temperature, WA, and month, along with the higher order interactions of cover temperature x WA, cover temperature x month, and WA x month all significantly affected soil volumetric water content (Table 5). Standard deviation of volumetric water content was significantly affected by the main effects of cultivar, WA, and month. The higher order interactions of cover temperature x month and WA x month also significantly affected standard deviation of volumetric water content (Table 5). In 2017, ‘Champion’ had a significantly greater standard deviation of volumetric water content compared to ‘TifEagle’ and ‘MiniVerde’ (Table 6).

Volumetric water content was significantly affected by cover temperature at every sampling date during 2017 (Fig. 10). Cover treatments of -4.0 and -5.6 °C, had significantly greater soil volumetric water content percentages compared to the uncovered control on every sampling date excluding 15 Apr. 2017. On 15 Mar. 2017, the -9.4 °C cover treatment contained 10.5% soil volumetric water content, which was significantly greater than 6.9% in the uncovered treatment and also significantly greater than all other cover treatments (Fig. 10). Soil volumetric water contents ranged from a high of 15.2% to a low of 6.3% during the 2017 data collection period.

The WA treatment in 2017 had a significant effect on volumetric water content on two sampling dates (Fig. 8). The WA treatment had significantly greater soil volumetric water content compared to the untreated control on 30 Mar. and 30 Apr. 2017. The largest difference in soil volumetric water content during 2017 was 1%, which occurred on 30 Apr. 2017, when the

WA treatment contained 12.7% soil volumetric water content compared to 11.7% in the untreated control.

In 2017, all cover temperatures contained significantly greater soil volumetric water contents compared to the uncovered control in both the WA treatment and the untreated control (Table 7). The WA treatment significantly increased volumetric water contents in cover treatments of -4.0, -5.6, and -7.8 °C compared the untreated control under the same cover treatments.

The WA treatment significantly affected the standard deviation of volumetric water content on three dates, in 2017 (Table 8). The WA treatment had a significantly lower standard deviation of volumetric water content on 15 Feb., 30 Mar., and 30 Apr. 2017. Unlike 2016, cover temperature significantly affected the standard deviation of volumetric water content across time, in 2017 (Table 9). Cover temperature significantly affected the standard deviation of volumetric water content on three dates. The uncovered treatment generally had statistically comparable standard deviations when compared to all cover treatments and the standard deviations were never greater than every cover temperature treatment at any one sampling date.

DISCUSSION

Reductions in winter injury from the use of protective covers may be due to the ability of protective covers to modify soil temperatures. Acting as an insulator, the increased minimum soil temperatures in this study under protective covers (Fig. 2) were consistent with previous research conducted by Goatley et al. (2009) who showed the ability of three different types of protective covers to increase surface temperatures compared to an uncovered control on a stand of ‘Riviera’ bermudagrass. Future research investigating effects of various cover materials and thicknesses on winter injury of ultradwarf bermudagrass putting greens may be beneficial in helping golf course superintendents make informed decisions regarding which covers to purchase and at which air temperature specific covers must be deployed to avoid catastrophic loss of turf.

Across both seasons and all cultivars, protective covers reduced severity of winter injury, regardless of cover temperature treatment. Although the uncovered control did not sustain detrimental winter injury during winter 2016, the benefits of using protective covers were still evident in relation to green turf coverage during the spring green-up period (Fig. 3). During both seasons, differences in green turfgrass coverage between cover temperature thresholds, although statistically significant on multiple dates, were not of practical significance to a golf course superintendent and did not result in drastic differences in winter injury. In 2017, ‘MiniVerde’ covered at -5.6 °C containing more green turf coverage than all other cover temperature and cultivar treatments is likely a statistical anomaly and does not indicate that covering greens at -5.6 °C would be more beneficial than covering greens at -4.0 °C. The uncovered control throughout spring 2016, had percentages of green turfgrass coverage comparable to all cover treatments, regardless of temperature. This was likely caused by unseasonably warm temperatures in Fayetteville, AR during 2016 (Fig. 11). Although monthly average low temperatures appear similar between both seasons, uncovered control plots experienced fatal winter injury during 2017. This injury was likely due to exposure to multiple nights of extreme low temperatures not experienced during 2016. This reinforces the importance of utilizing protective covers, regardless of temperature, to mitigate risk of catastrophic turf loss. Several reductions in green turfgrass coverage during the late winter and early spring 2016 (Figures 3, 4, 5) were caused by injury to green turfgrass from frost events occurring at forecasted temperatures below 0 °C but above the largest cover temperature threshold of -4.0 °C. These reductions in green turf coverage illustrate the need for superintendents to cover putting greens in the spring prior to predicted frost events to avoid imminent low-temperature damage to turfgrasses recently emerging from dormancy.

This research demonstrates the potential to lower the critical predicted low temperature for placing protective covers on ultradwarf bermudagrass putting greens. Waiting to cover the putting green until temperatures were predicted to fall below -4.0 °C resulted in a considerable reduction in total cover installation and removal events and a potential increase in days in which a golf course could remain open for play. Over two winters in Fayetteville, AR, covering greens at -9.4 °C reduced total covering events from 18 to 4 when compared to covering at -4.0 °C, and increased the total potential days open for play by 41 days (Table 10). Using the previously discussed labor costs for covering putting greens from Jared Nemitz (The Peninsula Club, Cornelius NC, personal communication) and applying them to this research, would have resulted in a two-year, $10,388 labor savings by reducing the covering temperature from -4.0 °C to -9.4 °C (Table 10). This significant beneficial financial effect can be further enhanced when coupled by the potential increase in revenue from remaining open for play more days throughout the winter months.

During both seasons, ‘Champion’ consistently had less green turfgrass coverage compared to ‘MiniVerde’ and ‘TifEagle’. Reductions in green turfgrass coverage in ‘Champion’ may be due to increased winter injury sustained by ‘Champion’ during both winters. This is consistent with Anderson et al. (2002) who reported ‘Champion’ to be the least cold-hardy of the three cultivars used in this research. Using similar methodology as Anderson et al. (2002), Kauffman (2010) reported the freeze-tolerance levels of ‘Champion’ (-9.0 °C) and ‘TifEagle’ (-10.0 °C) to be similar in a laboratory setting. Although not statistically different, the one-degree difference in freeze-tolerance levels between ‘TifEagle’ and ‘Champion’ could partially explain increased levels of winter injury sustained by ‘Champion’ in this study. Increased rates of spring green-up achieved by ‘TifEagle’ and ‘MiniVerde’ compared to ‘Champion’ could potentially reduce total days of golf being played on a dormant putting surface and also lower the risk of losing turfgrass due to fatal winter injury. Future research investigating genetic differences between the three cultivars used in this research may help explain differences in cold tolerance between cultivars.

In this study, the late-fall wetting agent application had an inconsistent effect on soil volumetric water content. The wetting agent application may have allowed increased surface infiltration of water but may not have resulted in a subsequent increase in water retention. Leinauer et al. (2001) stated that the type of wetting agent, soil composition, and application rate may all influence soil moisture retention at different depths in the soil profile. The ability of the wetting agent application to increase green turfgrass coverage during 2016 may have been influenced more by increased water infiltration, hindering formation of LDS, compared to increased overall soil water content. Localized dry spot may increase winter injury resulting in reduced green turfgrass coverage. Localized dry spot is reported to form after extended periods of soil dry down (Soldat et al., 2010). In this study where wetting agent applications were made, water likely infiltrated more readily after periods of soil dry down, resulting in a reduction of LDS formation leading to a decrease in winter injury. Beneficial effects of the wetting agent application may have been reduced in 2017 due to differences in the timing of precipitation events between years. Although total precipitation was greater in 2016, precipitation totals in 2016 were lower during spring compared to 2017 (Table 11). Increased precipitation in spring 2017 may have reduced the potential beneficial effects of a late-season wetting agent application that would otherwise have been manifest in a year with less precipitation.

Volumetric water contents also varied statistically between cover treatments. In 2017, the uncovered treatment consistently had less volumetric water content compared to all cover temperature treatments, but this effect was not seen in 2016. Because this research was designed to mimic a transition-zone golf course, covers were removed for extended periods throughout both winters during periods of warm weather. Results may have differed if protective covers remained on the experimental area throughout the entire winter. Shashikumar and Nus (1993) covered various cultivars of bermudagrass from mid-December through April and reported consistently greater crown moisture contents in covered bermudagrass compared to an uncovered control. Throughout the trial, no single cover treatment retained more moisture than other cover treatments and effects on volumetric water content were inconsistent. Protective covers composed of different materials of varying thickness may be further researched to quantify effects on soil moisture retention.

Research investigating the effects of a late-fall wetting agent application on soil moisture distribution is lacking. However, several common wetting agents were reported to increase soil moisture uniformity on experimental sand-based creeping bentgrass putting greens during summer months (Karcher and Richardson, 2014; Soldat et al., 2010). In this research, the lack of a consistent trend in the ability of a wetting agent to reduce standard deviation of volumetric water content showed soil moisture distribution was marginally affected by wetting agent application, if at all. Making repeated winter wetting agent applications may increase the ability of a wetting agent to affect soil moisture distribution but further research is needed to substantiate this claim. Nonetheless, the wetting agent treatment did enhance survival in one year of the trial, which could justify its use as a preventative measure against desiccation, especially in regions prone to dry winter conditions.

CONCLUSIONS

This study showed the ultradwarf bermudagrass cultivars ‘MiniVerde’ and ‘TifEagle’ to be significantly more cold-tolerant than ‘Champion’ ultradwarf bermudagrass during two winters in Fayetteville, AR. Protective covers enhanced winter survival across all cultivars, regardless of temperature used for their implementation. Differences in winter injury between various cover temperature thresholds, although often statistically significant, were not of practical significance to a golf course superintendent. Substantial cost savings associated with cover installation and removal events were realized by reducing the low-temperature threshold for covering ultradwarf greens without negatively impacting turf survival. The ability of a late-season wetting agent application to significantly reduce winter injury of ultradwarf bermudagrass was inconsistent across two winter seasons, but may potentially be applied as insurance against winter tissue desiccation.

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Figure legends

Figure 1. Example replicate of treatment structure and experimental design.

Figure 2. Average weekly minimum soil temperatures under various cover temperature treatments during two winters in Fayetteville, AR.

Figure 3. Effect of cover temperature x day of year on green turfgrass coverage during the spring of 2016. Error bar indicates least significant difference for comparing means ($p < 0.05$).

Figure 4. Effect of cultivar x day of year on green turfgrass coverage during spring 2016. Error bar indicates least significant difference for comparing means ($p < 0.05$).

Figure 5. Effect of wetting agent x day of year on green turfgrass coverage during spring 2016. Asterisk indicates date with significant difference between treatment means ($p < 0.05$).

Figure 6. Effect of wetting agent x cultivar x cover temperature on green turfgrass coverage during spring 2016. Treatment means are not statistically different in plots containing “ns” according to LSD (0.05).

Figure 7. Effect of cultivar x cover treatment x day of year on green turfgrass coverage during spring 2017. Error bar represents least significant difference for comparing means ($p < 0.05$).

Figure 8. Effect of wetting agent x month on soil volumetric water content during spring 2016 and 2017. Asterisk indicates date with significant difference between treatment means ($p < 0.0001$).

Figure 9. Effect of cover temperature x month on soil volumetric water content during spring 2016. Error bar indicates least significant difference for comparing means ($p < 0.05$).

Figure 10. Effect of cover temperature x month on soil volumetric water content during spring 2017. Error bar indicates least significant difference for comparing means ($p < 0.05$).

Figure 11. Average monthly high and low temperature deviation from 30-yr. average during winter and spring 2016 and 2017.

Table 1. Analysis of variance testing the main effects and their interactions on green turfgrass coverage during the spring of 2016 and 2017.

Treatment factor	% Green turfgrass coverage (2016)	% Green turfgrass coverage (2017)
	——— *P* > F ———	
Cultivar (Cv)	NS†	0.0001
Cover temperature (Temp)	NS	<.0001
Cv*Temp	NS	0.0003
Wetting agent (WA)	<.0001	NS
Cv*WA	NS	NS
Temp*WA	NS	NS
Cv*Temp*WA	0.0136	NS
Day of year (DOY)	<.0001	<.0001
Cv*DOY	<.0001	<.0001
Temp*DOY	<.0001	<.0001
Cv*Temp*DOY	NS	<.0001
WA*DOY	<.0001	NS
Cv*WA*DOY	NS	NS
Temp*WA*DOY	NS	NS
Cv*Temp*WA*DOY	NS	NS

† NS, nonsignificant at the 0.05 probability level.

Table 2. Analysis of variance testing the main effects and their interactions on soil volumetric water content (m^3 m^{-3}) and the standard deviation of soil volumetric water content during the spring of 2016.

Treatment factor	**Soil volumetric water content**	**Standard deviation† of soil volumetric water content**
	P > *F*	
Cultivar (Cv)	NS‡	0.048
Cover Temperature (Temp)	NS	NS
Cv*Temp	NS	NS
Wetting Agent (WA)	<.0001	NS
Cv*WA	NS	NS
Temp*WA	NS	NS
Cv*Temp*WA	NS	NS
Month	<.0001	<.0001
Cv*Month	NS	0.0003
Temp*Month	0.0112	NS
Cv*Temp*Month	NS	NS
WA*Month	<.0001	0.0084
Cv*WA*Month	NS	NS
Temp*WA*Month	NS	NS
Cv*Temp*WA*Month	NS	NS

† Standard deviation of volumetric water content used as indicator of soil moisture variability within plots.

‡ NS, nonsignificant at the 0.05 probability level.

Table 3. Effect of cultivar x month interaction on standard deviation of volumetric water content during the winter/spring of 2016.

	Champion	**MiniVerde**	**TifEagle**
	Standard deviation†		
Jan. 2016	1.04 a‡	0.76 b	0.71 b
Feb. 2016	1.57 a	1.32 b	1.32 b
Mar. 2016	1.42 a	1.01 b	0.95 b
Apr. 2016	1.04 a	1.03 a	0.99 a
May 2016	1.16 a	0.76 b	0.82 b

† Standard deviation of volumetric water content used as indicator of soil moisture variability within plots.

‡ Within rows, values followed by the same letter are not significantly different according to LSD (0.05)

Table 4. Effect of wetting agent x month interaction on standard deviation of soil volumetric water content during the winter/spring of 2016.

	Wetting agent	Untreated
	Standard deviation†	
Jan. 2016	0.81 a‡	0.86 a
Feb. 2016	1.49 a	1.32 b
Mar. 2016	1.13 a	1.12 a
Apr. 2016	1.10 a	0.91 b
May 2016	0.91 a	0.91 a

† Standard deviation of volumetric water content used as indicator of soil moisture variability within plots.

‡ Within rows, values followed by the same letter are not significantly different according to LSD (0.05).

Table 5. Analysis of variance testing the main effects and their interactions on soil volumetric water content and the standard deviation of soil volumetric water content during the spring of 2017.

Treatment effect	Soil volumetric water content	Standard deviation† of soil volumetric water content
	P > *F*	
Cultivar (Cv)	NS‡	0.0432
Cover Temperature (Temp)	0.0187	NS
Cv* Temp	NS	NS
Wetting agent (WA)	0.0003	0.0143
Cv*WA	NS	NS
Temp*WA	0.0324	NS
Cv* Temp*WA	NS	NS
Month	<.0001	<.0001
Cv*Month	NS	NS
Temp*Month	<.0001	0.0429
Cv*Temp*Month	NS	NS
WA*Month	<.0001	0.0120
Cv*WA*Month	NS	NS
Temp*WA*Month	NS	NS
Cv*Temp*WA*Month	NS	NS

† Standard deviation of volumetric water content used as indicator of soil moisture variability within plots.

‡ NS, nonsignificant at the 0.05 probability level.

Table 6. Main effect of cultivar on standard deviation of volumetric water content during the winter/spring of 2017.

Cultivar	Standard deviation†
Champion	1.63 a‡
MiniVerde	1.35 b
TifEagle	1.38 b

† Standard deviation of volumetric water content used as indicator of soil moisture variability within plots.

‡ Values followed by the same letter are not significantly different according to LSD (0.05).

Table 7. Effect of wetting agent x cover temperature interaction on soil volumetric water content during winter/spring of 2017.

	Volumetric water content	
Cover temp.	Wetting agent	Untreated
°C	m^3 m^{-3}	
No cover	9.6 d†	9.8 d
-9.4	11.1 bc	10.8 c
-7.8	11.6 ab	10.9 c
-5.6	11.8 a	11.2 bc
-4.0	11.8 a	11.4 b

† Values followed by the same letter are not significantly different according to LSD (0.05).

Table 8. Effect of wetting agent x month on standard deviation of soil volumetric water content (%) during winter/spring of 2017.

	Wetting agent	Untreated
	Standard deviation†	
15 Jan. 2017	1.4 a‡	1.4 a
31 Jan. 2017	1.3 a	1.4 a
15 Feb. 2017	1.5 b	1.7 a
28 Feb. 2017	1.2 a	1.2 a
15 Mar. 2017	1.4 a	1.5 a
30 Mar. 2017	1.4 b	1.7 a
15 Apr. 2017	1.3 a	1.2 a
30 Apr. 2017	1.7 b	2.0 a

† Standard deviation of volumetric water content used as indicator of soil moisture variability within plots.

‡ Values followed by the same letter are not significantly different according to LSD (0.05).

Table 9. Effect of cover temperature x month on standard deviation of soil volumetric water content during winter/spring of 2017.

	No cover	**-9.4 °C**	**-7.8 °C**	**-5.6 °C**	**-4.0 °C**
	Standard deviation†				
15 Jan. 2017	1.31 bc‡	1.56 ab	1.28 bc	1.62 a	1.23 c
31 Jan. 2017	1.32 a	1.20 a	1.39 a	1.44 a	1.36 a
15 Feb. 2017	1.69 a	1.64 a	1.41 a	1.56 a	1.53 a
28 Feb. 2017	1.25 a	1.26 a	1.25 a	1.20 a	1.10 a
15 Mar. 2017	1.45 ab	1.60 a	1.33 ab	1.27 b	1.37 ab
30 Mar. 2017	1.44 b	1.62 b	1.35 b	1.96 a	1.46 b
15 Apr. 2017	1.40 a	1.32 a	1.18 a	1.34 a	1.15 a
30 Apr. 2017	1.71 a	1.88 a	1.87 a	1.86 a	1.79 a

† Standard deviation of volumetric water content used as indicator of soil moisture variability within plots.

‡ Within rows, values followed by the same letter are not significantly different according to LSD (0.05).

Table 10. Summary of total covering events and equivalent potential labor cost reduction by reducing cover temperature threshold.

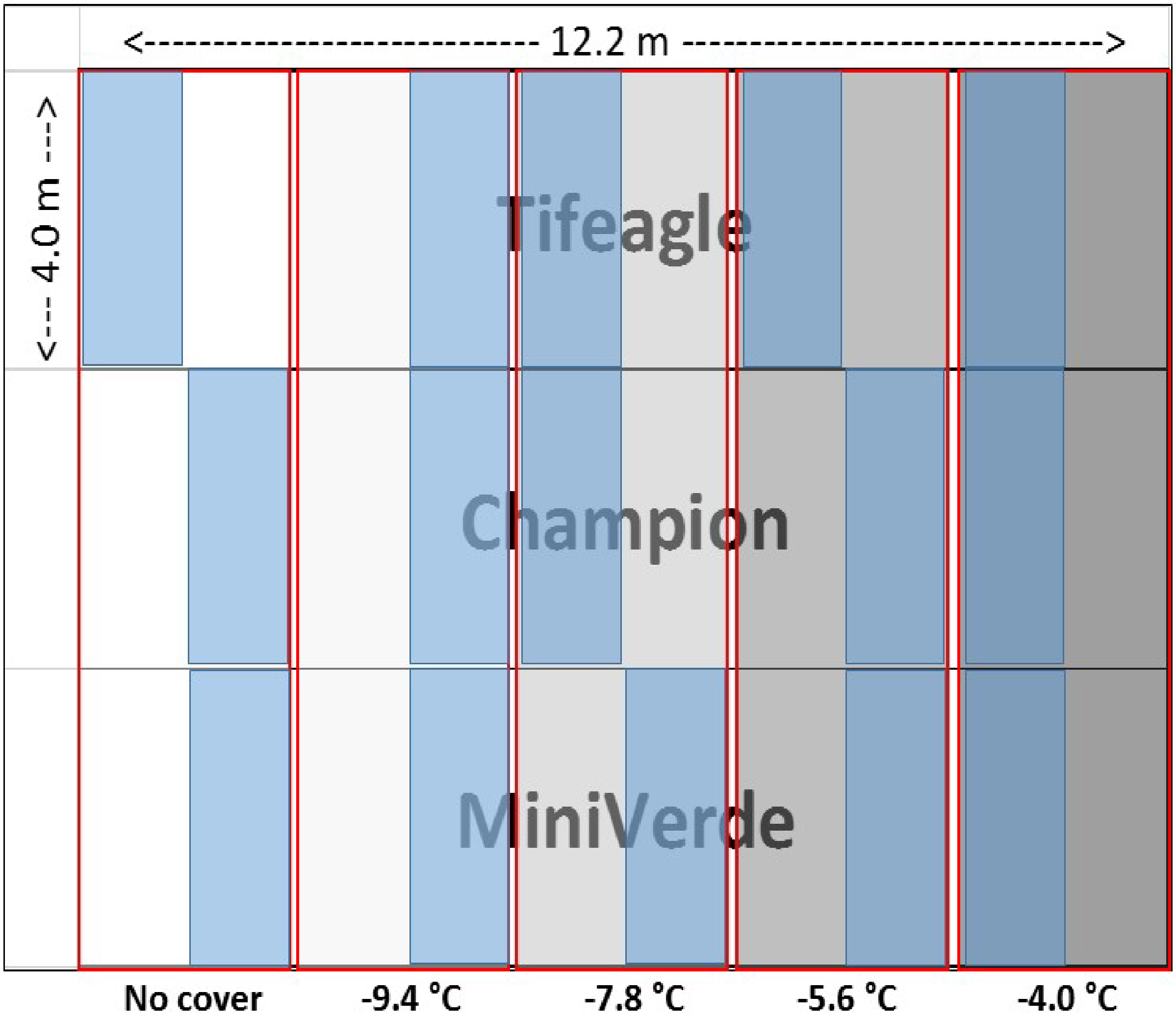
Cover temperature	Total covering events	Total days covered	Potential savings†	Increased days open for play
-4.0 °C	18	60	-	-
-5.6 °C	14	53	$2,968	7
-7.8 °C	6	28	$8,904	32
-9.4 °C	4	19	$10,388	41

† Based on average labor costs for installation and removal of all covers at The Peninsula Club, Cornelius, NC (Jared Nemitz, personal communication).

Table 11. Monthly total rainfall in Fayetteville, AR during the winter and spring of 2015-2016 and 2016-2017.

Year	Monthly precipitation†							
	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	Total
	mm							
2015-2016	214	278	13	16	92	100	140	853
2016-2017	21	46	54	28	152	327	159	787

† Precipitation totals as reported by the National Oceanic and Atmospheric Administration.



<--- 12.2 m --->
<--- 4.0 m --->
Tifeagle
Champion
MiniVerde
No cover
-9.4 °C
-7.8 °C
-5.6 °C
-4.0 °C

Figure 1.

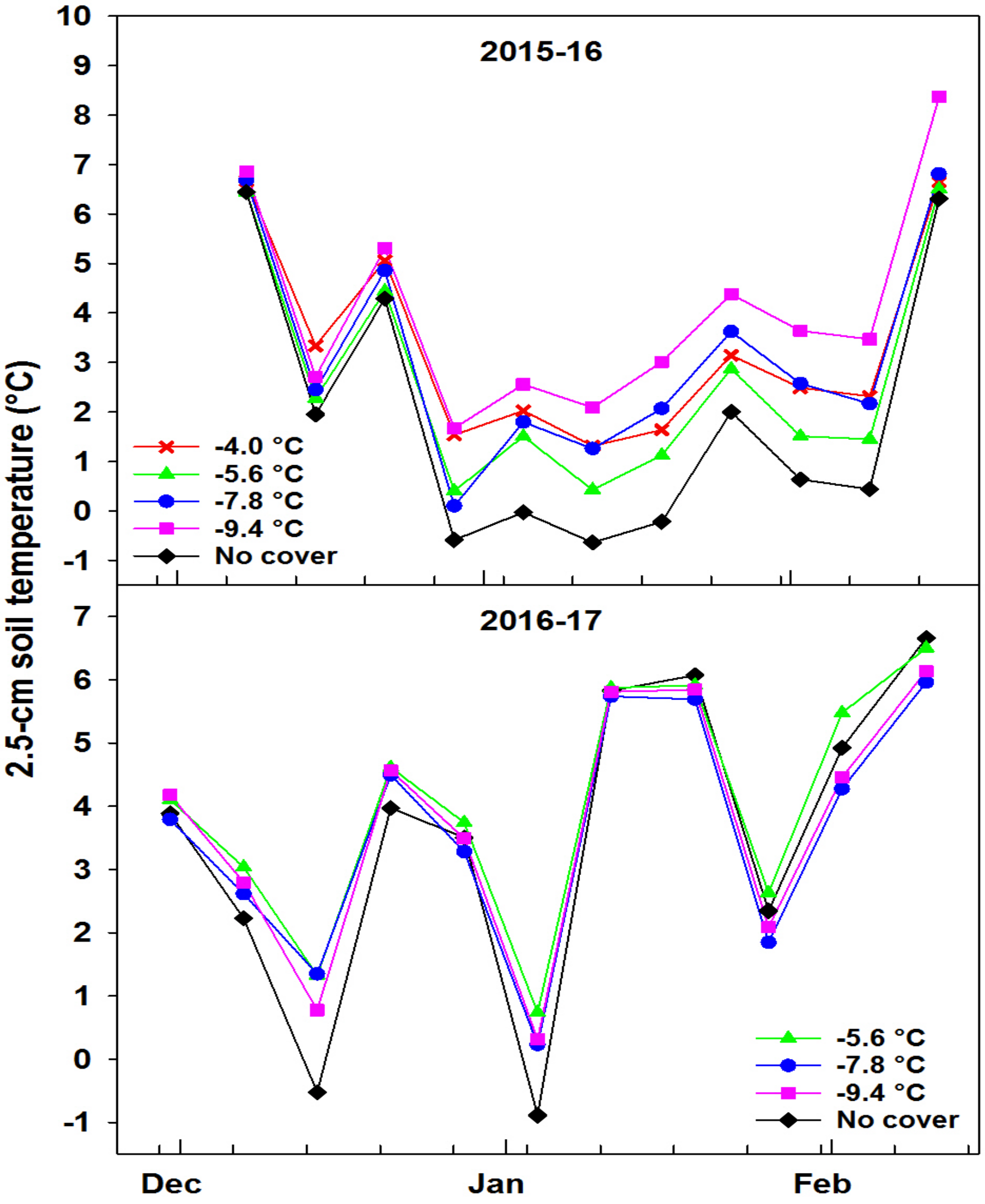

2015-16
2016-17
2.5-cm soil temperature (°C)
10
9
8
7
6
5
4
3
2
1
0
-1
-4.0 °C
-5.6 °C
-7.8 °C
-9.4 °C
No cover
Dec
Jan
Feb

Figure 2.

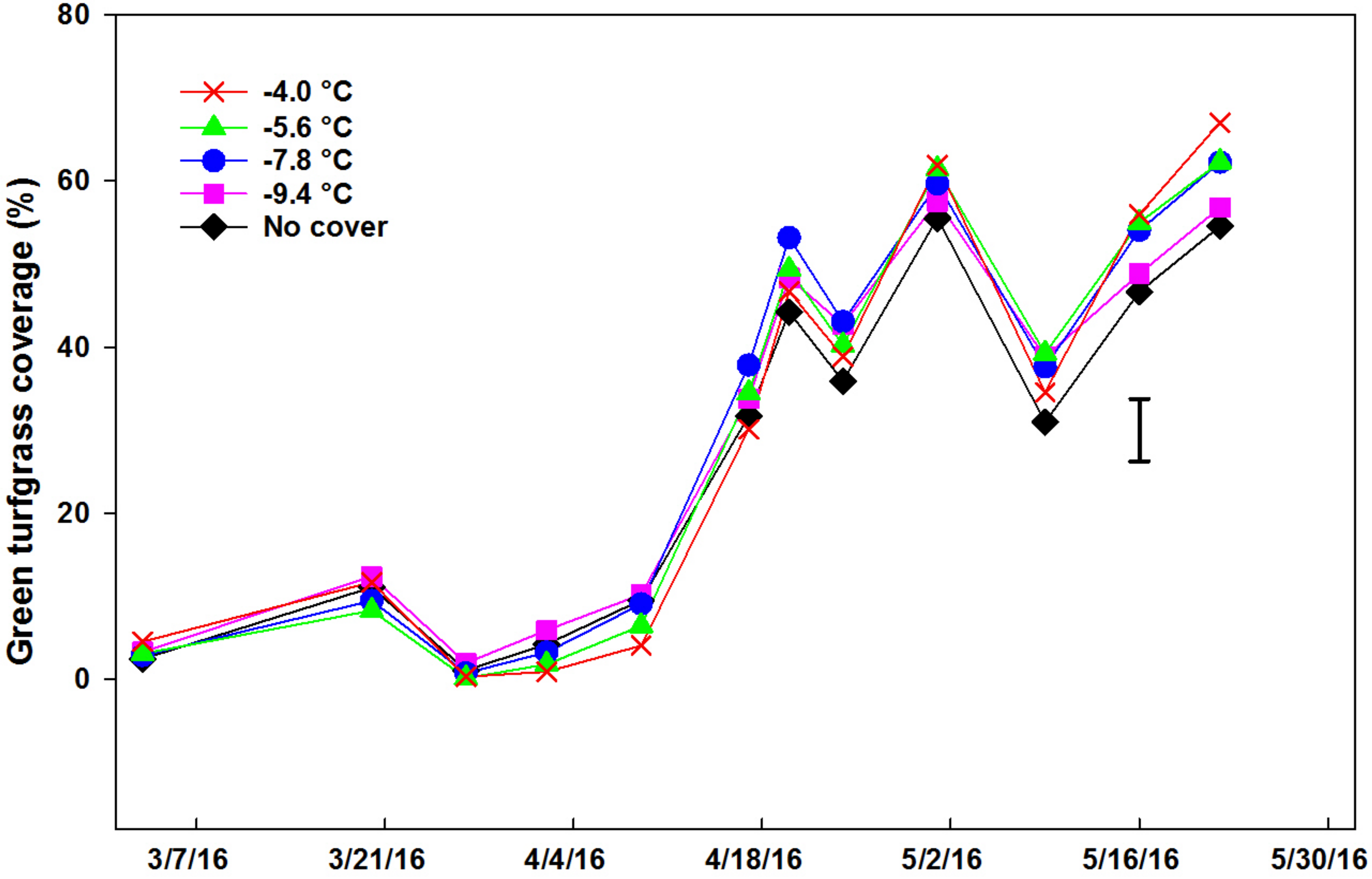

80
60
40
20
0
Green turfgrass coverage (%)
-4.0 °C
-5.6 °C
-7.8 °C
-9.4 °C
No cover
3/7/16
3/21/16
4/4/16
4/18/16
5/2/16
5/16/16
5/30/16

Figure 3.

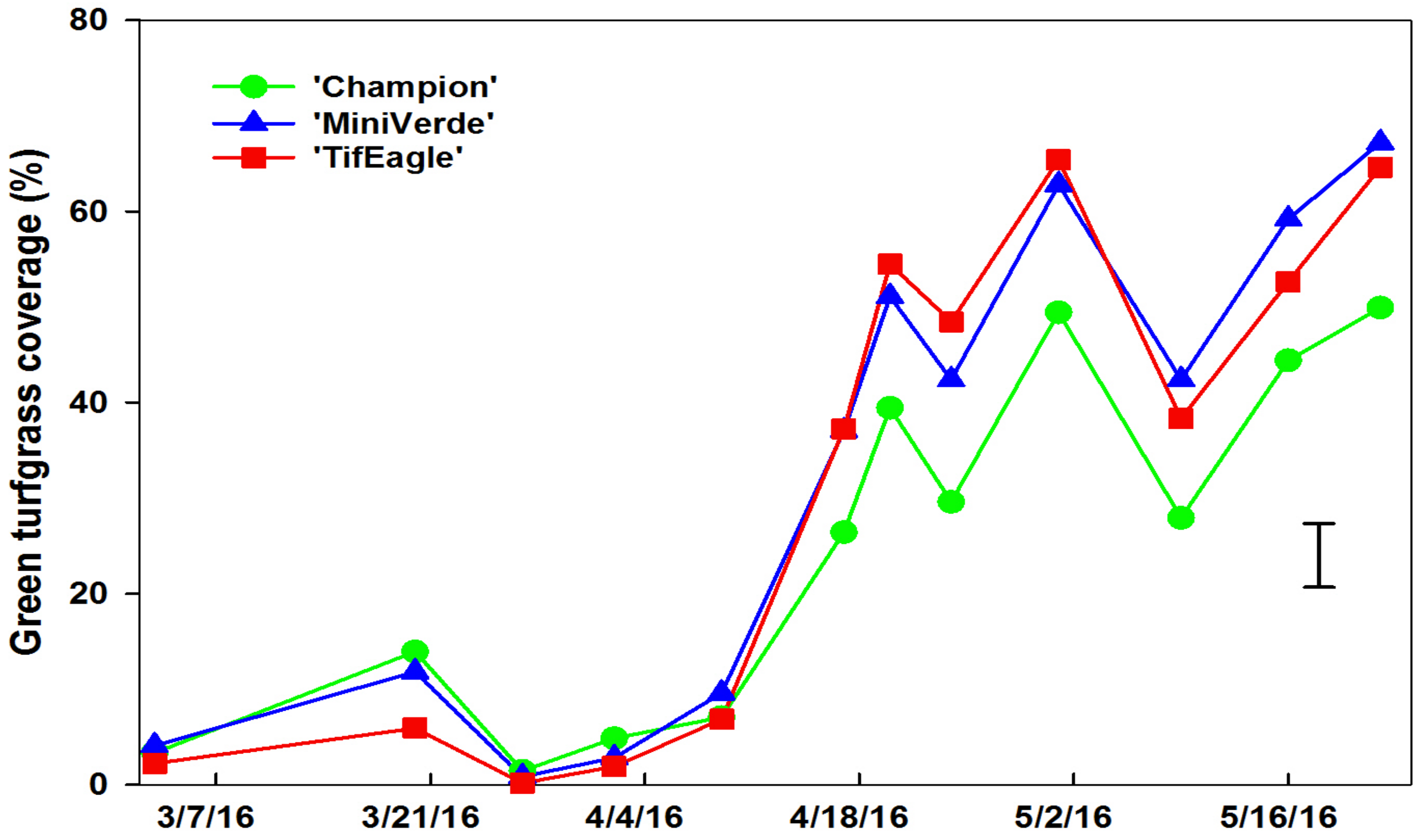
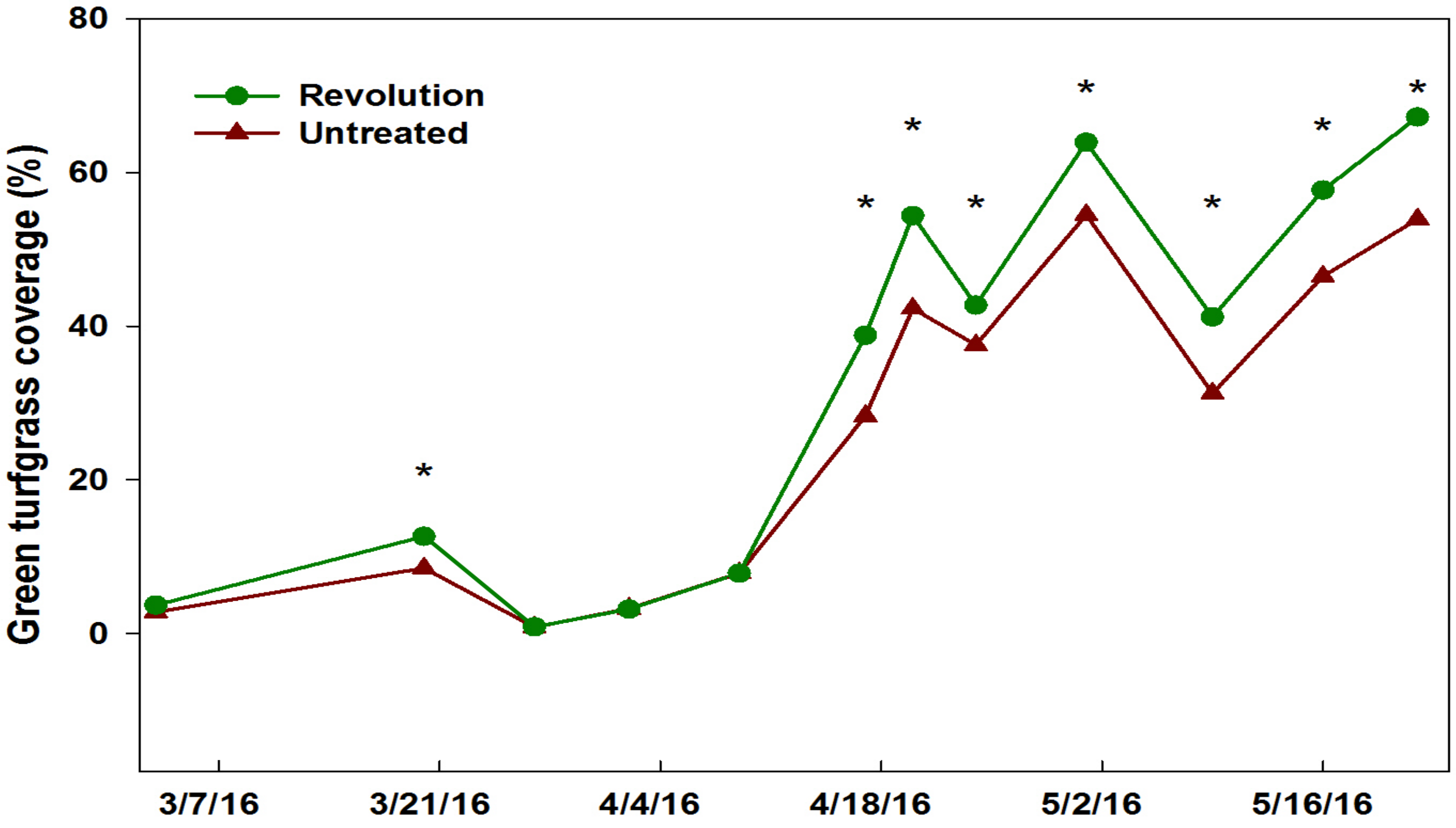

80
60
40
20
0
Green turfgrass coverage (%)
'Champion'
'MiniVerde'
'TifEagle'
3/7/16
3/21/16
4/4/16
4/18/16
5/2/16
5/16/16

Figure 4.



Green turfgrass coverage (%)
80
60
40
20
0
Revolution
Untreated
*
3/7/16
3/21/16
4/4/16
4/18/16
5/2/16
5/16/16

Figure 5.

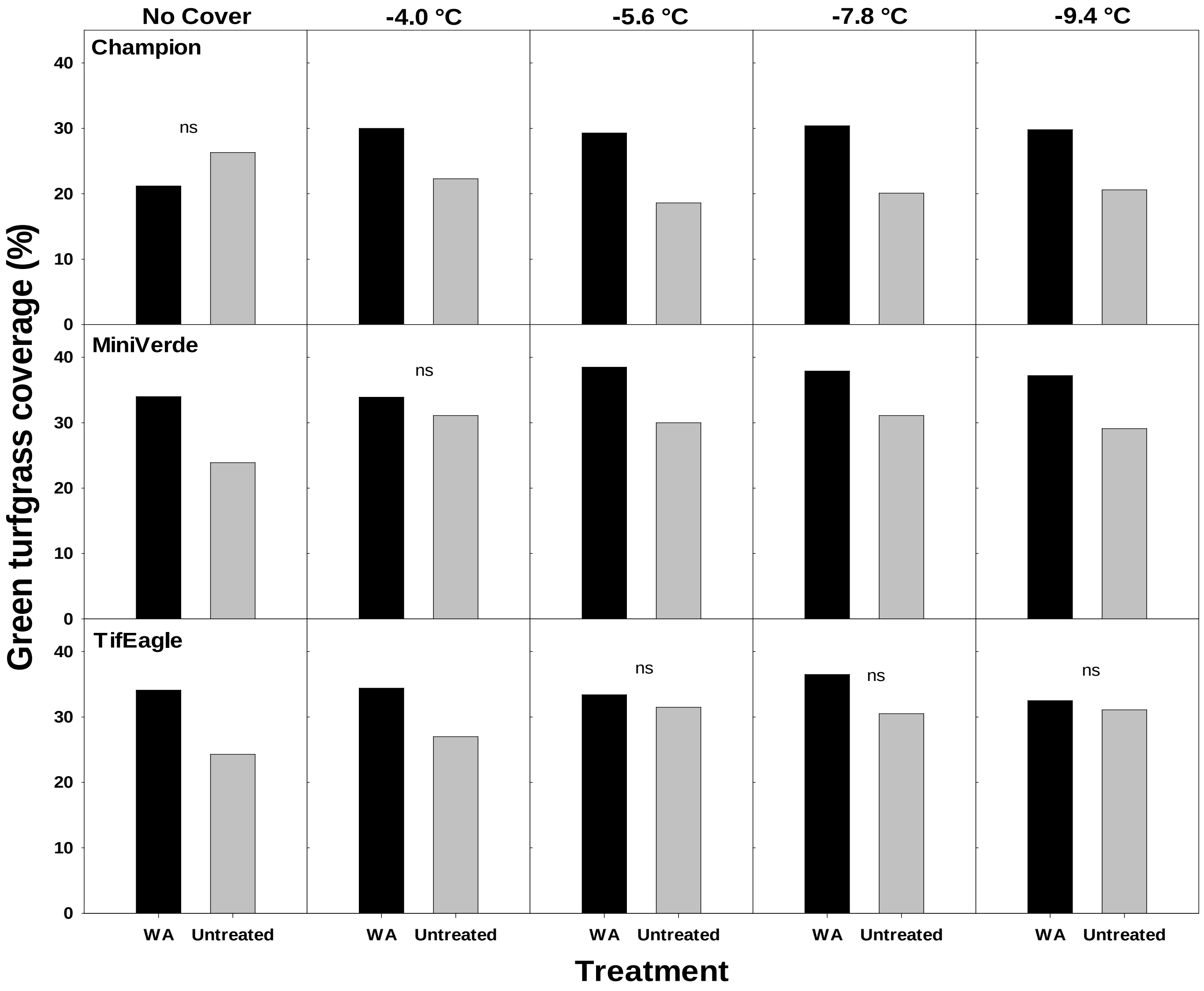
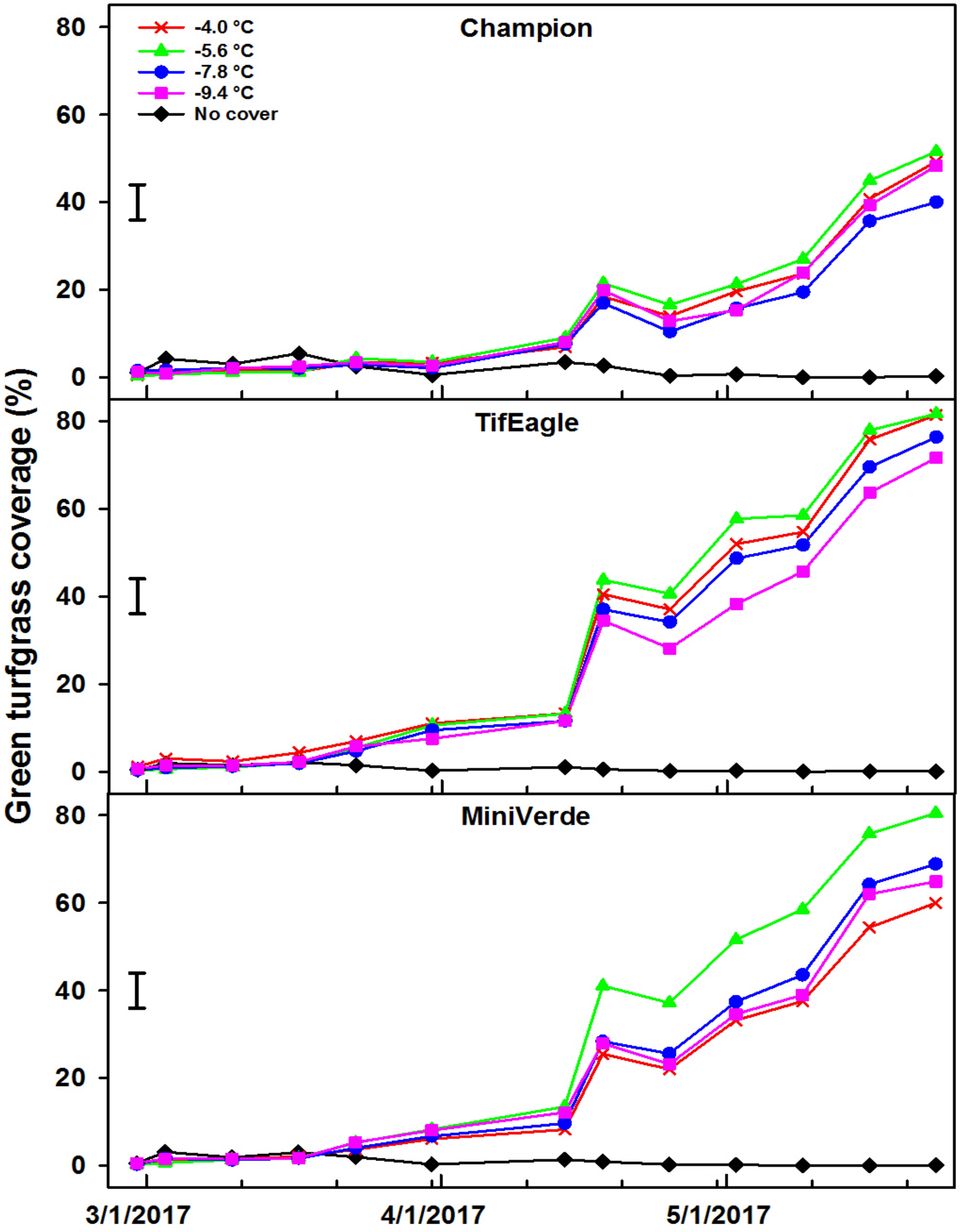

No Cover
-4.0 °C
-5.6 °C
-7.8 °C
-9.4 °C
Champion
MiniVerde
TifEagle
ns
ns
ns
ns
ns
Green turfgrass coverage (%)
0
10
20
30
40
WA
Untreated
Treatment

Figure 6.



-4.0 °C
-5.6 °C
-7.8 °C
-9.4 °C
No cover
Champion
TifEagle
MiniVerde
Green turfgrass coverage (%)
0
20
40
60
80
3/1/2017
4/1/2017
5/1/2017

Figure 7.

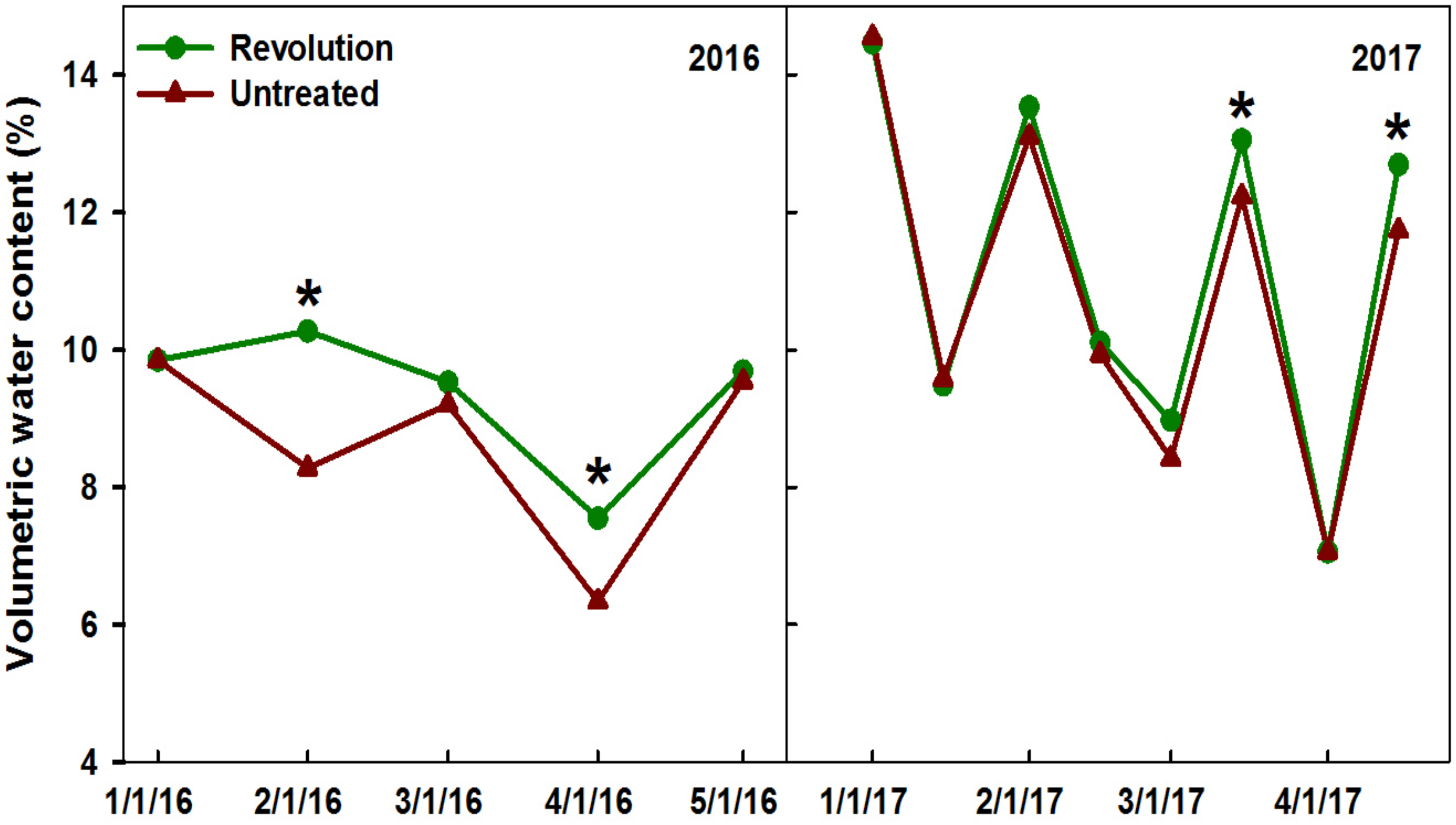

Revolution
Untreated
2016
2017
Volumetric water content (%)
4
6
8
10
12
14
*
*
*
*
1/1/16
2/1/16
3/1/16
4/1/16
5/1/16
1/1/17
2/1/17
3/1/17
4/1/17

Figure 8.

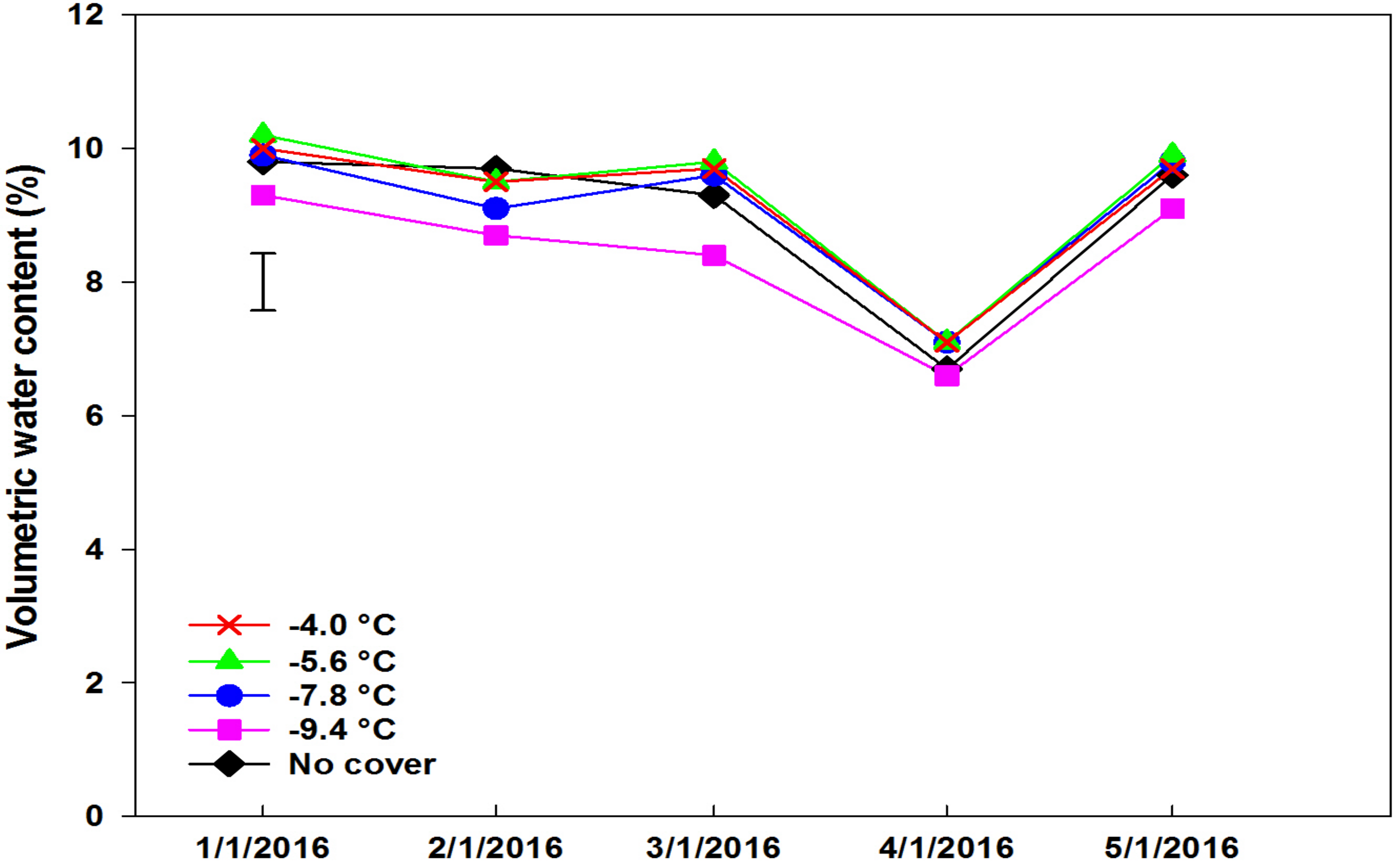

Volumetric water content (%)
12
10
8
6
4
2
0
1/1/2016
2/1/2016
3/1/2016
4/1/2016
5/1/2016
-4.0 °C
-5.6 °C
-7.8 °C
-9.4 °C
No cover

Figure 9.

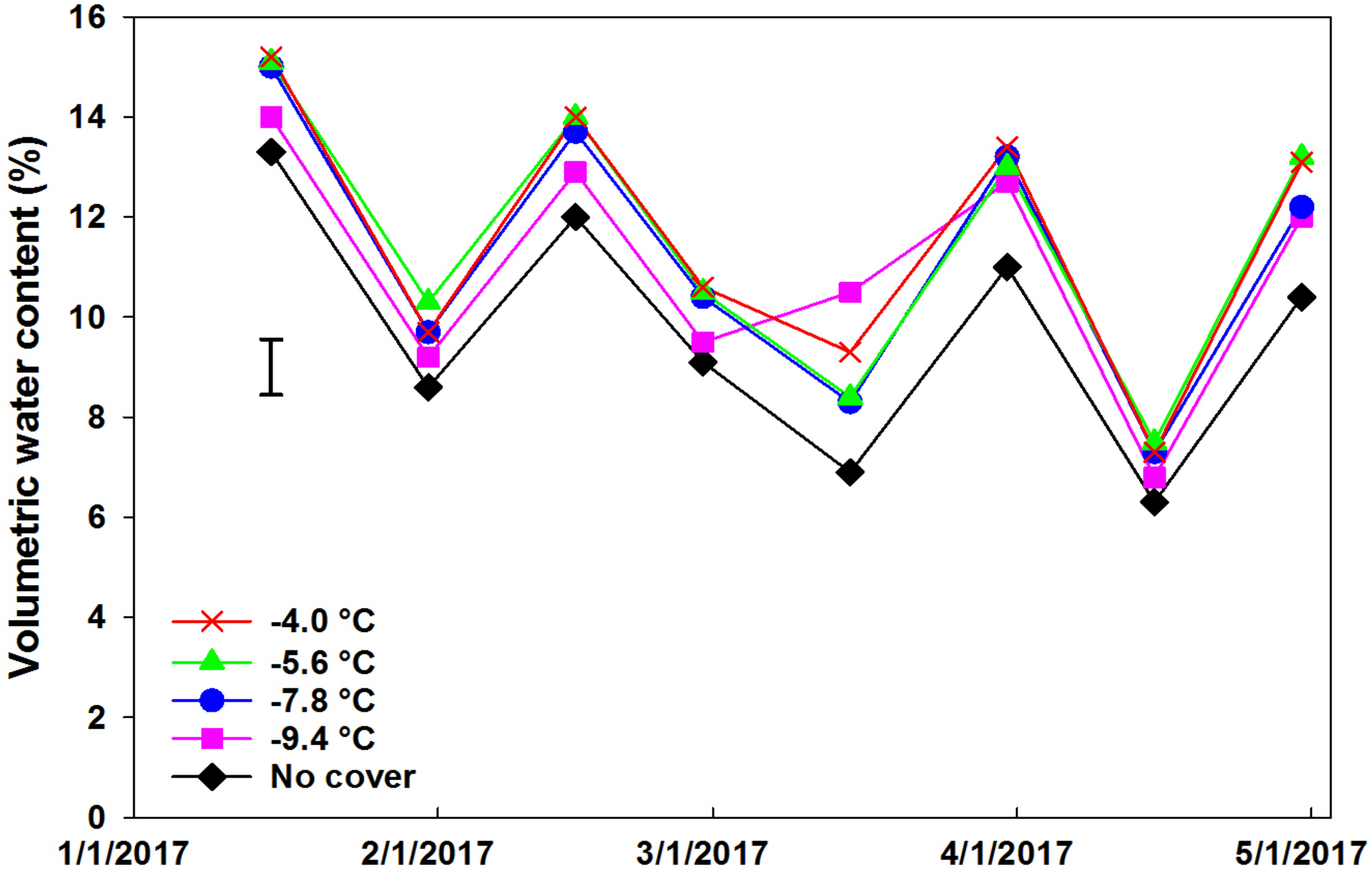

Volumetric water content (%)
16
14
12
10
8
6
4
2
0
1/1/2017
2/1/2017
3/1/2017
4/1/2017
5/1/2017
-4.0 °C
-5.6 °C
-7.8 °C
-9.4 °C
No cover

Figure 10.

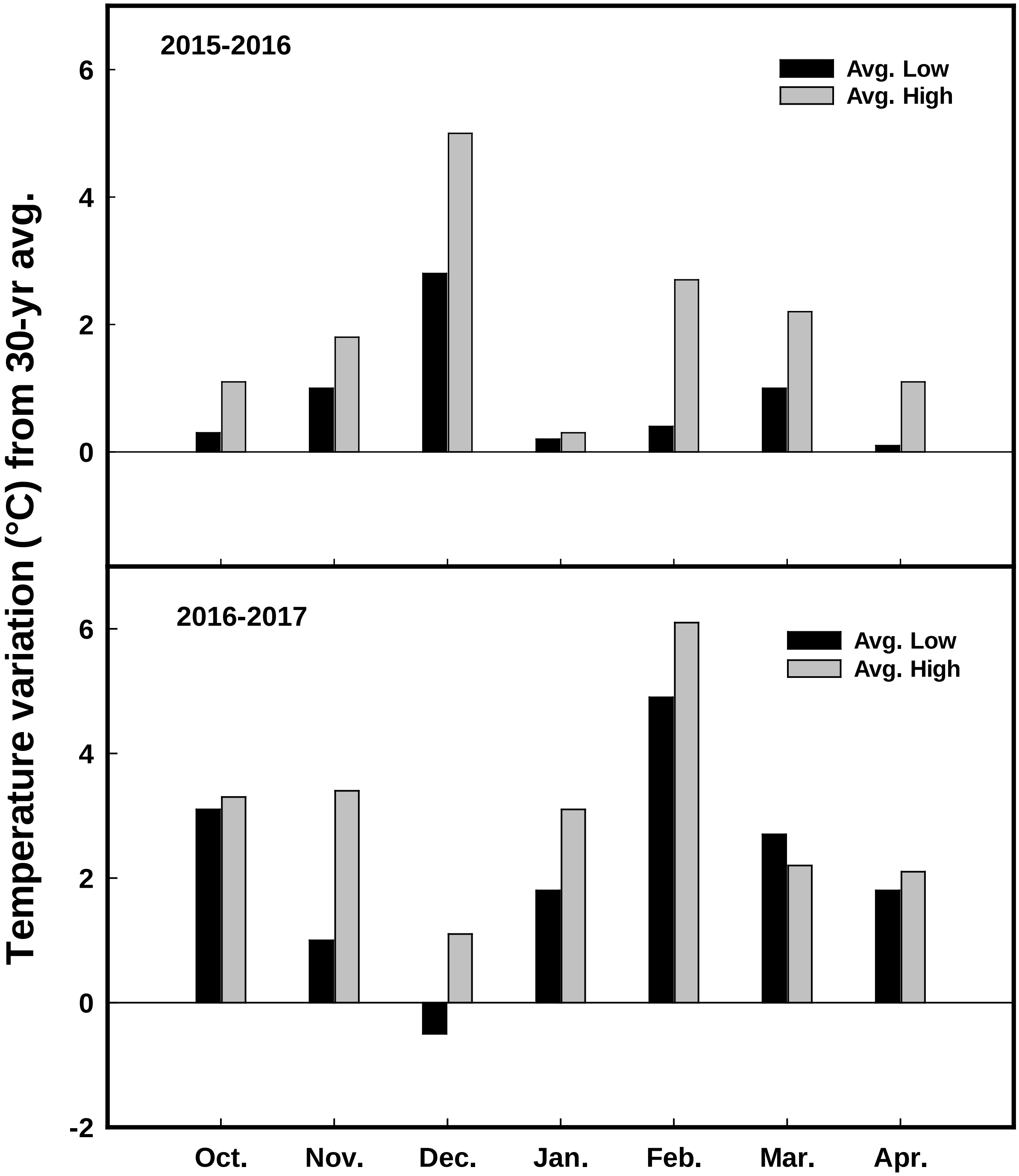

2015-2016
Avg. Low
Avg. High
2016-2017
Avg. Low
Avg. High
Temperature variation (°C) from 30-yr avg.
6
4
2
0
-2
Oct.
Nov.
Dec.
Jan.
Feb.
Mar.
Apr.

Figure 11.

Effect of late-fall wetting agent application on winter survival of ultradwarf bermudagrass putting greens

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and John H. McCalla

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Abbreviations: DIA, digital image analysis; DOY, day of year; LDS, localized dry spot; N, nitrogen; UAAREC, University of Arkansas Agricultural Research and Extension Center; WA, wetting agent. WDPT, water drop penetration time.

ABSTRACT

Winter injury is a common problem for transition zone ultradwarf bermudagrass (*Cynodon dactylon x C. transvaalensis)* putting greens. One possible cause of winter injury is plant tissue desiccation. Desiccation injury can be caused by the formation of hydrophobic soils resulting in irregular-shaped patches of injured turf. Wetting agents are commonly applied to actively growing ultradwarf greens to relieve or prevent plant stress from hydrophobic soils. Less is known about the effects of a late-fall wetting agent application to dormant bermudagrass greens. This research aimed to quantify any reduction in winter injury by making a late-season wetting agent application to a dormant ultradwarf bermudagrass putting green, as well as the effect of late-season wetting agent application on soil volumetric water content. Single applications of three commonly used wetting agents were made to sand-based ultradwarf bermudagrass putting greens and were compared to an untreated control. Wetting agents were applied at the label rate (1x) and twice the label rate (2x) to quantify any residual benefits of making a more concentrated application. Spring green-up was determined by quantifying percent green turfgrass coverage through digital image analysis. Soil volumetric water content was monitored bi-weekly using time-domain reflectometry. Water drop penetration tests were conducted on air-dried soil cores 2 weeks after application and again the following spring to quantify any reductions in hydrophobicity compared to the untreated control. On multiple dates during spring 2016, wetting agent treatments had significantly more green turfgrass coverage when compared to the control. These effects were not significant during 2017. Wetting agents significantly reduced water drop penetration times with the 2x rate of Revolution providing the most consistent ability to reduce hydrophobicity. This research suggested that a golf course

without the option of irrigating during the winter may benefit through the one-time application of a wetting agent in the late-fall.

BACKGROUND

Winter injury is a common problem for transition zone ultradwarf bermudagrass [*Cynodon dactylon* (L.) Pers. × *C. transvaalensis* Burtt Davy] putting greens. One factor that may be contributing to winter injury of ultradwarfs is desiccation caused by hydrophobic soils. Soil hydrophobicity often occurs in sandy soils. Jamison (1946) described sandy surface soils in citrus groves located in central Florida that resisted wetting from irrigation and precipitation even during the summer rainy season. Hydrophobicity has also been documented in watersheds of burned forest land in southern California (DeBano et al., 1970). Sandy soils are preferred for use as putting green rootzones due to their resistance to compaction and rapid water drainage potential (Lunt, 1956). The sandy rootzone mixture of a putting green constructed to USGA specifications (USGA, 2004) can make soil hydrophobicity a major problem. As hydrophobicity pertains to golf course putting greens, areas that become water repellent are most commonly near the upper region of the root zone. This repellency is likely caused by individual sand particles that have become coated with an organic compound exhibiting hydrophobic properties (Miller and Wilkinson, 1977; Henry and Paul, 1978). Localized dry spot (LDS) is a term used in the golf course industry to define irregularly shaped areas of desiccated, brown turf resulting from soil that has become resistant to wetting from both irrigation and rainfall (Beard and Beard, 2005). This is a major issue during summer months on putting greens when uniform moisture distribution throughout the root zone is a necessity for both the playability and the aesthetic property of an intensely managed putting surface.

Wetting agents have become a popular and reliable way to mitigate damage caused by LDS and are utilized for other purposes as well. Wetting agents belong to a chemical group called surfactants or “Surface Active Agents”. Surfactants effectively reduce the surface tension of water by lowering its cohesive properties, allowing water to penetrate the surface of a hydrophobic soil (Karnok et al., 2004), however, the underlying cause of the hydrophobicity may still be present in the rootzone. Studying the efficacy of wetting agents to relieve symptoms of hydrophobicity in the field can be difficult. The ability to predict the formation of hydrophobic soil is not realistic due to many uncontrollable environmental factors responsible for hydrophobic soil formation. In a study on the effects of wetting agents on sand based rootzone hydrophobicity, ten commercially available wetting agents were applied to creeping bentgrass on a ninety-six percent sand based rootzone. Leinauer (et al., 2007) revealed wetting agents could relieve hydrophobicity at depths of 0.5 and 1.5 cm and, as expected, the most hydrophobic soils exhibited the lowest turf stand quality.

Testing various wetting agents in a controlled setting, Song et al., (2014) showed laboratory constructed hydrophobic sand root zones treated with various wetting agents when compared to the untreated controls had increased water infiltration rates and enhanced soil rewettability, the capacity of a soil to absorb water after a period of drying, although results were not consistent across all products tested. Karnok and Tucker (2001) performed a study to determine the impact of a soil wetting agent on soil hydrophobicity, as well as root growth and shoot quality of ‘Penncross’ creeping bentgrass. The study was conducted using root observation chambers at the University of Georgia Rhizotron in Athens, GA. Observation chamber root zones were constructed according to United States Golf Association Green Section specifications and the top 10.1 cm of the root zone consisted of a hydrophobic soil. The wetting agent used in the study reduced soil hydrophobicity for up to 12 weeks after application. Turfgrass color and quality, as well as root length, were also found to be superior in wetting agent treatments compared to the control. Because only one specific wetting agent was used, the authors could not speculate if these effects would be observed using other wetting agent products (Karnok and Tucker, 2001).

In the field, beneficial effects from wetting agents can be short lived. Wetting agents are commonly applied to putting greens many times throughout the spring and summer months. Golf course superintendents commonly cease wetting agent applications to ultradwarf bermudagrass putting greens in the fall months or once turf begins to enter dormancy. Since wetting agents do not cure the root cause of soil hydrophobicity, soils may remain hydrophobic during the winter, resulting in turfgrass desiccation due to soil water repellency, even though symptoms (LDS) may not be evident due to the dormant state of the turf.

Research is currently lacking regarding the effect of a late-season wetting agent application to dormant ultradwarf bermudagrass putting green turf for the purpose of combating winter turfgrass desiccation. It was hypothesized that a late-season wetting agent application would reduce winter injury, reduce soil hydrophobicity, and increase soil volumetric water content. The main objective of this research was to examine the effect of a late-fall application of various commercially available wetting agents and treatment rates on winter injury reduction of ultradwarf bermudagrass, winter soil hydrophobicity, and soil moisture content and uniformity.

MATERIALS AND METHODS

A two-year, multiple-site field study was conducted at the University of Arkansas Agricultural Research and Extension Center (UAAREC) in Fayetteville, Arkansas (36.10° N, 94.17° W) during the winters of 2015-2016 and 2016-2017. Research was also conducted at The Blessings Golf Club in Johnson, AR (36.13° N, 94.20° W) in 2015-2016 and at Scotsdale Golf Course in Bella Vista, AR (36.48° N, 94.30° W) in 2016-2017. Research at the UAAREC during both seasons was conducted on a putting green with a sand-based root zone with 5-year-old 'TifEagle' ultradwarf bermudagrass. Research at the Blessings Golf Club was conducted on experimental plots of 4-year-old 'Champion' ultradwarf bermudagrass grown on a sand-based practice putting green (United States Golf Association, 2004). Research at Scotsdale Golf Course was conducted on a nursery of 2-year-old 'Champion' ultradwarf bermudagrass grown on a sand-based rootzone.

Experimental plots at the UAAREC measured 0.9 by 0.9 m during winter 2015-2016 and were replicated three times. During winter 2016-2017, experimental plots measured 0.9 by 2.75 m and were replicated four times. Core aerification and use of plant growth regulators were conducted according to typical putting green management practices for the region. Mowing during the growing season was performed 6 d wk^{-1} at a 3.2-mm bench setting height of cut using a Jacobsen Eclipse 322 (Jacobsen, A Textron Company, Charlotte, NC). Approximately one month prior to the onset of winter dormancy, the bench setting height of cut was raised to 3.6 mm. During the growing season, nitrogen (N) was applied bi-weekly at a rate of 8 kg N ha^{-1} alternating between applications of Contec DG 18-9-18 (The Andersons, Maumee, OH) and Thrive 46-0-0 spray grade urea (Mears Fertilizer Inc., El Dorado, KS). Phosphorous, potassium, and micronutrients were applied according to annual soil testing. Irrigation was withheld during the winter months but was applied to replace 100% of reference evapotranspiration throughout the growing season. Sand topdressing applications of 0.3 mm were made on two-week intervals during the growing season. During the growing season, routine wetting agent applications were made to the entire experimental area from May through August, but no wetting agents were applied after September 1 in each growing season. During the winter, a black permeable polypropelene protective cover (Xton Inc., Florence, AL) was placed on the green when forecasted temperatures were predicted to drop below -4.0 °C. The protective cover was removed for favorable weather to mimic a golf course removing covers to allow for play on warmer winter days.

Experimental plots at The Blessings Golf Club measured 0.9 by 0.9 m. Mowing during the growing season was performed daily at a bench setting height of cut of 4.2 mm using a Toro Greensmaster Flex 1800 (The Toro Company, Bloomington, MN). Mowing heights were not raised prior to the onset of winter dormancy. During the growing season, N was applied every other week at a rate of 3.7 kg N ha^{-1} using Harrell’s 46-0-0 spray grade urea (Harrell’s LLC., Lakeland, FL) and Harrell’s bentgrass special 28-5-18 (Harrell’s LLC., Lakeland, FL). Phosphorous, potassium, and micronutrients were applied according to annual soil testing. During the winter months, a black permeable polypropelene protective cover (Xton Inc., Florence, AL) was placed on the green when low temperatures were forecast to reach 0 °C and were removed for favorable weather. Light irrigation was applied during the winter months every time the protective cover was removed. Irrigation was applied at the discretion of the golf course superintendent to replace 100% of reference evapotranspiration during the growing season. Light sand topdressing applications were made weekly during the growing season. Routine wetting agent applications were applied throughout the growing season but were withheld after 1 Oct. 2015. An erroneous wetting agent application was made to the entire experimental area in late-February 2016 prior to the completion of data collection and may have potentially impacted the findings of this trial.

Experimental plots at Scotsdale Golf Course measured 0.9 by 2.75 m. Mowing during the growing season was performed daily at a bench setting height of cut of 2.95 mm using a Jacobsen Greens King IV triplex mower (Jacobsen, A Textron Company, Charlotte, NC). One month prior to the onset of winter dormancy, mowing heights were raised to a bench setting height of cut of 4.5 mm. During the growing season, N was applied every 10 days at a rate of 4.8 kg N ha^{-1} using Harrell’s 46-0-0 spray grade urea (Harrell’s LLC., Lakeland, FL). Phosphorous, potassium, and micronutrients were applied according to annual soil testing. During the winter months, an Evergreen Smart Edge (Evergreen Turf Covers, Mississauga, ON) protective cover was placed on the green when low temperatures were predicted to drop below -4.0 °C and were removed for favorable weather. Irrigation was applied at the discretion of the golf course superintendent to replace 100% of reference evapotranspiration during the growing season. Light sand topdressing applications were made every ten days throughout the growing season. Routine wetting agent applications were applied throughout the growing season but were withheld after 1 October 2016.

The three wetting agents used for this study included: Revolution (Aquatrols, Paulsboro, NJ), Cascade Plus (Precision Laboratories, Waukegan, IL), and Tricure (Mitchell Products, Millville, NJ). Revolution and Tricure were applied at 19 and 38 L ha^{-1}; Cascade Plus was applied at 25.5 and 51 L ha^{-1}. Wetting agents were applied at two rates to quantify any residual benefit of making a more concentrated application. Wetting agent applications for both seasons at all sites were made using a 3-nozzle, CO_2-pressurized plot sprayer with flat fan nozzles (8005VS; TeeJet, Springfield, IL) delivering 701 L ha^{-1} of spray volume and were compared to untreated control. Wetting agent applications were made on 14 Dec. 2015 at both the UAAREC and The Blessings Golf Club. Applications the following year were made on 8 Dec. 2016 at the UAAREC and 22 Dec. 2016 at Scotsdale Golf Course. At all locations, approximately 7 mm of irrigation was applied to the green immediately after wetting agent applications to facilitate movement of the product into the rootzone.

Data collection

Nine, randomly located soil volumetric water content measurements per plot were recorded monthly for winter and spring 2015-2016 and 12, randomly located soil volumetric water content measurements per plot were recorded twice monthly during winter and spring 2016-2017. Measurements were obtained using time-domain reflectometry (TDR) with a FieldScout TDR 300 Soil Moisture Meter (Spectrum Technologies, Aurora, IL) equipped with 3.81 cm probes. Digital image analysis (DIA) was used to determine percent green turfgrass coverage (Richardson et al., 2001) during the spring green-up periods. One picture per plot was taken weekly from February through May during spring 2016. Three pictures per plot were taken weekly from February through May during spring 2017, to account for the larger plot dimensions during 2017. All pictures were taken using a digital camera (Canon PowerShot G12, Canon Inc., Melville, NY) mounted to a 0.9- by 0.9-m metal box equipped with four light bulbs, providing a consistent light source to collect comparable images. Images collected were then analyzed in SigmaScan (SigmaScan Pro, SPSS Inc., Chicago, IL). Green pixels were selected based on a hue range of 45 to 125 and a saturation range from 10 to 100. The total number of green pixels was divided by the total number of pixels present in the image to calculate percent green turfgrass coverage present in the image.

A water drop penetration time (WDPT) test was conducted twice during each season on soil samples collected two weeks after wetting agent application and again on samples collected prior to the onset of spring green-up. Samples consisting of five intact soil cores, 7.0 cm long and 2.5 cm in diameter, were taken from each plot, air-dried for 2 wk and tested for water repellency using the WDPT (Kostka et al., 1997; Letey, 1969). The WDPT test was performed by placing a 36.0 μL droplet of deionized water on the cores at depths of 2, 3, 4, 5, and 6 cm (measured from the top of the soil core downward), and recording the time in seconds for the droplet to penetrate the surface of the soil core. Any water droplet remaining after 600 s was recorded as 600 s. Values from the five subsamples per plot were averaged for statistical analyses.

Experimental design

All data were analyzed separately each year due to inconsistencies in the evaluation dates between the two years. Data for percent green cover and soil volumetric water content were analyzed using a repeated measures analysis of variance as an augmented factorial (Piepho et al., 2006) randomized complete block design using PROC MIXED (SAS v 9.4, SAS Institute, Cary, NC). Sampling depth was added as an additional factor in the WDPT data analysis and data were analyzed using a repeated measures analysis of variance as an augmented factorial (Piepho et al., 2006) randomized complete block design using PROC MIXED (SAS v 9.4, SAS Institute, Cary, NC). For all data, slicing was performed in PROC MIXED to identify evaluation dates when treatment effects were significant. Treatment means for significant effects were separated using Fisher’s protected LSD ($\alpha = 0.05$).

RESULTS

Green turfgrass coverage

In 2016, green turfgrass coverage was significantly affected by the main effects of wetting agent (WA) and day of year (DOY), as well as the higher order interaction of WA x DOY at UAAREC and The Blessings (Table 1). Data for the three wetting agents of interest to this research were included within the statistical analysis along with the various experimental wetting agents not of interest to this manuscript. This analysis resulted in a significant p-value for the WA x DOY interaction at The Blessings in 2016, although no products of interest to this research significantly affected green turfgrass coverage. This was not the result at the UAAREC in 2016, where products of interest resulted in significant differences in green turfgrass coverage. In 2017, green turfgrass coverage differed over time at both UAAREC and Scotsdale Golf Course but was unaffected by wetting agent treatment (Table 2).

Wetting agents significantly increased green turfgrass coverage on multiple dates during the 2016 at the UAAREC. From 15 Mar. 2016 through 11 Apr. 2016, all treatments achieved similar percentages of green turfgrass coverage. On 19 Apr., the 2x rate of Cascade Plus was the only treatment to achieve significantly more green turfgrass coverage compared to the untreated control. On two consecutive sampling dates in late-April, Revolution and Cascade Plus at both treatment rates had significantly more green turfgrass coverage compared to both rates of Tricure and the untreated control. On 28 Apr. 2016, the Cascade Plus treatment, regardless of rate, had achieved greater than 90% green turfgrass coverage. The untreated control did not achieve more than 90% green turf coverage until 11 May 2016, nearly two weeks later than plots treated with Cascade Plus (Fig. 1). From 3 May 2016 through the last sampling date, all treatments had achieved similar percentages of green turfgrass coverage compared to the untreated control. Throughout the data sampling period in 2016, both rates of Tricure never achieved green turfgrass coverage percentages significantly greater than the untreated control.

Volumetric water content

At all sites during both years, soil volumetric water content was unaffected by any of the wetting agent products applied at either rate. During both seasons, soil volumetric water content varied across time but was unaffected by wetting agent treatments (Tables 1, 2) as soil volumetric water contents varied throughout data collection presumably due to responses to natural rainfall. The standard deviation of soil volumetric water content varied across time at all sites during both years excluding UAAREC in 2017 (Tables 1, 2). Wetting agent treatments significantly affected the standard deviation of soil volumetric water content in 2016 at The Blessings Golf Club, however, no product or rate consistently resulted in significantly lower standard deviations of volumetric water content compared to untreated controls (Table 3).

Water drop penetration times

Water drop penetration times (WDPT) were significantly affected by the main effects of WA and depth and by the higher order interactions of WA x depth, WA x date, depth x date, and WA x depth x date in 2016 at the UAAREC. At the Blessings Golf Club, in 2016, water drop penetration times were significantly affected by the main effects of date and depth, and by the higher order interaction of depth x date (Table 4).

The depth x date effect on WDPT at the Blessing Golf Club resulted in reductions in WDPT with increasing depth in the soil profile (Data not shown). The WA x depth x date interaction at the UAAREC in 2016, resulted in significant reductions in WDPT compared to the untreated control in the top two sampling depths of the soil cores (Fig. 2). For both sampling dates, Tricure at both rates did not reduce WDPT compared to the untreated control. On the Apr. sampling date, Tricure at the label rate significantly increased WDPT at the 2-cm depth of the soil core compared to the untreated control. In January, the WDPT for the 2-cm depth of the untreated control was determined to be 115 s. Revolution and Cascade Plus at both rates were able to significantly reduce the WDPT by at least 70 s (Fig. 2). The WDPT generally decreased with increasing depth on the soil core at both sampling dates. The 2x rate of Revolution was the only treatment to significantly reduce WDPT compared to the untreated control at the 3-cm depth of the soil core, occurring at the January sampling date (Fig. 2). Water drop penetration times for all treatments at the 4-cm depth were comparable the untreated control, excluding the 2x rate of Cascade Plus, which significantly increased WDPT on the Apr. sampling date (Fig. 2).

In 2017, WDPT at the UAAREC were significantly affected by the main effects of WA and depth, as well as the higher order interactions of WA x date and depth x date (Table 4). At Scotsdale Golf Course, WDPT were significantly affected by the main effects of WA and depth and by the higher order interactions of WA x depth, WA x date, depth x date, and WA x depth by date (Table 4).

Wetting agent treatments at UAAREC in Jan. 2017 significantly reduced WDPT compared to the untreated control by a minimum of 32 s, but treatments and rates did not differ from each other (Table 5). In April, this effect was reduced and the untreated control had similar WDPT compared to all WA treatments (Table 5). The depth x date interaction at the UAAREC in Jan. 2017 revealed a general trend of increasing WDPT with increasing depth in the soil profile (Table 6). Statistical differences did not seem to follow any specific pattern but the 2, 3, and 4-cm depths had significantly lower WDPT compared to the 6-cm depth. In Apr. 2017, WDPT decreased with increasing depth in the soil profile (Table 6). The 2-cm depth had significantly greater WDPT compared to all other depths. The 4, 5, and 6-cm depths had comparable WDPT, but WDPT were significantly lower than both the 2 and 3-cm depths.

Wetting agent treatments across depth significantly affected WDPT at Scotsdale Golf Course during 2017. In Jan. 2017, all wetting agent treatments and rates significantly reduced WDPT compared to the untreated control at the 2 and 3-cm sampling depth (Figure 3). At the 4-cm depth, Tricure at the label rate in Jan. 2017, had significantly greater WDPT compared to all other treatments and rates and was comparable to the untreated control (Figure 3). Tricure at the label rate across all depths in Jan. 2017, had greater WDPT compared to all other treatments, although differences were not consistently significant. In Apr. 2017, all products excluding Cascade Plus at the label rate, significantly reduced WDPT compared to the untreated control at the 2 and 3-cm depths. In Jan. 2017, WDPT of WA treatments generally increased with increasing depth, but the untreated control had decreasing WDPT with increasing depth (Fig. 3). On the Apr. 2017 sampling date, WDPT generally decreased with increasing depth in the soil profile (Figure 3).

DISCUSSION

Through two seasons, a late-fall wetting agent application had an inconsistent ability to increase green turfgrass coverage at all sites. Doubling treatment rates did not result in significant increases in green turfgrass coverage compared to treatments at the label rate. The ability of both rates of Cascade Plus and Revolution to hasten spring green-up of ‘TifEagle’ ultradwarf bermudagrass during one season suggests winter wetting agent application may help reduce winter injury of ultradwarf bermudagrass putting greens. Because specific climatic factors are different every winter, beneficial effects of a winter wetting agent application may be reduced during seasons with adequate rainfall during winter months. Although total precipitation during this trial was greater in 2015-2016 compared to 2016-2017 (Table 7), the timing of precipitation may have affected the wetting agent interaction on spring green-up. The reduced rainfall totals from Jan. 2016 through May 2016 compared to the same period in 2017 (Table 7), may explain how a wetting agent application was able to increase green turfgrass coverage during 2016, but not 2017. The beneficial wetting agent effect may have been diminished due to increased precipitation during spring 2017 (Table 7). Because wetting agents enhanced survival during one year of the trial, a late-season wetting agent application could be justified as a preventative measure against desiccation.

Soil volumetric water contents were unaffected by any of the wetting agents or rates during both seasons at all sites. This could potentially be due to the limitations of the frequency at which volumetric water content was measured. Future research including continuous monitoring of soil moisture levels may enhance the ability to reveal differences between products and their ability to retain soil moisture. Several common wetting agents have been shown to increase soil moisture amount and uniformity on experimental sand-based creeping bentgrass putting greens during summer months (Karcher and Richardson, 2014; Soldat et al., 2010). In this research, the late-fall wetting agent application significantly affected moisture uniformity at the Blessings Golf Club in 2016, but this effect was inconsistent across products and rates and was not indicative of any one product providing increased moisture uniformity compared to other products. Making repeated wetting agent applications throughout the winter months could potentially increase moisture uniformity but further research is necessary to substantiate this claim.

Water drop penetration times were reduced compared to untreated controls in the upper portions of the root-zone. Bauer et al. (2017) showed the ability of wetting agents to persist in the root-zone throughout winter months on an experimental creeping bentgrass putting green. Testing 13 commercially available wetting agents, using WDPT, Bauer et al. (2017) concluded that Revolution had the greatest ability to persist in the soil throughout the winter months of all products tested, those of which did not include Tricure. This current research also demonstrated the ability of Revolution to persist in the root-zone, as WDPT were reduced by the doubled rate at UAAREC in 2016, and Scotsdale golf course in 2017 in both Jan. and Apr. sampling dates at the 2-cm soil depth (Figures 2, 3).

CONCLUSIONS

Wetting agents had an inconsistent ability to reduce winter injury compared to untreated controls during this trial. In 2016, Revolution and Cascade Plus significantly increased green turfgrass coverage compared to Tricure and the untreated control. This effect was reduced in 2017. Doubling the label rate of wetting agents did not increase green turf coverage or effect volumetric water content in either year. Wetting agents did not significantly affect soil volumetric water content during both years of research. Soil moisture variability was inconsistently affected by wetting agent application and no single product resulted in increased moisture uniformity. The doubled rate of Revolution resulted in the most consistent ability to reduce WDPT during both seasons.

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Figure legends

Figure 1. Effect of wetting agent x day of year on green turfgrass coverage during winter and spring 2016 at the University of Arkansas Agricultural Research and Extension Center. Error bar indicates least significant difference for comparing means ($p < 0.05$).

Figure 2. Effect of wetting agent x depth x date on water drop penetration times (WDPT) during winter and spring 2016 at the University of Arkansas Agricultural Research and Extension Center. Values followed by the same letter are not significantly different according to LSD (0.05).

Figure 3. Effect of wetting agent x depth x date on water drop penetration times (WDPT) during winter and spring 2017 at Scotsdale Golf Course. Error bar indicates least significant difference for comparing means ($p < 0.05$).

Table 1. Analysis of variance testing main effects and their interactions on multiple turfgrass parameters during the winter/spring of 2016.

Treatment factor	**Green turfgrass coverage**		**Volumetric water content**		**Standard deviation† of volumetric water content**	
	UAAREC‡	Blessings Golf Club	UAAREC	Blessings Golf Club	UAAREC	Blessings Golf Club
	P > *F*					
Wetting agent (WA)	0.0013	<.0001	NS§	NS	NS	NS
Day of year (DOY)	<.0001	<.0001	<.0001	<.0001	0.0489	<.0001
WA x DOY	<.0001	<.0001	NS	NS	NS	0.0163

† Standard deviation of volumetric water content used as indicator of soil moisture variability within plots.

‡ University of Arkansas Agricultural Research and Extension Center – Fayetteville, AR.

§ NS, nonsignificant at the 0.05 probability level.

Table 2. Analysis of variance testing main effects and their interactions on % green turfgrass coverage for multiple turfgrass parameters during the winter/spring of 2017.

Treatment factor	**Green turfgrass coverage**		**Volumetric water content**		**Standard deviation† of volumetric water content**	
	UAAREC‡	Scotsdale Golf Course	UAAREC	Scotsdale Golf Course	UAAREC	Scotsdale Golf Course
	P > *F*					
Wetting agent (WA)	NS§	NS	NS	NS	NS	NS
Day of year (DOY)	<.0001	<.0001	<.0001	<.0001	NS	<.0001
WA x DOY	NS	NS	NS	NS	NS	NS

† Standard deviation of volumetric water content used as indicator of soil moisture variability within plots.

‡ University of Arkansas Agricultural Research and Extension Center – Fayetteville, AR.

§ NS, nonsignificant at the 0.05 probability level

Table 3. Effect of wetting agent x day of year on standard deviation of volumetric water content at The Blessings golf club during the winter/spring of 2016.

Wetting agent	Rate	6-Jan.	5-Feb.	4-Mar.	5-Apr.
	L ha^{-1}	Standard deviation†			
Revolution	19.0	0.96 a‡	1.44 a	1.08 a	0.68 a
	38.0	0.85 a	0.71 bc	1.03 a	0.70 a
Cascade Plus	25.5	1.08 a	0.65 c	0.88 a	0.50 a
	51.0	0.90 a	0.69 bc	0.84 a	0.44 a
Tricure	19.0	1.06 a	1.06 ab	0.90 a	0.53 a
	38.0	1.24 a	0.87 bc	0.77 a	0.57 a
Untreated control		0.90 a	0.95 bc	0.67 b	0.62 a

† Standard deviation of volumetric water content used as indicator of soil moisture variability within plots.
‡ Within columns, values followed by the same letter are not significantly different according to LSD (0.05).

Table 4. Analysis of variance of fixed effects and their higher order interactions on water drop penetration times during two winter/spring seasons.

Treatment factor	UAAREC†	Blessings golf club	UAAREC	Scotsdale golf course
	2016		2017	
	P > *F*			
Wetting agent (WA)	<.0001	NS‡	= 0.01	<0.01
Depth	<.0001	<.0001	<.0001	<.0001
WA x depth	<.0001	NS	NS	<.0001
Date	NS	<.0001	NS	NS
WA x date	<.0001	NS	<0.01	<0.01
Depth x date	<.0001	<0.01	<.0001	<.0001
WA x depth x date	<.0001	NS	NS	<.0001

† University of Arkansas Agricultural Research and Extension Center- Fayetteville, AR.
‡ NS, nonsignificant at the 0.05 probability level.

Table 5. Effect of wetting agent x date interaction on water drop penetration times at the University of Arkansas Agricultural Research and Extension Center during the winter/spring of 2017.

Wetting agent	Rate	Jan. 2016	Apr. 2016
	L ha^{-1}	s	
Revolution	19.0	14 a†	23 a
	38.0	9 a	16 a
Cascade Plus	25.5	16 a	17 a
	51.0	6 a	14 a
Tricure	19.0	13 a	15 a
	38.0	6 a	24 a
Untreated control		49 b	27 a

† Within columns, values followed by the same letter are not significantly different according to LSD (0.05).

Table 6. Effect of depth x date interaction on water drop penetration times at the University of Arkansas Agricultural Research and Extension Center during winter/spring of 2017.

	Water drop penetration times	
Soil depth	Jan. 2017	Apr. 2017
cm	s	
2	13 ab†	61c
3	9 a	24 b
4	13 ab	8 a
5	21 cb	4 a
6	23 c	2 a

† Within columns, values followed by the same letter are not significantly different according to LSD (0.05).

Table 7. Monthly total rainfall in Fayetteville, AR during the winter and spring of 2015-2016 and 2016-2017.

Year	Monthly precipitation†							
	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	Total
	mm							
2015-2016	214	278	13	16	92	100	140	853
2016-2017	21	46	54	28	152	327	159	787

† Precipitation totals as reported by the National Oceanic and Atmospheric Administration.

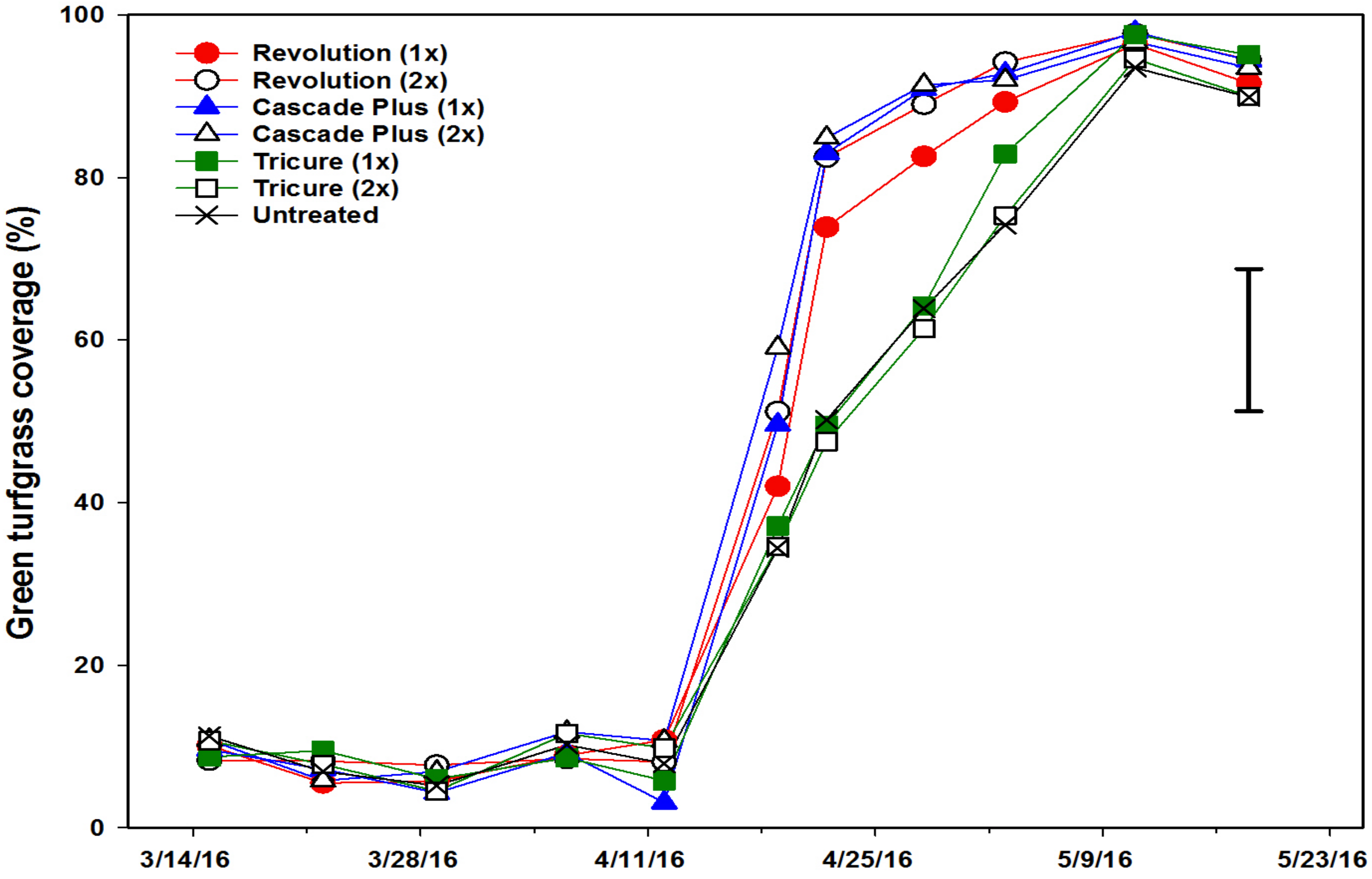
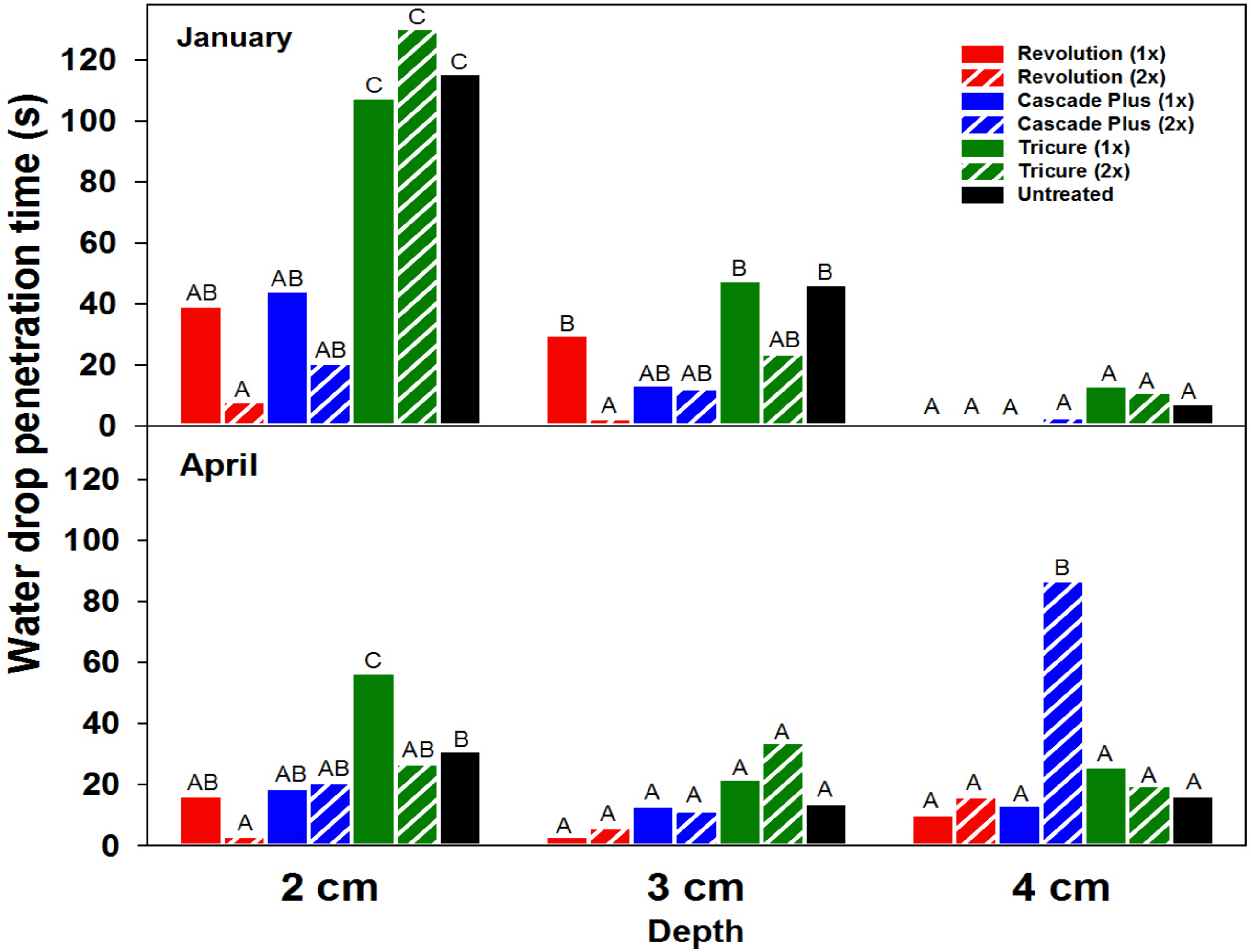

Revolution (1x)
Revolution (2x)
Cascade Plus (1x)
Cascade Plus (2x)
Tricure (1x)
Tricure (2x)
Untreated
Green turfgrass coverage (%)
100
80
60
40
20
0
3/14/16
3/28/16
4/11/16
4/25/16
5/9/16
5/23/16

Figure 1.


January
April
Water drop penetration time (s)
0
20
40
60
80
100
120
Revolution (1x)
Revolution (2x)
Cascade Plus (1x)
Cascade Plus (2x)
Tricure (1x)
Tricure (2x)
Untreated
AB
A
AB
AB
C
C
C
B
A
AB
AB
B
AB
B
A
A
A
A
A
A
A
AB
A
AB
AB
C
AB
B
A
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A
A
B
A
A
A
2 cm
3 cm
4 cm
Depth

Figure 2.

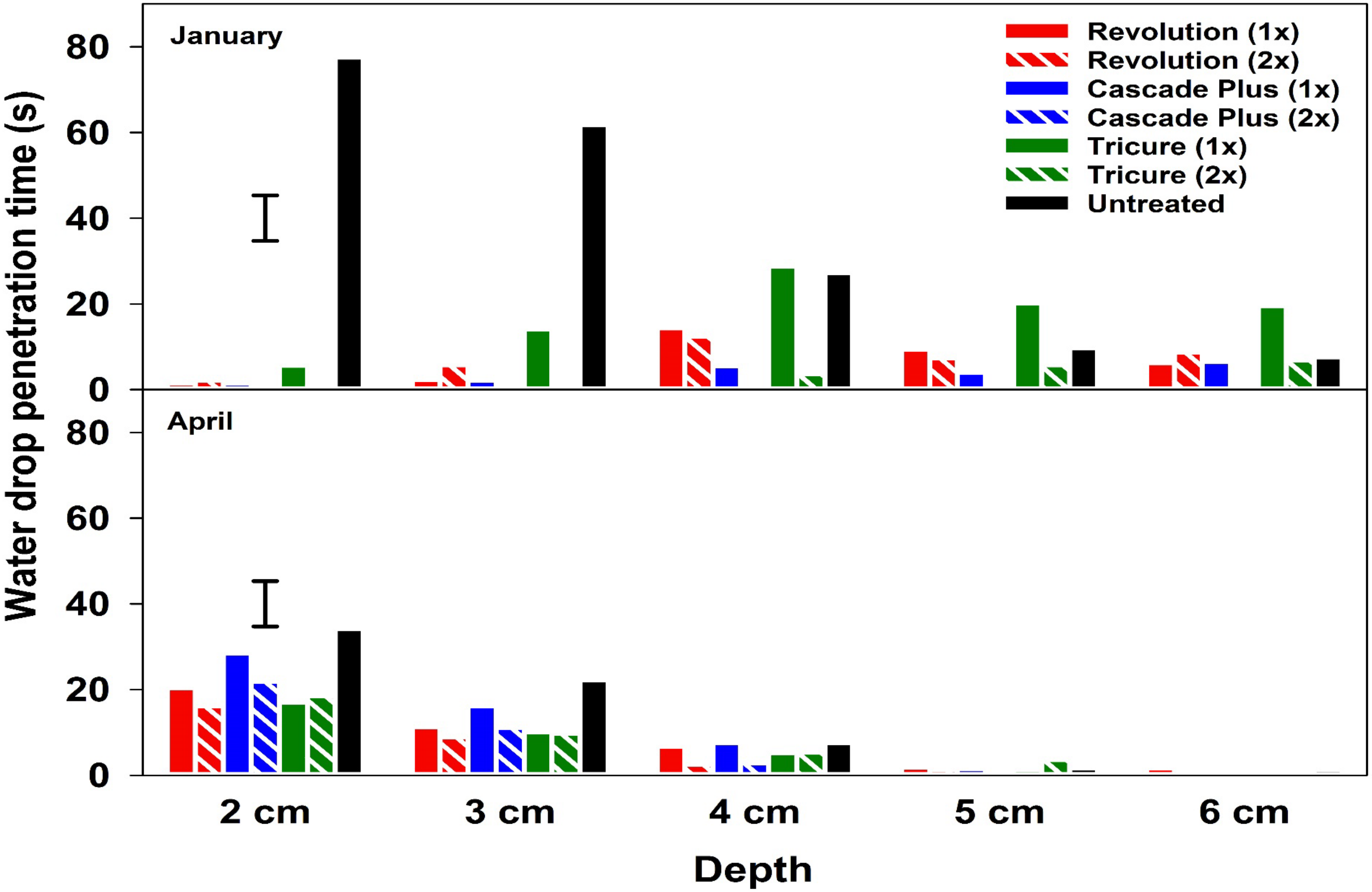
January
April
Revolution (1x)
Revolution (2x)
Cascade Plus (1x)
Cascade Plus (2x)
Tricure (1x)
Tricure (2x)
Untreated
Water drop penetration time (s)
0
20
40
60
80
2 cm
3 cm
4 cm
5 cm
6 cm
Depth

Figure 3.

Conclusion

This research demonstrated the ultradwarf bermudagrass cultivars, ‘MiniVerde’ and ‘TifEagle’ to be significantly more cold tolerant than ‘Champion’ ultradwarf bermudagrass during two winters in Fayetteville, AR. Protective covers enhanced winter survival across all cultivars, regardless of temperature used for their implementation. Differences in winter injury between various cover temperature thresholds, although occasionally statistically significant, were not of practical significance to a golf course superintendent. Substantial theoretical cost savings associated with cover installation and removal events were realized by reducing the low-temperature threshold for covering ultradwarf greens without negatively impacting turf survival. In 2016, Revolution and Cascade Plus significantly increased green turfgrass coverage compared to Tricure and the untreated control, but this effect was not observed in 2017. Doubling the label rate of wetting agents did not increase green turf coverage or effect volumetric water content in either year. Wetting agent application showed inconsistent effects on soil volumetric water content during both years of research. Soil moisture variability was not consistently affected by wetting agent applications and no single product consistently resulted in increased moisture uniformity. The doubled rate of Revolution resulted in the most consistent ability to reduce soil hydrophobicity, as determined by water drop penetration tests, during both seasons. Although the ability of a late-season wetting agent application to significantly reduce winter injury of ultradwarf bermudagrass was inconsistent across two winter seasons, wetting agents did enhance survival during one year of the trial and would be justified as a cost-effective, preventative measure against winter turf desiccation.