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Management strategies for preventing and recovering from bermudagrass winterkill

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Abstract

Bermudagrass (*Cynodon* spp. Rich) is a warm-season grass that is widely planted throughout tropical, sub-tropical, and even temperate climates, and it generally requires fewer inputs than most cool-season turfgrasses. In recent years, the area of adaptation for bermudagrass has progressively expanded to cooler climates due to the development of more cold-tolerant cultivars. The expanded area of adaptation as well as the reduced inputs required to maintain healthy turfgrass have made bermudagrass a popular choice in areas of marginal adaptation. In these areas, the greatest threat to bermudagrass health and survivability is winterkill. This management guide seeks to describe winterkill: what it looks like, what causes it, and where it occurs. Additionally, this management guide describes best management practices to both prevent winterkill and recover bermudagrass from winterkill damage.

Plain Language Summary

Bermudagrass is a popular warm-season turfgrass in the warmer climates of the United States. Despite having many desirable characteristics such as drought and traffic tolerance, its adoption and use in cold climates is challenging due to the risk of death from winter stresses. This guide delves into the specifics of bermudagrass winterkill, exploring causes, vulnerable areas, damage estimation methods, and effective management practices. This guide recommends actions to reduce the risk of winterkill in newly established bermudagrass and maintenance tips for existing stands. By following these recommendations, users can reduce winterkill risk, minimizing reestablishment costs and enhancing sustainability through decreased water and pesticide use, thus ensuring the success of bermudagrass in diverse climates.

Abbreviations: LDS, localized dry spot; NTEP, National Turfgrass Evaluation Program; PGR, plant growth regulator; SDS, spring dead spot; UAV, unmanned aerial vehicle; USGA, United States Golf Association.

1 | INTRODUCTION

Bermudagrass (*Cynodon* spp. Rich.) is a warm-season turfgrass that is planted throughout the southern United States (warm-humid and warm-arid climates) as well as the transition zone (climate between cool and warm regions). Bermudagrass is the most widely planted turfgrass in the United States (Shaddox et al., 2023), yet it has poor cold tolerance compared to many other turfgrass species, and it is highly susceptible to winterkill when grown in areas of marginal adaptation, such as the transition zone (Beard, 1973; Gopinath et al., 2021a). Winterkill is defined as turfgrass death during winter (Beard, 1973; Gopinath et al., 2021a) and it is problematic in both cool- and warm-season turfgrass species (DaCosta et al., 2020; Goatley et al., 2007). The causes of winterkill in turfgrass are variable and well documented (Beard, 1973). Moreover, best management practices for turfgrass winterkill prevention and mitigation have also been researched for decades (Dunne et al., 2019; Goatley et al., 1998; Gopinath et al., 2021a, 2021b; Reeves Jr. et al., 1970; Richardson, 2002; Sowers & Welterlen, 1988).

This management guide will focus in detail on winterkill of bermudagrass. Both common bermudagrass [*Cynodon dactylon* (L.) Pers.] and hybrid bermudagrass (*C. dactylon* × *C. transvaalensis* Burtt-Davy) are commonly used turfgrass species. Additionally, cultivars of hybrid bermudagrass with a dwarf growth habit, often referred to as "ultradwarf bermudagrass," are used on golf course putting greens (Brosnan et al., 2022; Reasor et al., 2016). Hereafter, both species will be referred to as "bermudagrass" as the causes of winterkill and winterkill prevention management strategies are the same for both. Specifically, this guide will thoroughly review the causes of winterkill, areas that are most vulnerable to winterkill, methods to estimate the amount of bermudagrass area damaged from winterkill, and best management practices to prevent and recover bermudagrass from winterkill.

2 | WINTERKILL

2.1 | Causes of winterkill

The primary factors promoting winterkill on bermudagrass include low-temperature exposure and soil moisture extremes: wet or dry. Winterkill from low-temperature exposure typically occurs from sustained low temperatures or rapid decreases in temperature. During the fall months, the combination of lower temperatures (<50˚F) and reduced daylengths initiate a cold acclimation (i.e., hardening-off) process that allows the turfgrass to better resist freezing stress (Zhang et al., 2006). These metabolic defenses are a result of shifts in fatty acid saturation, sugar synthesis, protein synthesis, and antioxidant production that offer cryoprotection (Fontanier et al., 2020; Munshaw et al., 2006; Samala et al., 1998; Zhang et al., 2006). However, cold-acclimated bermudagrasses may experience winterkill if lethal temperatures are sustained.

The freezing tolerance of cold-acclimated bermudagrasses in controlled environments is well-understood, as several studies have determined the lethal temperature to kill 50% of a bermudagrass population based on plant regrowth following exposure to low temperatures (Anderson et al., 1993, 2002; Dunne et al., 2019; Gopinath et al., 2021a, 2021b; Kimball et al., 2017). While this research can predict the northernmost limits for bermudagrass cultivars, it may not represent the dynamic outdoor growing environment with temperature fluctuations and variable soil moisture. If bermudagrass is exposed to lethal freezing temperatures prior to cold acclimation, winterkill can result. This is a common occurrence when a warmer-than-normal fall season does not allow bermudagrass to harden-off and is followed by a period of lethal freezing temperatures.

In spring, warm temperatures and increased daylengths hasten green-up and begin the cold de-acclimation process. De-acclimation is defined as a reduction in cold hardiness that was attained through the earlier acclimation process. De-acclimation and the loss in hardiness is due to warm temperatures (i.e., magnitude of increase in temperature and duration of exposure), phenological changes, and reactivation of growth (Kalberer et al., 2006). Premature initiation of cold de-acclimation in late winter or spring may increase susceptibility to winterkill or leaf damage, especially if freezing temperatures occur following de-acclimation.

Winterkill can also be promoted by plant tissue desiccation or poorly drained soils and can occur concurrently or independently of low-temperature exposure. Desiccation can be caused by limited precipitation or irrigation in addition to soil hydrophobicity, especially in sandy rootzones common on golf course putting greens constructed to United States Golf Association (USGA) specifications (USGA, 2018). In hydrophobic soils, individual sand particles repel water after becoming coated with organic compounds exhibiting hydrophobicity (Henry & Paul, 1978; Miller & Wilkinson, 1977). The hydrophobic sand particles contribute to localized dry spot (LDS), which is defined as "irregularly shaped areas of desiccated, brown turf resulting from soil that has become resistant to wetting from both irrigation and rainfall" (Beard & Beard, 2005). Poor drainage and excessive rainfall are common causes of saturated soils. If this occurs during winter when little to no evapotranspiration is occurring, the risk of winterkill also increases (Figure 1). More detail on how to manage or prevent these causes of winterkill will be discussed in Section 4.

2.2 | Areas most susceptible to winterkill

Based on these common causes of winterkill, north-facing slopes are a common site for winter injury. Further, exposed

FIGURE 1 'Midlawn' bermudagrass winterkill in poorly drained, low areas of a golf course fairway.

areas without windbreaks are more likely to suffer winterkill due to desiccation, and low or poorly drained areas are more likely to suffer winterkill if soils remain saturated during winter months.

Stress from shade, traffic, or nutritional deficiencies can predispose bermudagrass to winter injury. Shaded sites are more likely to winterkill from the combined stresses of poor health due to inadequate light during the growing months and the colder soil temperatures during the winter months (Dunne, 2016). Traffic stress prior to or during winter can also be detrimental to bermudagrass survival (Henry, 1985). Traffic can wear the plant and cause soil compaction, thereby weakening the plant (Carrow & Petrovic, 1992), which could also make it more susceptible to winterkill. Plants entering winter with nutrient deficiencies may also be less protected as this physiological stress can reduce the plant's ability to produce healthy rhizomes (Yarborough et al., 2017).

Insulation is key to prevent soils from cooling too much and causing direct, low-temperature winterkill. As such, natural snow cover provides ample insulation and is a defense for winterkill caused directly by low temperature (Sang-Kook, 2011). Various materials are also used as covers or blankets to help insulate the turfgrass during winter (DeBoer et al., 2019b). Areas with little snow cover or where covers may be blown off by high winds are more susceptible to winterkill. An excess thatch layer can also lead to increased winterkill, and this is also an insulation issue (Gasch et al., 2019; Steinegger, 1974). Due to their position and density differences, the soil near the surface will cool more slowly than the thatch directly above it. As such, growing points (i.e., meristematic tissue) in the thatch layer are less protected from potentially lethal temperatures.

Lastly, the age of the turfgrass sward is a significant factor in winterkill. Sod planted just before or during winter (Figure 2), bermudagrass established from seed that is immature with fewer and smaller stolons (Ahring et al., 1975; Richardson et al., 2004), or newly planted sprigs are all more subject to winterkill as they lack significant stolon and rhizome formation (Sowers & Welterlen, 1988), the survival meristems of the plant. Planting bermudagrass in the late spring or early summer is key to increasing bermudagrass survival in the subsequent winter (Ahring et al., 1975; Richardson et al., 2004). However, newly planted bermudagrass in the summer is still more susceptible to winterkill compared to well established bermudagrass (Figure 3).

Winterkill can be expected to occur more frequently when these conditions occur. Turfgrass managers can specifically sample these areas in comparison to well-drained, full-sun locations to assess potential winterkill prior to spring green-up.

2.3 | Methods for assessing winterkill

To detect areas of winterkill prior to green-up, one easy method is to inspect the rhizomes. Rhizomes that have a white, tan, and/or fleshy color and are vigorous enough to snap in two indicate healthy bermudagrass. However, rhizomes that are brown or black in color, are soft, collapse with pressure, and do not easily snap in two, indicate dead bermudagrass from winterkill (Chalmers, 1986) (Figures 4–5). One can also take a cup-cutter plug of bermudagrass in an area that is likely susceptible to winterkill after a hard freeze event and place that plug in an area with adequate light, heat,

FIGURE 2 Bermudagrass left of the sidewalk was established several years prior to taking this photo and little to no winterkill occurred. Bermudagrass to the right of the sidewalk in the foreground was sodded in late fall as part of a landscape renovation and it severely winterkilled.

FIGURE 3 Bermudagrass on the left was sodded in the summer of 2022 while the bermudagrass on the right was well established.

and water. From there, monitoring whether the bermudagrass forms new, green leaf tissue over the subsequent weeks will help the turfgrass manager determine if winterkill occurred. No remote sensing methods for early detection of winterkill on bermudagrass have been developed yet, but that is a possibility in the future with further research and technological development.

Although no remote sensing techniques have been developed for early detection of winterkill, remote sensing techniques have recently been adopted to detect turfgrass stressors such as drought, weeds, and disease (Henderson et al., 2021; Hong et al., 2019; Marin et al., 2021). Additionally, remote sensing techniques, specifically the use of small unmanned aerial vehicles (sUAVs), have the capability to rapidly determine the amount of area damaged from abiotic or biotic stressors (Bremer et al., 2023; Henderson et al., 2021; Jelowicki et al., 2020; Tian et al., 2023). Certain multi-rotor sUAVs can fly at an average speed of 17.9 mph while still capturing high resolution images, which is much faster than visually scouting on the ground level (Boon et al., 2017). Additionally, there is promising research suggesting satellite imagery could even be use for turfgrass detection and for scouting purposes (Caturegli et al., 2014). Rapid image collection and damaged area determination has been demonstrated with frost damage in other crops and proven especially useful for spring dead spot (SDS; caused by *Ophiosphaerella* spp.)in bermudagrass (Booth et al., 2021; Henderson et al., 2021; Jelowicki et al., 2020; Tian et al., 2023). The use of sUAVs could also be employed to rapidly detect the acreage of bermudagrass damaged from winterkill. This could speed up determining the amount of fertilizer, seed, sprigs, sod, etc. needed to repair winterkilled areas. Lastly, mapping high-risk sites such as low-lying areas, exposed slopes, areas with too little or too much moisture, and heavily shaded sites to predict where winterkill will occur could allow for prescriptive management practices to be deployed in those areas thereby lessening the likelihood of winterkill.

FIGURE 4 'Latitude 36' bermudagrass rhizomes that partially survived a severe winter. Notice both necrotic tissue and healthy, new growth.

FIGURE 5 'Latitude 36' bermudagrass rhizomes that completely winterkilled.

3 | WINTERKILL RECOVERY

3.1 | Spring management practices to recover from winterkill

3.1.1 | Preemergence herbicide options

Preemergence herbicides are commonly applied in the spring to prevent troublesome annual grassy weed species (e.g., crabgrass [*Digitaria* spp.] and goosegrass [*Eleusine indica* L.]), which can reduce turfgrass aesthetic quality and playability (Johnson, 1997). Several preemergence herbicides (e.g., prodiamine, dithiopyr, and pendimethalin) are commonly applied to bermudagrass. These herbicides (e.g., dinitroanilines and pyridines) function by disrupting mitosis of new weed seedlings, causing death shortly after germination. Additionally, these herbicides can inhibit root growth of newly formed roots on bermudagrass stolons and rhizomes (Begitschke et al., 2018; Bhowmik & Bingham, 1990; Bingham, 1967; Brosnan et al., 2014; Fishel & Coats, 1993, 1994) (Figure 6). Indaziflam, a newer preemergence herbicide, has a different mode of action but has a similar effect

FIGURE 6 Bermudagrass root injury from a mitotic-inhibiting herbicide applied to the soil in spring which causes a swollen, "club-shaped" root on stolons growing over treated soil.

on bermudagrass growth (Beck et al., 2013). Since these herbicides continue to persist in the soil for weeks to months (depending on soil type, pH, moisture, and temperature), the potential reduction in rooting could reduce the recovery rate of bermudagrass after winterkill or winter-related diseases such as SDS (Beck et al., 2013; Gasper et al., 1994; Jones et al., 2013; McCullough et al., 2006). Oxadiazon is a preemergence herbicide that does not affect stolon and rhizome rooting, but labeling does not permit its use in residential areas. All preemergence herbicides; however, inhibit seeded bermudagrass germination.

In areas with concerns of winterkill, spring preemergence herbicide applications should be made after considering the risk of winterkill based on environmental conditions, bermudagrass cultivar, and growing environment (e.g., north facing slope, poor drainage, high traffic, shade) (Patton & Bigelow, 2014). Recommended preemergence options based on estimated damage thresholds are as follows:

- **No damage expected**: Preemergence herbicide applications can be made as normal.
- **Minimal damage expected**: If the estimated loss is minimal, it is best to wait until after spring-greenup to assess winter injury. If little winter injury is visible, dithiopyr is recommended as the preemergence herbicide option since this herbicide has pre- and early postemergence activity. A postemergence herbicide can also be tank-mixed with a preemergence herbicide to control any emerged weeds and prevent the emergence of summer annual weeds.
- **Moderate damage expected**: Recovering damaged areas will need to be done either through renovation (seeding, sprigging, or sodding), or by waiting for the existing turfgrass to recover. With either strategy, postemergence herbicides are recommended to control summer annual weeds. If re-planting with sprigs or sod in non-residential areas, oxadiazon can be used as a preemergence herbicide (McCarty & Weinbrecht, 1997). If waiting for the area to recover, root inhibiting preemergence herbicide applications should be avoided as they can slow recovery. If seeding damaged areas, do not apply a preemergence herbicide and use postemergence herbicides that are safe on bermudagrass seedlings (Patton et al., 2008).
- **Severe damage expected**: Re-establishment strategies should be employed in severely damaged areas after bermudagrass greenup, and root inhibiting preemergence herbicides (prodiamine, dithiopyr, indaziflam, and pendimethalin) should not be used. Postemergence herbicides can be used according to label directions. Additionally, oxadiazon can be applied and irrigated into the soil prior to planting newly sprigged or sodded bermudagrass in non-residential areas.

3.1.2 | Postemergence herbicide options

For established bermudagrass, there are many effective postemergence herbicide strategies for control of major broadleaf and grassy weed species (Johnson, 1997; Patton et al., 2023). Due to the risk of reduced recovery with most preemergence herbicides, postemergence herbicide applications are potentially the best option for summer annual grassy weed control in areas with moderate to severe winterkill damage.

When renovating severely damaged areas, early management of weeds is key for success in successful bermudagrass establishment. Select herbicides that are labeled for sprigging, sodding, or seeding bermudagrass. Some of these products, especially the pre-formulated combination products, could cause temporary phytotoxicity, with injury potentially being cultivar dependent (McCalla et al., 2004; McElroy et al., 2005). Combinations of monosodium acid methanearsonate (MSMA) with postemergence herbicides can be applied to recently sprigged or seeded bermudagrass on golf courses and sod farms without reducing growth rate and only temporary foliar injury with some combinations (McCalla et al., 2004; Richardson et al., 2005). Quinclorac can also be used on recently sprigged or seeded bermudagrass for control of crabgrass and some broadleaf weeds; however, some temporary phytotoxicity can occur on the bermudagrass (McCalla et al., 2004; McElroy et al., 2005). Foramsulfuron can be applied, according to the label, no sooner than 2 weeks after sprigging or 2 weeks after emergence of seeded bermudagrass if goosegrass control is needed (Busey, 2004; Patton et al., 2010). Carfentrazone is one of the safest broadleaf herbicides on seedlings; however, other herbicides such as 2,4-D and clopyralid are also safe on bermudagrass seedlings (Patton et al., 2008). Follow label instructions for application intervals, rates, and adjuvant use to improve weed control and reduce risk of bermudagrass injury.

3.2 | Growing bermudagrass in damaged areas

Once winterkill damage is observed, recovery options are dependent on the severity of damage, time available for recovery, and overall budget. In damaged areas that are large, it will take a considerable amount of time for bermudagrass to fill in from stolon and rhizome growth alone. Establishment techniques such as sodding, sprigging, and over-seeding can be viable options to improve recovery. If winterkill is low to minimal (<30%), management practices to hasten bermudagrass recovery, such as changes to the spring/summer nitrogen (N) fertilization program, should be employed.

3.2.1 | Optimal reestablishment techniques

Sod is the fastest method to recover large areas damaged by winterkill compared to seeding or sprigging, but budget, playability needs, and desired cultivar/species availability should be considered. Proper cultivar/species selection is crucial as certain cultivars or species clash due to their morphological differences (e.g., color, density, texture). If sod is the selected re-establishment method, the damaged area should be tilled prior to laying the sod if the area was previously treated with a preemergence herbicide. This will help reduce, but not prevent, rooting issues on the newly planted sod if soil was previously treated with prodiamine, pendimethalin, or dithiopyr prior to sod establishment. After laying the sod, provide adequate irrigation and reduce traffic to prevent sod from drying and encourage rooting.

Renovating damaged areas with sprigs is another viable re-establishment technique. Sprigs can be introduced using no-till, slit sprigging, but sprigs can also be broadcasted uniformly over the soil at a rate of 200 to 800 bu ac^{-1} (Munshaw et al., 2017). Higher sprigging rates will encourage faster recovery. Planting bermudagrass late in the growing season increases the risk of winterkill (Musser & Perkins, 1969). To ensure rapid establishment and optimal growth, plant sprigs by late spring or early summer. Previous studies have also shown that sprigs planted January–March in Virginia often reached full coverage by May or June (Herrmann et al., 2020; Zhang et al., 2021). Irrigate immediately after planting and continue to water generously to maintain adequate soil moisture. If re-sprigging during cooler temperatures and large enough areas are re-sprigged, growth covers can help maintain warmer soil temperatures to increase establishment rates.

Reestablishment into damaged areas using seeded bermudagrass cultivars is another viable method if preemergence herbicides were not applied prior to planting. Seeded bermudagrass provides flexibility in establishment scheduling, increased genetic diversity, potential improved winter hardiness, and reduced establishment costs compared to vegetative methods (Deaton & Williams, 2013; Patton et al., 2004; Schiavon et al., 2016). Prior to seeding, site preparation to encourage seed-to-soil contact and prevent seed movement, such as tilling or verticutting damaged areas, should be employed. Alternatively, employing a slit seeder during seeding is another effective method for achieving this goal. Recommended seeding rates should range from 0.5 to 1.0 lb pure live seed 1,000 ft^{-2} (Patton et al., 2008). Earlier plantings, similar to sprigging, can reduce the risk of winterkill (Ahring et al., 1975; Richardson et al., 2004). In Arkansas, dormant seeding in mid-February and mid-March led to germination around mid-April and complete establishment sooner than seed sown in April and May (Shaver et al., 2006). Frequent, light watering is crucial for keeping seeds moist until germination, followed by reduced watering to maintain ideal seedling development. Daily irrigation replacing over 100% of reference evapotranspiration proved sufficient for establishing bermudagrass from seed (Sandor et al., 2021).

3.2.2 | Fertilizer options

During winterkill recovery, adjustments to soil pH, phosphorus, and potassium (K) should be made based on soil test results. Nitrogen fertilization to improve recovery should depend on the re-establishment method chosen for the damaged area. In areas with low to minimal damage, small additions (approximately 50% more) to the annual N fertility program can encourage recovery from rhizome and stolon growth, and then be reduced to the normal N fertilization program after desired recovery is achieved (Hutchens et al., 2022b). Excessive N applications could result in poor rooting, excess shoot growth, reductions in rhizome and stolon mass, increased disease susceptibility, and may lead to nontarget water quality issues due to exceeding the capacity of the plant to absorb N (runoff and leaching) (Burwell et al., 2011).

Although there is a tendency for turfgrass managers to apply increased N rates to encourage quick establishment of sprigged bermudagrass, sprigging rate and cultivar selection potentially have a greater effect on improving recovery than increasing N rates (Guertal & Hicks, 2009; Munshaw et al., 2017). Rice et al. (2019) reported fertilizing sprigged bermudagrass with 0.25 or 1.0 lb N 1,000 ft^{-2} $week^{-1}$ using ammonium sulfate resulted in similar establishment rates from sprigging. For newly sprigged bermudagrass, we recommend applying 0.25-0.5 lb N 1,000 ft^{-2} $week^{-1}$ using soluble N sources and sprigging improved cultivars at higher rates (Guertal & Hicks, 2009; Munshaw et al., 2017; Rice et al., 2019). Alternatively, 1.0–1.5 lb N 1,000 ft^{-2} of a slow-release N source could be applied per month.

For newly seeded bermudagrass, recommendations are to apply 1.0 lb N 1,000 ft^{-2} after seed emergence, and monthly thereafter until 4 weeks prior to an anticipated hard frost (Munshaw et al., 2001; Patton et al., 2004, 2008). Overapplication of N should be avoided during seeding to avoid smaller stolons, reduced carbohydrate storage, excessive growth, and nutrient movement (Burwell et al., 2011; Munshaw et al., 2001). Light and frequent soluble N applications promote recovery and growth without increasing relative growth rate of seedlings and existing bermudagrass until desired recovery is achieved. A single application of a controlled release N source at seeding using an increased N rate (e.g., 2 lb N 1,000 ft^{-2}) has also been reported to increase bermudagrass establishment rate compared to frequent applications of soluble N without increasing relative growth rate (Powlen & Bigelow, 2023). Applications of slow-release fertilizer sources (e.g., polymer coated urea) also reduces the risk of N loss through leaching (Guertal & Howe, 2012). Once desired bermudagrass recovery is achieved, N rates should be reduced, and a typical annual N fertilization program should resume.

4 | WINTERKILL PREVENTION

4.1 | Cultivar selection

The selection of appropriate cultivars plays a crucial role in preventing winterkill. With a wide variety of bermudagrasses available, it is essential to consider their cold hardiness to ensure they can withstand and recover from winter conditions. Moreover, when selecting a bermudagrass cultivar, it is crucial to consider the specific cold hardiness requirements of the intended region or climate. There are many cultivars commercially available, some of which lack cold hardiness, while others were not specifically bred for cold tolerance. A series of studies tested the varying degrees of freeze tolerance among bermudagrass cultivars (Anderson et al., 1993; 2002, 2008; Anderson & Taliaferro, 2002). Those studies served as a valuable resource for understanding the freeze tolerance characteristics of different cultivars.

For seeded cultivars, studies conducted by Anderson et al. (2002, 2008) and Anderson and Taliaferro (2002) identified cultivars that exhibit limited freeze tolerance, yet many of those cultivars are no longer commercially available. These cultivars may not adequately withstand freezing temperatures and may suffer fatal damage in colder regions. Similarly, among vegetative type cultivars, 'Celebration', 'GN-1', 'MS-Choice', 'TifSport', 'Premier', and 'Tifway' were identified as examples of cultivars that may struggle to withstand colder temperatures. It is worth noting that all dwarf-type bermudagrasses exhibit limited cold tolerance. Popular dwarf cultivars such as 'Champion', 'FloraDwarf', 'MS-Supreme', 'MiniVerde', 'TifEagle', 'Tifgreen', and 'Tifdwarf' are not adequately equipped to endure harsh cold conditions. In colder regions, those dwarf cultivars may require additional protection, such as the use of protective covers for overwintering.

However, it is important to recognize that cultivars are available that demonstrate excellent cold tolerance. For seeded cultivars, selections such as 'Transcontinental' and 'Yukon' have demonstrated relatively good cold tolerance (Anderson et al., 2008). Additionally, newer seeded cultivars such as 'Monaco' and 'Rio' exhibit promising cold tolerance, making them suitable options for regions with colder climates (NTEP, 2020). For the vegetative cultivars, several options offer desirable cold tolerance traits. These include 'Quickstand', 'Patriot', 'Tahoma 31', 'Latitude 36', and 'NorthBridge' (Anderson et al., 2008; Anderson & Taliaferro, 2002; Anderson et al., 1993; Dunne et al., 2019; Gopinath et al., 2021a, 2021b; NTEP, 2020; Wu & Martin, 2015). In recent developments, certain putting green type grasses have shown significant improvement in freeze tolerance compared to other putting green cultivars (Gopinath et al., 2021b). A summary outlining the winter hardiness of these cultivars is presented in Table 1.

While planting a new cultivar with improved abiotic (drought, heat, salinity, etc.) and biotic (disease, insect, weeds, nematodes, mites, etc.) stress tolerance is important, many of these stresses occur annually or can be induced readily by researchers. While laboratory data on plant freeze tolerance is important, it is more important to have data on winter survival

TABLE 1 Winter hardiness of bermudagrass cultivars established vegetatively or by seed.

	Winter hardiness level		
Type	**Low/poor**	**Medium**	**High/ excellent**
Vegetative (non-putting green)	Bull's Eye (MS-Choice) Celebration GN-1	Astro[a] Premier[b] TifGrand TifSport TifTuf[b] Tifway	Iron Cutter[a] Latitude 36 Midiron Midlawn[c] Northbridge Patriot Quickstand Tahoma-31[b] Vamont [c]
Vegetative (putting green)	Champion Dwarf Floradwarf[a] MS-Supreme	MiniVerde Sunday Tifdwarf TifEagle[b] Tifgreen	
Seeded	Arizona common [a] Contessa[a] Majestic Maya Numex Sahara Oasis Princess 77[a] Royal TXD Sahara II SR 9554 Sultan Sundevil II[a] Veracruz[a]	Arden 15[c] Casino Royale Hollywood Mohaweek Southern Star [a] Sun Queen* Sunbird [a]	Monaco[a] Rio[a] Riviera[c] Transcontinental Yukon**

Note: Table developed from Anderson and Taliaferro (2002), Anderson et al. (1993, 2002, 2008), Dunne et al. (2019), Gopinath et al. (2021a, 2021b), and Xiang et al. (2022) and an assessment of turf quality and living spring ground cover from NTEP trials in transition zone locations such as Indiana and Kansas (NTEP, 2023).
[a]Provisional ranking, limited data on winter hardiness is available as this cultivar is relatively new.
[b]Better cold tolerance than average in this category.
[c]No longer available or limited plant material or seed available for purchase.

in field studies. However, not all winters are equally stressful. Some regions may go 10 or more years without a winter capable of killing bermudagrass. During these times, new, untested cultivars may enter the marketplace and widespread use of these selections is risky. One example is the historic winter of 1969–1970 which led to catastrophic losses of bermudagrass on several high-profile golf courses in the St. Louis, MO, area (Zontek, 1983). In light of this event and previous issues (Ferguson, 1965), some courses opted to transition from 'U-3' bermudagrass, originally selected from Savannah, GA, to 'Meyer' zoysiagrass (*Zoysia japonica* Steud.), which was more cold hardy.

Consider prioritizing the introduction of new cultivars that have undergone rigorous testing over multiple winter seasons to ensure their long-term sustainability. We recommend allowing for thorough university testing to best understand the winter hardiness of a cultivar compared to other standard selections. We also recommend establishing small quantities (50–250 ft^{-2}) of new cultivars on site in both well-drained, full-sun areas as well as microclimates prone to winterkill (i.e., shade, poorly drained, north-facing slope) to evaluate their adaptation.

FIGURE 7 Bermudagrass lawn decimated by winterkill in a dry climate, with the exception of the area where the rain gutter drains.

4.2 | Soil moisture management

Managing soil moisture is crucial for mitigating winter injury of bermudagrass as both insufficient (Figure 7) and excessive soil moisture (Figure 1) can lead to winterkill.

4.2.1 | Winter irrigation

Unlike low-temperature exposure, injury from tissue desiccation can occur regardless of air or soil temperature. Desiccation pressure is typically greatest on elevated sites that lack snow cover and is increased by high wind speeds (Beard, 1973; Kreuser, 2014). During prolonged periods of drought, cell membranes and organelles can become permanently dehydrated, resulting in a loss of their function, leading to eventual plant death (Stier & Fei, 2008).

Detecting tissue desiccation during the winter is challenging when bermudagrass is dormant. The typical signs of moisture stress, like wilting (i.e., loss of turgor) and purpling of the foliage, are not as salient in a brown, dormant bermudagrass stand. Even though the main centers of meristematic activity in dormant bermudagrasses are in a resting state, they must remain hydrated for optimum winter survival. Soil moisture can be managed throughout the winter months using a combination of periodic applications of water using an irrigation system, wetting agent applications, and protective covers to reduce soil moisture loss.

4.2.2 | Wetting agents

According to Richardson and Booth (2021), critical winter soil moisture thresholds have not been adequately studied or defined. However, soil moisture readings a turfgrass professional uses during the summer can guide winter soil moisture management. In recent years, some golf course superintendents have made late-fall wetting agent applications to reduce the risk of sustaining turfgrass injury from desiccation (Jacobs & Barden, 2018). Evidence of wetting agents persisting in the soil through the winter has been demonstrated on creeping bentgrass and bermudagrass putting greens (Bauer et al., 2017; DeBoer et al., 2020). Over three winter seasons, research at the University of Arkansas on sand-based putting greens suggested that late-fall or winter applications of wetting agents can reduce injury and enhance spring green-up of ultradwarf bermudagrass (DeBoer et al., 2020). The benefits of the wetting agent application were not consistent from year to year, but a positive effect was observed during the drier years of the study.

Golf courses with the ability to irrigate during the winter months, especially those with sand-based ultradwarf bermudagrass putting greens, have a significant advantage for preventing winter desiccation injury over courses that require winterization of their irrigation systems. Regardless of the ability to irrigate, a single wetting agent application timed before the first covering event of the season can be a relatively low-cost option for mitigating winter desiccation injury, especially in locations where the irrigation system is shut down for the winter.

4.2.3 | Drainage

Ensuring proper drainage is also important for reducing winter injury of bermudagrass. Poorly drained areas and low spots where water accumulates are highly susceptible to winter injury. This is related to high tissue water content during low-temperature exposure, resulting in excessive freeze damage of viable plant tissue (Chalmers, 1986). Additionally, waterlogged soil can deprive viable bermudagrass tissue of the oxygen essential for aerobic respiration. Insufficient soil oxygen can impair root function and weaken the overall health of

FIGURE 8 Severe winterkill on a 'TifEagle' ultradwarf bermudagrass putting green that was left uncovered during the winter.

the turf, thus potentially leading to increased susceptibility to winter injury and death.

4.3 | Insulation

4.3.1 | Covering strategies

Protecting sensitive bermudagrass from exposure to damaging low-temperature extremes is essential for turfgrass survival. Protective covers are well known to increase soil temperatures when compared to uncovered turfgrass, preventing lethal exposure to low-temperature extremes (DeBoer et al., 2019a, 2019b; Goatley et al., 2007, 2017; Richardson et al., 2019; Shashikumar & Nus, 1993; Walton, 2022). Utilizing protective covers to reduce winter injury of bermudagrass putting greens and high-value athletic fields is an essential practice for turfgrass managers in areas where air temperatures frequently fall below 32˚F during the winter (Figure 8).

As the use of ultradwarf bermudagrass putting greens began gaining popularity in more northern climates, agronomists with the United States Golf Association (USGA) developed a conservative recommendation for installing protective covers on bermudagrass putting greens when forecasted air temperatures are predicted to fall below 25˚F (O'Brien & Hartwiger, 2013). This approach has been

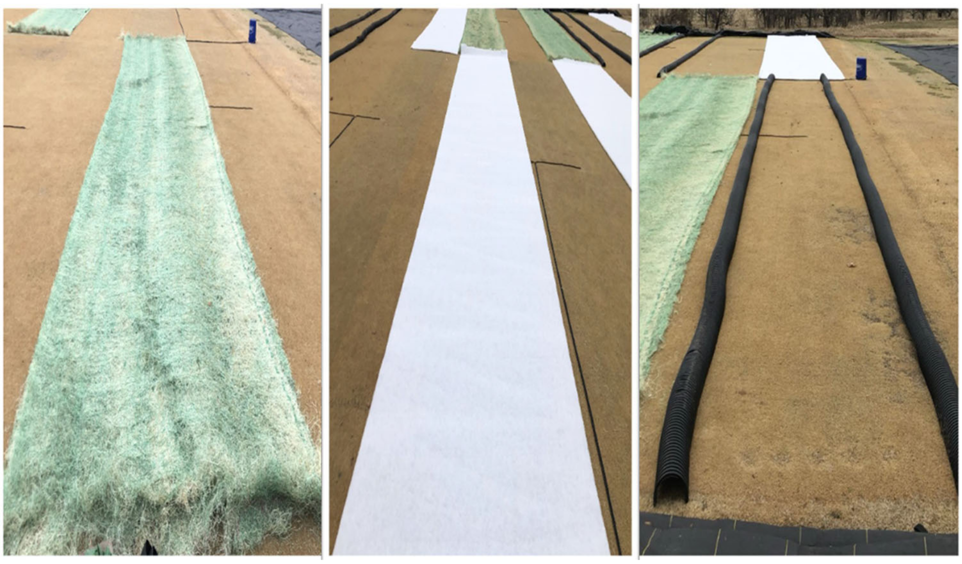

FIGURE 9 Straw erosion control mat (left), synthetic batting material (middle), and pipe to create air gap (right) placed on ultradwarf bermudagrass putting green prior to covering.

documented to provide adequate winter protection (DeBoer et al., 2019a); however, deciding when to install covers during the winter can be a nuanced decision affected by operating budget, winter employee retention, membership expectations, length and intensity of cold spell, and time of year. Research from the University of Arkansas, conducted over three winters from 2015–2018, investigated the effects of reducing the USGA recommended temperature for installing covers on a sand-based ultradwarf bermudagrass putting green (DeBoer et al., 2019a). Champion, MiniVerde, and TifEagle bermudagrasses were covered using black, woven polypropylene covers when forecasted air temperatures were predicted to reach 25˚F, 22˚F, 18˚F, and 15˚F and were compared to an uncovered control. Significant winterkill of bermudagrass occurred during two of the three winters resulting in a complete kill of all uncovered turf. However, protective covers installed at every investigated low-temperature threshold resulted in adequate protection from major winter injury. The best practice remains to err on the side of caution when choosing to cover greens, but golf courses with smaller budgets and less labor may save costs by waiting for lows below 25˚F without experiencing catastrophic bermudagrass loss.

Covering bermudagrass putting greens is a proven method for protecting turfgrass from low-temperature exposure but does not guarantee survival throughout the winter, specifically during periods of extreme low-temperature exposure (<15˚F). During extreme low-temperature events, adding protection in addition to a turf cover will help maximize bermudagrass survival. Extra protection can be added by creating an air gap between the protective cover and the turfgrass. The trapped air acts as a layer of extra insulation. Materials like pine straw, drainage pipe, synthetic batting (Figure 9), and use of multiple protective covers can be used to create air gaps. DeBoer et al. (2019a) investigated the effect of synthetic batting material placed underneath protective covers on the 1-inch soil temperature of an ultradwarf bermudagrass putting green compared to a cover alone. Soil temperature at a depth of 1 inch did not differ between different weights of batting material, but all batting materials increased the 1-inch soil temperature relative to a cover alone. It is important to remember that the weight of the batting material, the need for additional storage space, and the labor necessary to install the material will limit the "wall-to-wall" use of synthetic batting for extra protection.

Although air gaps have been demonstrated to increase soil temperatures compared to covers alone (Booth, 2022; Walton, 2022), Booth (2022) observed the most consistent increase in average overnight canopy temperatures and daily minimum canopy temperatures when using two covers, and even observed detrimental effects to the canopy temperature from treatments that included an air gap. Walton (2022) found that straw mats provided superior protection during extreme cold events (<0˚F) compared to air gaps created using other materials (e.g., synthetic batting, drainage pipe, etc.) when protecting specific turfgrass areas, particularly on north-facing slopes and elevated sites.

4.3.2 | Topdressing

In addition to protective covers, sand topdressing is another common practice that is often thought to reduce winter desiccation and low-temperature damage to putting greens. It is thought that late-season, heavy sand-topdressing creates a physical barrier providing the turfgrass crowns protection from desiccating environmental conditions. Although this practice is frequently carried out, sand topdressing in the late fall to protect bermudagrass putting greens from desiccation injury has not been evaluated in peer-reviewed research. However, a late-fall sand topdressing of 0.2 inch increased turfgrass crown moisture content during the following spring on a sand-based creeping bentgrass putting green (Michael & Kreuser, 2020). The University of Tennessee suggests that topdressing bermudagrass before the first autumn freeze may help buffer plants from direct low-temperature kill during winter dormancy (Samples & Sorochan, 2008). Miller and McCauley (2022) investigated the canopy temperature effects on a MiniVerde ultradwarf bermudagrass putting green topdressed with different colored sands. Warmer canopy temperatures were observed for black- and green-colored sands compared to a natural-colored sand control. Even though fall and winter topdressing have demonstrated beneficial effects necessary for winter survival of bermudagrass, the use of protective covers for ultradwarf bermudagrass winter protection combined with winter playability expectations limits the applicability of a one-time heavy sand topdressing for courses that must remain open for play throughout the winter months.

Lastly, the best cover to prevent winter injury is snow, yet snow cover is sporadic and unreliable. Experience shows that snow cover (prior to periods of cold air temperatures) provide significant insulation and protection against winter injury (Patton & Bigelow, 2014).

4.4 | Overseeding

Throughout the transition zone and southern United States, bermudagrass can be overseeded with perennial ryegrass (*Lolium perenne* L.) (Figure 10) or other cool-season grasses in the fall to provide green color, a uniform surface, and increased wear tolerance while bermudagrass is dormant (Mazur & Rice, 1999; Ward et al., 1974). However, overseeded cool-season grasses, especially perennial ryegrass, compete with the underlying bermudagrass for light and other resources. Additionally, improved genetics and erratic weather patterns allow perennial ryegrass to persist long into the spring and even summer, complicating the spring transition back to the bermudagrass base. Shading of the bermudagrass canopy by actively growing perennial ryegrass along with root competition can extend the dormancy period of bermudagrass further into the spring (Horgan & Yelverton, 2001). It is well documented that the stand density of bermudagrass declines over time when overseeded with perennial ryegrass (Gelernter & Stowell, 2005; Horgan & Yelverton, 1998, 2001; Jackson et al., 2017; McCauley, 2009).

FIGURE 10 Dormant hybrid bermudagrass overseeded with perennial ryegrass in the foreground and non-overseeded dormant hybrid bermudagrass in the background.

It stands to reason that a perennial ryegrass overseed would provide the underlying bermudagrass insulation and protection from low-temperature extremes. However, Jackson et al. (2017) observed only slight increases (1.0–1.5˚F) and somewhat variable effects on surface soil temperature attributed to overseeding bermudagrass with perennial ryegrass. Jackson et al. (2017) also reported a decline in stolon total carbohydrates of overseeded Patriot and 'Riviera' bermudagrass. If the main goal of a turfgrass manager is to protect bermudagrass from winterkill, the focus should be placed on best management practices for optimizing bermudagrass growth and winter protection rather than prioritizing a potential fall overseed. If overseeding must be done, choosing to wait as long as possible to overseed in the fall and using chemical controls for overseeded ryegrass removal early in the spring will maximize the amount of competition-free growing days necessary for the long-term health of bermudagrass. Failure to remove overseeded ryegrass in the spring will result in a poor bermudagrass sward and a lack of stolon and rhizome development prior to winter (Keese et al., 2005). A total of 603 to 959 competition-free growing degree days and 227 to 423 mol ft^{-2} (2,447 to 4556 mol m^{-2})competition-free daily light integral are what is required for bermudagrass to recover (>97%) when transitioning from perennial ryegrass overseed (Peppers et al., 2021).

FIGURE 11 'Quickstand' bermudagrass mown at a shorter height and trafficked on a soccer field (left) had little survival compared to the sideline turf which was mown at a higher height of cut (right).

4.5 | Mowing

Bermudagrass is popular on golf course putting greens, fairways, and sports fields due in part to its tolerance to low mowing heights. Prior to dormancy in the fall, it is common practice to slightly raise the height of cut on bermudagrass. On ultradwarf bermudagrass putting greens, Richardson and Booth (2021) recommend raising height of cut by 25% heading into fall while bermudagrass is actively growing, then by another 25% heading into winter dormancy. On sports fields, height of cut should be increased approximately 0.25 to 0.5 inches, ensuring the final height of cut still delivers acceptable playing conditions (Munshaw et al., 2017).

The theory of raising mowing heights to protect against winterkill has not been studied thoroughly, but one may infer that higher heights of cut elevate carbohydrate production while also providing insulation for storage organs (i.e., crowns, stolons, and rhizomes). Additionally, increasing height of cut has resulted in improved traffic tolerance, which also reduces damage to storage organs (Strunk et al., 2021) (Figure 11). As a result of increased height of cut, mowing frequency requirements are also reduced. This subsequently reduces traffic stress on bermudagrass entering dormancy.

4.6 | Plant growth regulators

As the name implies, plant growth regulators (PGRs) are chemicals that are commonly applied to turfgrasses to reduce growth (Fagerness et al., 2000). Plant growth regulators have many more uses than solely suppressing turfgrass growth—they can increase turfgrass quality, color, shade tolerance, and drought tolerance (Glab et al., 2020; Schiavon et al., 2014; Serena et al., 2020; Steinke & Stier, 2003). Certain PGRs, such as paclobutrazol, can suppress turfgrass diseases such as dollar spot (caused by *Clarireedia* spp.) (Putman & Kaminski, 2011). When the PGR trinexapac-ethyl is applied only in the fall to hybrid bermudagrass, it can increase spring green-up (i.e., cold de-acclimation) and sometimes enhances cold tolerance of hybrid bermudagrass rhizomes (Richardson, 2002). In contrast, when trinexapac-ethyl is applied in both the fall and winter, it has the capability to delay cold de-acclimation of ultradwarf bermudagrass in the spring (Booth et al., 2024). The delay of cold de-acclimation could also actually be beneficial for reducing winterkill and enhancing turfgrass health and quality. This is because late frosts during the springtime on recently cold de-acclimated bermudagrass are known to be a cause of winterkill, so a delay in cold de-acclimation could be a best management practice for preventing bermudagrass winter injury (Booth et al., 2024; Reicher et al., 2007).

4.7 | Shade

It is difficult to find an Extension or outreach article about turfgrass winterkill where the authors do not at least mention the compounding effects of shade on winter injury (Frank, 2016; McCarty & Miller, 2018; Richardson & Booth, 2021; Richardson et al., 2014). Warm-season turfgrasses are notoriously susceptible to shade stress, with species like zoysiagrass and St. Augustinegrass [*Stenotaphrum secundatum* (Walter) Kuntze] exhibiting superior shade tolerance than

FIGURE 12 'Midlawn' bermudagrass winterkill caused by tree-shade during winter to a well-drained section of fairway in Indiana.

FIGURE 13 Shade in the southern endzone of Donald W. Reynolds Razorback Stadium in Fayetteville, AR (left photo), can both weaken the bermudagrass during the growing season and cause colder temperatures during the winter due to extended snow or ice coverage (right photo).

bermudagrass (Beard, 1969). However, zoysiagrass and St. Augustinegrass remain sensitive to low light conditions, and shade stress could exacerbate winterkill susceptibility (Meeks & Chandra, 2021; Peterson et al., 2014; Wherley et al., 2011, 2013).

There is ample, anecdotal evidence that shaded areas on golf courses, in sports stadiums, and in landscapes are more likely to experience winterkill (Figures 12–14). However, there have been almost no studies that have attempted to document the extent to which shade contributes to winterkill. Baldwin et al. (2013) demonstrated that TifEagle experienced significantly delayed spring greenup when exposed to 55% continuous shade. Recent work by Stover et al. (2022), suggested that problematic, shaded areas on a golf course might be mapped using remote sensing (drones) to help better define areas that might need to be addressed during the growing season.

While there is no definitive research quantifying the precise amount of shade that increases winter injury risk on bermudagrass, it is reasonable to assume that the shade threshold for winter injury is likely less than the shade threshold that causes a significant decline in turfgrass quality during the growing season. As observed in Figures 12–14, all these areas produced acceptable playing conditions during the growing season, yet experienced winter-related injury that is closely aligned with reduced light. It is important for turfgrass managers to clearly map areas that experience more winter injury and then document light conditions during the growing season to see how closely the damage is associated with reduced light conditions. This could provide opportunities to make some modifications to those areas, such as planting a more shade-tolerant species or cultivar or modifying the environment to enhance overall light conditions.

FIGURE 14 Greater winterkill observed in the south endzone of Donald W. Reynolds Razorback Stadium in Fayetteville, AR, which is likely due to prolonged shade stress in those areas.

4.8 | Traffic

Bermudagrass actively grows in the summer months and can rapidly recover from traffic stress. As temperature and daylength decrease in the fall, the ability for bermudagrass to recover from traffic reduces. Excessive traffic during fall, winter, and early spring will decrease bermudagrass coverage (Henry, 1985), potentially limiting crown and/or stolon protection from lethal temperatures. If traffic is extreme, this could lead to loss of turfgrass and require replanting the following growing season.

When possible, it is important to minimize use on bermudagrass entering dormancy, during dormancy, or exiting dormancy. If the surface must be used, traffic distribution will minimize isolated traffic stress. For example, rotating drills on athletic fields, and scattering or limiting golf cart traffic can help bermudagrass resist the effects of low temperatures in winter.

4.9 | Nutrient management

There has been great past (and present) debate about when and which nutrients should be applied to increase bermudagrass winter hardiness. Nitrogen is an important nutrient for bermudagrass health. Nitrogen applications not only supply needed nutrition to the plant, but they drive the uptake of other nutrients in the soil (Goatley et al., 1994). Late summer and early fall (late-season) applications of N ($\leq$2 lb N 1,000 ft^{-2}) result in improved bermudagrass fall and spring color without decreasing winter hardiness (Goatley et al., 1994; Munshaw et al., 2001; Reeves et al., 1970; Richardson, 2002). Goatley et al. (1994) note that while late season applications of N may not lead to increased winterkill, they could result in N leaching, increased weed encroachment, or disease.

Two prominent studies reported that K fertilizer applications can decrease bermudagrass winterkill (Gilbert & Davis, 1971; Juska & Murray, 1974). However, a close examination of these experiments and the soils used in these research studies demonstrates that bermudagrass was K deficient prior to winter, and that plants increase in winter hardiness when nutrient deficiencies are corrected prior to winter stress. As such, additional autumn K fertilization will not reduce winter injury if a soil test indicates that your soil has optimum levels of K (Miller & Dickens, 1996). In the absence of a soil test, applying N and K in a 2:1 ratio has proven sufficient for maintaining quality bermudagrass (Park et al., 2017).

4.10 | Disease management

Although winterkill can be attributed to multiple factors such as desiccation and extreme cold temperatures, localized winterkill patches can be caused by the disease spring dead spot (SDS; caused by *Ophiosphaerella* spp.) of bermudagrass (Figures 15–16). SDS appears in the spring as localized winterkill patches, and symptoms are exacerbated by frigid temperatures during winter dormancy (Tredway et al., 2009).

FIGURE 15 Severe spring dead spot symptoms on 'TifEagle' ultradwarf bermudagrass in Fayetteville, AR, in May of 2023.

FIGURE 16 Spring dead spot disease of 'TifSport' hybrid bermudagrass in late spring with weeds encroaching the center of the patches.

The disease is aggregated and often appears in areas that have high thatch layers and low soil fertility (Hutchens et al., 2023). SDS is caused by three pathogens: *O. herpotricha*, *O. korrae*, and *O. narmari* (Tredway et al., 2009). The predominant species in North America are *O. herpotricha* and *O. korrae*, and these two species respond differently to certain cultural and chemical practices making management challenging (Flores et al., 2017; Hutchens et al., 2019, 2021; Iriarte et al., 2004, 2005; Tredway et al., 2009, 2020; Wetzel et al., 1999).

SDS caused by *O. korrae* is suppressed by calcium nitrate applications while *O. herpotricha* is not; moreover, SDS caused by *O. herpotricha* is suppressed by ammonium sulfate applications while *O. korrae* is not (Tredway et al., 2020). The two species also have varying sensitivities to fungicides in vitro and in situ, with *O. korrae* generally being less sensitive to fungicides than *O. herpotricha* (Hutchens et al., 2019; Tredway et al., 2020). Sensitivity of *O. narmari* to different fungicides is less understood. Management strategies for SDS are optimized if they are tailored for the specific species that are causing the disease at a given location. However, certain management practices reduce disease severity regardless of the *Ophiosphaerella* species causing the disease.

Planting cold-tolerant bermudagrass cultivars, reducing or preventing thatch buildup, and maintaining proper soil fertility and pH are amongst the most effective cultural management practices for preventing SDS (Cottrill et al., 2016;

TABLE 2 Efficacy of turfgrass fungicide active ingredients against spring dead spot.

Efficacy	Fungicide
Excellent	Isofetamid
Very good	Mefentrifluconazole Penthiopyrad Pydiflumetofen
Good	Fluxapyroxad Pyraclostrobin Tebuconazole
Fair	Azoxystrobin Fluoxastrobin Myclobutanil Propiconazole

NOTE: Table adapted from Hutchens et al. (2022a).

Hutchens et al., 2023; Miller et al., 2017; Tredway et al., 2009, 2020). The best cultural management practice to enhance bermudagrass recovery from SDS damage in late spring and early summer is the application of quick-release N fertilizers in the absence of aggressive cultivation (Hutchens et al., 2022b). Cultivation practices such as fraze mowing, aerification, and verticutting are helpful for preventing SDS, but aggressive cultivation too early in the spring can inhibit bermudagrass recovery (Hutchens et al., 2022b; Miller et al., 2017; Tisserat & Fry, 1997). Beyond cultural practices, SDS can be readily managed with fall applications of fungicides (Table 2), especially mefentrifluconazole, isofetamid, penthiopyrad, or pydiflumetofen (Hutchens et al., 2022a). In addition to the positive benefits of fungicides on SDS suppression, fall applications of efficacious fungicides can also increase the rate of spring green-up as well as recovery from SDS damage (Kerns et al., 2017; McCarty et al., 1992).

5 | CHECKLIST

If planting bermudagrass, consider the following action items to reduce the risk of winterkill the subsequent winter after establishment:

- Remove or reduce shade where possible prior to planting.
- Analyze the soil and correct any nutrient deficiencies.
- Improve site drainage prior to planting.
- Plant in late spring or early summer.
- Plant cold hardy cultivars.
- If needed, use herbicides that allow for safe and rapid establishment.
- Apply a wetting agent in late fall.
- Use insulating winter covers on high-values sites.
- Apply a heavy sand topdressing in late-fall or early winter.
- Do not overseed bermudagrass in the fall within the first year of planting.
- Raise mowing heights at the end of the growing season.
- Remove or reduce traffic stress starting 1 month prior to winter where possible.
- Apply fungicides in the fall to control SDS disease.

If maintaining existing bermudagrass, consider the following action items to reduce the risk of winterkill.

- Add additional drainage in low-lying areas of high-value turf.
- Apply a wetting agent in late fall.
- Consider wintertime irrigation of exposed areas.
- Use insulating winter covers on high-value sites.
- Apply a heavy sand topdressing in late-fall or early winter.
- Raise mowing heights at the end of the growing season.
- Reduce tree shade where possible.
- Remove or reduce traffic stress beginning 1 month prior to winter where possible.
- Apply fungicides in the fall to control SDS disease.
- Test plugs for survivability from sensitive areas in late winter to assess potential losses.
- Develop an herbicide program appropriate for the expected level of winter injury.

6 | SUMMARY

This guide summarizes the research and practical knowledge surrounding winterkill, covering causes, assessment methods, recovery options, and mitigation strategies. Minimizing winterkill on bermudagrass will reduce re-establishment costs, improve turfgrass quality and uniformity, and increase sustainability through decreased water and pesticide use.

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CONFLICT OF INTEREST STATEMENT

The authors declare no conflicts of interest.

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