HortScience 60(8):1389–1397. 2025. https://doi.org/10.21273/HORTSCI18673-25

The Economic Cost of Winter Injuries on Golf Courses in North America

Chengyan Yue
Department of Horticultural Science, Department of Applied Economics, University of Minnesota-Twin Cities, 1970 Folwell Avenue, St. Paul, MN 55108, USA

Uma Parasuram
Department of Applied Economics, University of Minnesota-Twin Cities, 1970 Folwell Avenue, St. Paul, MN 55108, USA

Eric Watkins
Department of Horticultural Science, University of Minnesota-Twin Cities, 1970 Folwell Avenue, St. Paul, MN 55108, USA

Doug Soldat
Department of Soil and Environmental Sciences, University of Wisconsin–Madison, 1525 Observatory Drive, Madison, WI 53706, USA

Paul Koch
Department of Plant Pathology, Molecular and Environmental Toxicology Center, University of Wisconsin–Madison, 1630 Linden Drive Madison, WI 53706, USA

Kevin Frank
Department of Plant, Soil and Microbial Sciences, Michigan State University, 1066 Bogue Street, Room A584E, East Lansing, MI 48824, USA

Michelle DaCosta
Stockbridge School of Agriculture, University of Massachusetts-Amherst, 161 Holdsworth Way, Amherst, MA 01003, USA

Keywords. crown hydration, desiccation, ice encasement, low temperatures, snow mold, winter stress, turfgrass

Abstract. **Golf courses in North America experience occasional damage from winter injuries. This damage can sometimes be very severe, resulting in substantial financial impacts. Winter damage to turfgrass surfaces affects golf course finances in three primary ways: winter injury prevention costs, additional costs of inputs to recover from winter injuries, and revenue losses due to delayed openings. We conducted a survey of golf course superintendents in North America to assess the economic impact of winter injuries. The survey collected data on the causes of winter injuries, the extent of damage across the golf course, and management practices that were employed. We found that, on average, the cost of preventing winter injuries was between $12,000 and $17,999 annually per golf course, and additional costs of inputs to recover from winter injury ranged from $6000 to $8999. The revenue losses due to delayed openings, ranging from $3000 to $8999 per golf course, further emphasize the far-reaching consequences of winter injuries.**

Received for publication 18 Apr 2025. Accepted for publication 30 May 2025.
Published online 21 Jul 2025.
This project was supported by the National Institute of Food and Agriculture, US Department of Agriculture, Specialty Crop Research Initiative under award number 2021-51181-35861. Any opinions, findings, conclusions, or recommendations expressed in this publication are those of the author(s) and should not be construed to represent any official US Department of Agriculture or US Government determination or policy.
C.Y. is the corresponding author. E-mail: yuechy@umn.edu.

The golf industry has a significant impact on the economies of the United States and Canada. According to a recent economic impact study conducted by the US Golf Industry Coalition in 2022, the direct economic impact of the US golf course industry was about $102 billion, with the total economic impact (direct, indirect, and induced economic impact) reaching $226 billion. Approximately one million jobs were directly tied to the US golf industry (US Golf Industry Coalition n.d.). Similarly, in Canada, the golf industry contributed $23 billion of national gross domestic product in 2023 (Golf Course Industry n.d.).

The economic output of golf courses in many northern climates can be at risk due to damage from winter-associated stresses. Winter injury refers to damage caused to turfgrass during the winter and is a major risk in much of the northern United States, Canada, northern Europe and other cold climates. The three main sources of costs to golf courses due to winter injuries are the prewinter costs to prevent winter injuries, additional costs of inputs to recover from winter injuries, and the loss in revenue due to delays in opening the golf course. Research focused on the five Nordic countries (Denmark, Finland, Iceland, Norway, and Sweden) estimated the cost of winter injuries to be at least 14 million Euros (Kvalbein et al. 2017). In years with significant winter injuries, 88% of courses reported the cost of repairs ranged from 3000 to 12,000 Euros. Furthermore, the reported revenue loss was 6000 Euros or less for 50% of courses, and between 6000 and 12,000 Euros for 25% of the golf courses. To date, there has not been a comprehensive study to estimate the economic impact of winter injuries in northern United States and Canada (hereafter collectively referred to as North America). This study aimed to fill the gap in the literature.

Winter injury is a multifaceted problem with current and future relevance that is influenced by weather change, grass physiology, maintenance practices, topographical variations, and other environmental conditions. There are many types of winter injuries, including damage from crown hydration, desiccation, direct low temperature kill, ice encasement, and snow mold (Beard 1964, 1969).

Crown hydration is a type of winter injury that typically occuring in late winter after thawing and freezing (Frank 2015). Turfgrasses susceptible to this stress, such as annual bluegrass (*Poa annua* L.) and perennial ryegrass (*Lolium perenne* L.), become hydrated during warming periods as snow melts and surface soils thaw, leading to intracellular ice formation and subsequent cell death upon re-exposure to freezing temperatures. Direct low temperature kill also causes intracellular ice formation and can be independent of the crown moisture content. This stress is observed when temperatures drop below the plant's maximum low temperature limit and is influenced by factors including the plant's cold hardiness level, freezing rate, and post-thawing rate.

Desiccation occurs when unprotected turfgrass exposed to drying cold winds for extended periods without snow cover, loses significant moisture in leaf and crown tissues (Kreuser 2019). Some preventative measures to reduce desiccation risk include heavy sand topdressing, protective covers on the turf, and wind breaks to assist in snow retention.

Ice encasement injury occurs when a thick layer of ice covers the turfgrass, resulting in the loss of oxygen and buildup of carbon dioxide and toxins. The degree of damage depends on multiple factors, from the grass type to the thickness of the ice and total duration of ice cover. Preventive measures involve covering with impermeable covers, adding

insulating layers, or removing ice with dark melting agents (Landschoot 2023).

Snow mold is another common winter injury that happens when there are periods of cool and wet weather or when turfgrass is under snow cover resulting in the fungi to infect the turfgrass. Applying preventative fungicides before snowfall is the most effective preventive measure taken to protect against snow mold.

Grass species used on the golf course can have a role to play in the extent of damage caused to golf courses due to winter injuries. Grass species differ in their tolerance to environmental conditions, dormancy behaviors, and physiological traits. Cool season grass species like annual bluegrass (*Poa annua*) are commonly used on golf courses but are known to be highly susceptible to winter injuries like ice encasement, desiccation, and crown hydration (Beard 1964; Valverde 2007). Poa annua's low tolerance to winter injury is often associated with its shallow root system and sensitivity to lower oxygen conditions under ice cover for prolonged periods of time (Beard 1972). On the other hand, creeping bentgrass (*Agrostis stolonifera*) is known to be more winter hardy with the ability to sustain harsher and colder temperatures.

Changing weather patterns are another recent, but important phenomenon that has increased the challenge of winter injuries for not only turfgrass managers but also homeowners with lawns. According to Rantanen et al. (2022), the Arctic has been warming nearly four times faster than the global average since 1970s, a phenomenon known as Arctic amplification. Furthermore, research by Karl et al. (2009) showed that even regions like the northern Great Plains and Upper Midwest have started to experience warmer and wetter winters, which may call for different turfgrass management strategies. These changes can result in winters with inconsistent snowfall, which may lead to more frequent free–thaw cycles, exposing the turfgrass to more significant winter injuries. Recent data from the US Environmental Protection Agency (2025) on the changes in the freeze–thaw conditions showed that there have been 17 more unfrozen days in 2023 compared to the long-term average (1979–2023) within the 48 contiguous states of the United States.

By collecting primary data from golf course superintendents in North America through an online survey (Wells et al. 2014), this study seeks to provide important insights on the impacts of winter injury relevant to the turfgrass and golf industry.

Methodology

Our data were collected using a survey instrument that was distributed via Qualtrics, an online survey platform widely used in academia. A comprehensive survey was designed and distributed to golf course superintendents located in North America where winter injury of cool season turfgrasses can occur. The survey targeted golf courses through social media, email lists, and through communication at various professional conferences attended by golf course superintendents during the data collection period. The survey was comprehensive and had detailed questions designed to collect information about the causes and frequency of winter injuries, the extent of damage across various parts of the golf course, the types of grass utilized and the diverse management practices employed to maintain the golf course's condition during the winter. Questions regarding the frequency and intensity of winter injuries spanned over the past 23 years (2000–22), wherein participants were asked to think about their experience with managing winter injuries for the last 23 years. Participants were informed that the responses to the survey were anonymous, ensuring their confidentiality, and promoting a more open and honest sharing of information from participants.

Data. We received a total of 96 responses from golf course superintendents. About 60% of the data collected from the United States was from golf courses in Connecticut, Iowa, Massachusetts, Michigan, and Minnesota. In Canada, 80% of the data were from golf courses located in Ontario and Alberta.

Table 1 shows summary statistics for survey participants as well as information about the golf courses. Similar to research by Wang et al. (2023), we found that the average age of golf course superintendents in the sample was between 46 and 55 years old. All participants in the sample had at least a high school diploma or equivalent degree. The majority of participating golf course superintendents had a bachelor's degree. Specifically, 10.7% had completed a short course or certificate program, about 6% had completed some college, 20.2% had an associate's degree, 59.5% had a bachelor's degree, and the remaining 3.6% had a graduate degree. The average level of experience as a golf course superintendent was between 16 and 20 years, and approximately 20% of the sample had been in the role for more than 30 years. On average, participants had been working on their current golf course (the golf course they were working at during the time of answering the survey) for about 12 years. Most participants (84.4%) were members of a local or national golf course superintendent association.

Some of the relevant golf course characteristics were that approximately 45.3% of the courses were publicly owned, 43.2% were private, and the rest were owned by the local government (municipal). The general distinction between public and private golf courses is that the public golf courses are open to all golfers without the requirement of a membership while private courses are restricted to their members and the members' guests; municipal courses are a subset of publicly owned courses operated by local governments. On average, golf courses in our sample each had 7.7 permanent and 12.5 seasonal employees for turfgrass maintenance. Golf course annual operation budget and yearly gross income were, on average, between $400,000 and $424,999 and between $750,000 and $799,999, respectively. Additionally, we found that the average operational budget for public golf courses was between $325,000 and $349,999 and for private golf courses it was between $550,000 and $599,999.

Results

Most prevalent winter injuries. We asked superintendents to report the most prevalent winter injuries affecting their golf course. While some injuries, such as snow mold, are relatively easy to confirm, the cause reported by the superintendent might not be definitive. For instance, it may be particularly difficult to distinguish between damage caused by ice encasement or crown hydration, especially when the damage incurred is under ice. In cases like these, the reported causes reflect the superintendents' best judgment based on their field experiences. The predominant cause of winter injury was reported as ice encasement by 70% of participants (Fig. 1). For about 60% of the participants, crown hydration was a significant contributor to winter injuries on their courses, followed by snow mold at 54%, and desiccation at 46%.

Coverage percentage of grass types on golf courses. Different grass species have different tolerance levels to winter injuries. To get a better understanding of how different grass species respond to different types of winter injuries, we identified which grass species are most prevalent in different areas of golf courses (Fig. 2). The grass types that were reported to be most used on the greens of the golf course were creeping bentgrass (*Agrostis stolonifera*) and annual bluegrass, which accounted for 65% and 33% of the greens, respectively. Creeping bentgrass was the most used grass type on the fairways (39%), followed by Kentucky bluegrass (*Poa pratensis*) (23%) and annual bluegrass (22%). Likewise, creeping bentgrass, Kentucky bluegrass, and annual bluegrass were the most reported grass types for tees while roughs were mainly Kentucky bluegrass and fine fescues. These species distributions align with estimates by Gelernter et al. (2017).

Impact of winter injuries to grass types. To understand the impact of various winter injuries on the grass types used, we asked golf course superintendents to report how susceptible they perceived the different grass types were to various winter injuries. Figure 3 shows the impact of different winter injuries on various grass types.

Consistent with some previous research, superintendents reported that annual bluegrass was the grass species that was most prone to all types of winter injuries, followed by creeping bentgrass and then perennial ryegrass. Tall fescue (*Schedonorus arundinaceus*) and fine fescues (*Festuca spp.*) were identified as the least affected grass types, and were also in the least common species present on golf courses (Fig. 2). Annual bluegrass was shown as single most sensitive species to most of the listed injuries, such as dehardening (71%), crown hydration (56%), low temperature (48%), and ice encasement (46%). In

Table 1. Summary statistics of participating superintendents and golf courses based on survey data from golf course superintendents in the United States and Canada (N = 96).

Variable	Variable description	Variable coding	North America (N = 96) %	Mean	*SD*
Participant characteristics					
Age	Age of the golf course superintendent (years)	1 = 18–25	2.38	3.77	1.12
		2 = 26–35	10.71		
		3 = 36–45	25.00		
		4 = 46–55	35.71		
		5 = 56–65	21.43		
		6 = older than 65	4.76		
Education	Highest level of education of the golf course superintendent	1 = High school diploma or equivalent	0	4.39	1.04
		2 = Short course or certificate program	10.71		
		3 = Some college	5.95		
		4 = Associate's degree	20.24		
		5 = Bachelor's degree	59.52		
		6 = Graduate degree	3.57		
Experience	Number of years the participant has been involved in the golf course as a superintendent	1 = ≤5 years	10.71	4.19	2.04
		2 = 6–10	17.86		
		3 = 11–15	8.33		
		4 = 16–20	19.05		
		5 = 21–25	13.10		
		6 = 26–30	10.71		
		7 = >30 years	20.24		
Member	Is the participant a member of a local or national golf course superintendents' association	Yes	84.38	—	—
Certified	Is the participant a certified superintendent	Yes	22.62	—	—
Golf course characteristics					
Ownership	Gold course ownership type	1 = Public	45.26	1.66	0.68
		2 = Private	43.16		
		3 = Municipal	11.53		
		4 = Associated clubs	0		
Permanent employees	Total number of turfgrass maintenance-related permanent employees	—	—	7.65	24.46
Seasonal employees	Total number of turfgrass maintenance-related seasonal employees	—	—	12.51	12.95
Operational budget	Annual operational budget of the golf course	—	—	$400,000–$424,999	—
Gross income	Yearly gross income of the golf course	—	—	$750,000–$799,999	—

SD = standard deviation.

contrast, the primary weakness for creeping bentgrass were identified as desiccation (27%). Perennial ryegrass was thought to be significantly affected by low temperature, snow mold, and desiccation. Tall fescue and fine fescues were considered resistant to dehardening and were primarily affected by snow mold.

Percentage of grass lost due to winter injury. To better understand the impact of winter injury on different parts of the golf course, we asked golf course superintendents to indicate the percentage of grass lost at various locations on average and in years with considerable winter injuries.

To calculate the weighted average acreage percentage of grass damaged on different parts of the golf course due to winter injuries, we used data from two questions in the survey: one on the percentage of grass lost in different parts of the golf course due to winter injuries and the other on the area (in acres) of different golf areas (greens, tees, fairways and roughs). We then weighted the percentage of grass lost on different areas by the actual acreage to get the weighted average percentages (Fig. 4). Greens and fairways, averaging 4 acres and 30 acres, respectively, were the most affected by winter injuries.

We also asked superintendents about the level of winter injuries when averaged over their tenure at their current course. Participants reported that, on average, 10.4% of greens and 11.1% of fairways were damaged due to winter injuries during the entire period, and these numbers increased to 19.0% and 15.1%, respectively, when only considering years with considerable winter injuries. Winter injury was reported to affect, on average, about 6.5% to 7.2% of tee and rough areas, and the damage can go up to 8.8% and 8.2%, respectively, during years when considerable winter injuries occurred.

Extent of winter injuries and delays to golf course openings. The survey gathered comprehensive data regarding the severity and economic implications of winter injuries from golf course superintendents for the time they have been employed at their current golf course. Over a 12-year period, which is the average tenure of a superintendent on the current course, a typical golf course experienced winter-related injuries in four of those years. In years marked by winter injuries, golf courses, on average, encountered opening delays of up to 2.3 weeks in opening, which increased to 3 weeks in years with considerable winter injuries. In years with normal winter injuries, 20.4% reported delays of less than 1 week, 26.5% reported delays of about 2 weeks, 16.33% reported delays of 4 to 5 weeks, and only 2% reported delays of 8 weeks. No one reported delays of more than 8 weeks. In years with considerable winter injuries, 22.5% reported delays of less than 1 week, 14.3%

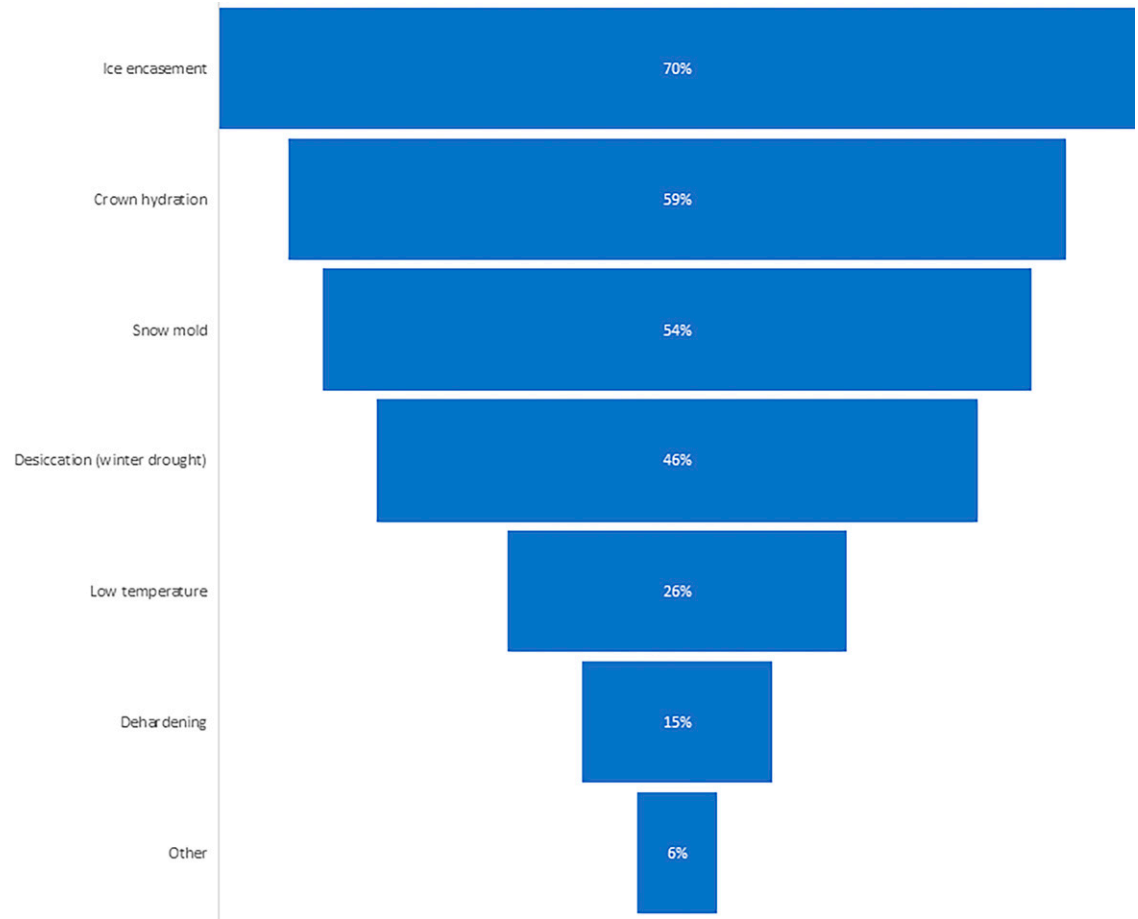

Fig. 1. Perceived causes of winter injury in North America based on survey data from US and Canada golf course superintendents (N = 96).

reported delays of 3 weeks, 22.45% reported delays of 4 to 5 weeks and 4% reported delays of 6 to 7 weeks.

Use of temporary greens and duration of ice cover. The use of temporary greens is a common practice to prevent winter injury from affecting the opening date of a golf course. Notably, 31% of golf course superintendents in the sample reported the use of temporary greens. Figure 5 depicts the distribution of the duration for which temporary greens were utilized. Blue bars represent frequencies for years with winter injuries, while orange bars indicate frequencies for years with considerable winter injuries. During the years in which temporary greens were used, they were used for an average duration of 3 to 4 weeks, varying depending on the extent of winter injuries. Though temporary greens can allow golf courses to open earlier than otherwise possible, the use of temporary greens often provides substandard quality and, in most cases, will result in reduced revenue as golfers choose to play elsewhere.

To assess the correlation between turfgrass damage and ice cover, superintendents were asked to indicate whether they observed such a relation and the duration for which the most severely affected areas were covered in ice. In the sample, 67% of superintendents noted that the areas with the most severe injury had been those covered with ice for an extended period of 3 months.

Figure 6 shows the distribution of time of ice coverage. About 6.2% of the golf courses reported that their turfgrass with the most severe injury was covered by ice for less than 1 month, 29.2% reported ice coverage for 2 months, and 35.4% reported ice coverage for 3 months. Additionally, 16.9% reported 4 months of coverage and 7.7% observed 5 months of coverage. None of them reported that grass most severely affected to be covered by ice for 6 months or more.

Financial cost of winter injury. Financial costs of winter injury originate from three primary sources: expenses related to preventing winter injuries; additional costs of inputs to recover from winter injuries; and revenue losses due to delays in opening golf courses. To estimate these costs, we asked the golf course superintendents to report the average costs and revenue losses from winter injuries for the years when injuries have occurred during their time on the current golf course. On average, the costs of preventing winter injuries amounted to $12,000 to $17,999 per year per golf course, while additional costs of inputs to recover from winter injury reached between $6000 and $8999 per year per golf course. Costs of inputs included labor, equipment, fertilizers, seeds, and weed control.

We asked golf course superintendents to report two types of revenue loss due to delayed openings: the average annual revenue loss due to delays in golf course openings caused by winter injuries and the revenue loss due to delayed openings in years with considerable winter injuries. The average annual revenue loss in normal years ranged from $3000 to $5999, while in only those years with considerable winter injuries the loss ranged from $6000 to $8999. About 50% of the courses reported no revenue loss due to delayed openings from winter injuries and 26% of the courses reported revenue losses of less than $5999, and only 3% of the golf courses reported revenue losses exceeding $75,000.

To standardize the costs across golf courses of various sizes, we also report the costs of winter injury per acre (see Fig. 7); this was calculated using the self-reported acreage data from the survey. On average, the cost of preventing winter injuries was approximately $200 per acre, with a median of $121 per acre, although some golf courses spent over $3000 per acre. The additional cost to recover from winter injuries in years with normal winter injuries was about $89 per acre on average. The costs went up to $147 per acre on average in years with considerable winter

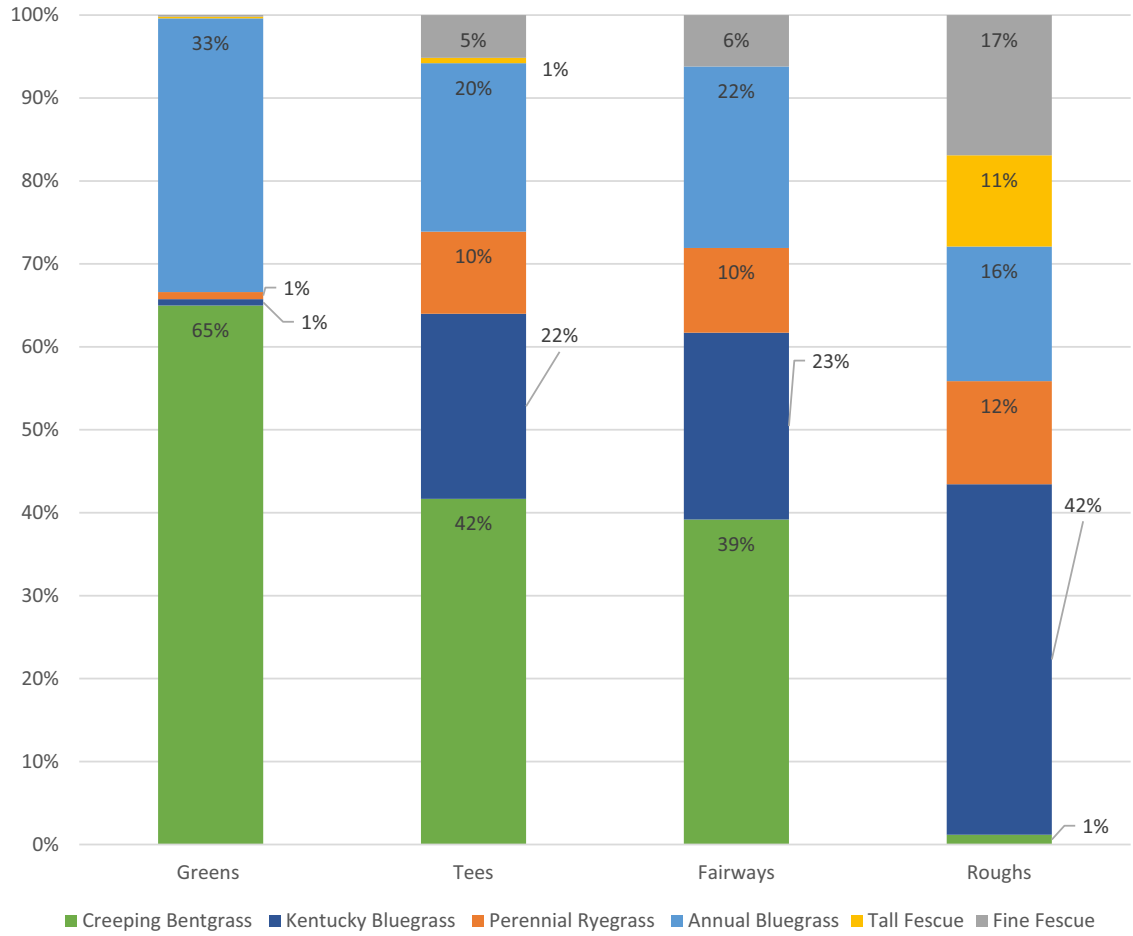

Fig. 2. Reported coverage percentage of grass types on surveyed golf courses in North America based on survey data from golf course superintendents in the United States and Canada (N = 96).

injuries. Finally, the revenue losses averaged about $115 per acre in years with normal winter injuries and $159 per acre in years with considerable winter injuries. However, there were a lot of variations in the revenue losses reported as many courses did not report any revenue losses but some courses reported a loss as high as $3055 per acre.

Indirect effects of winter injury. The loss in revenue due to winter injuries can also have an indirect effect on employees and their salaries. About 92.6% of participants said the effects of turfgrass winter injury did not lead to reductions in the number of employees on their course for the growing season following the damage. However, for the 7.4% who indicated reductions found that, on average, about 3 staff positions were eliminated during years with normal winter injuries and 4 staff positions were eliminated during the years with considerable winter injuries. Regarding salary reductions, 9.5% of superintendents reported that the effects of winter injury on the golf course's budget have led to reductions in employee salaries. On average, these reductions ranged from 6% to 10% in years with normal winter injuries and went up to 11% to 15% in years with considerable winter injuries.

We also asked superintendents to describe the measures taken to adjust for decrease in profits due to winter injuries. Most golf courses decreased their expenditure in other areas of the course budget (69.4%). Other adjustment methods included decreasing planned investments (28.2%), decreasing the budget reserve (15.3%), or opting for 'other' solutions (15.3%), which may involve borrowing money or the golf course owner covering the costs.

Management practices. We found that both public and private golf courses implemented measures to safeguard against winter injuries. The three most prevalent management practices across public golf courses included applying preventative snow mold fungicides, aerifying late fall, and applying plant protectants (Fig. 8). Private golf courses implemented these as well but also prioritized heavy fall topdressing as a management practice (Fig. 9). Almost all participants, irrespective of ownership type, indicated the application of snow mold fungicides. Private courses exhibited a greater inclination toward practices that were thought to build carbohydrate reserves and reduce irrigation in the fall. Private courses demonstrated higher adoption of protective measures such as the use of covers for greens (46%) and directing the flow of water with sandbags (10%); these practices were all less prevalent on public courses. This could be for a couple of possible reasons such as cost and labor considerations, or due to some public courses remaining open later in the year or even intermittently throughout the winter, which precludes the covering greens. Research by Valverde (2007) also found that using covers was a great source of insulation and helped turf survival and early spring quality of the turfgrass.

The management practices used on the golf course are related to how much winter injuries might impact the golf course. Thus, we compared the direct and indirect economic costs incurred to public and private golf courses. Overall, the total financial costs of winter injuries were between $27,000 and $35,997 for a public course compared to between $21,000 and $32,997 for a private course per year. First, public courses on average spent less on preventing winter injuries ($9,000–$11,999 per year) compared to private golf courses ($12,000–$17,999 per year). Consequently, the additional costs to recover from winter injuries in years when averaging the normal and considerable winter injuries were higher for public courses (between $9000 and $11,999 per year) compared to private courses (between $6000 and $8999 per year). Finally, the revenue losses for public and private golf courses were between $9000 and 11,999 and between $3000 and $5999, respectively.

In terms of the indirect costs of winter injuries, about 11.6% and 17.1% of the public

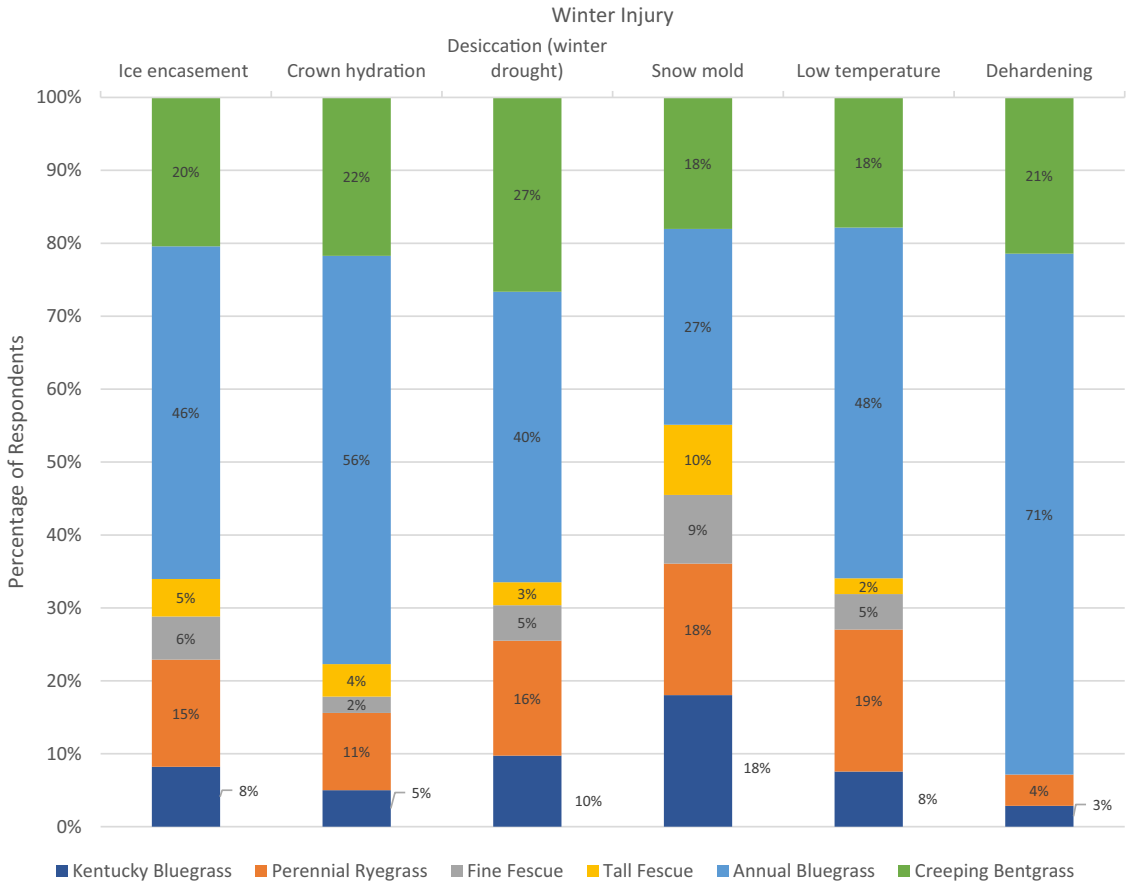

Fig. 3. Winter injury reported by grass type in North America based on survey data from golf course superintendents in the United States and Canada (N = 96).

and private golf courses reported reductions in employees when winter injuries occurred, respectively. On average, one staff position was reduced on public courses and six to seven staff positions were eliminated due to winter injuries each year on private courses when winter injuries occurred. In years with normal winter injuries, public golf courses reported a 6% to 10% reduction in employee salaries on average while private courses reported a 16% to 20% reduction.

Discussion and Conclusions

Turfgrass winter injury poses a significant economic threat to the golf course industry in North America. We found that ice encasement was the most prominent winter injury reported; other common injuries included crown hydration, desiccation, snow mold, and low temperatures. We found that annual bluegrass was considered by superintendents to be the most susceptible grass type to all winter injuries. This aligns with the findings by Beard (1964)

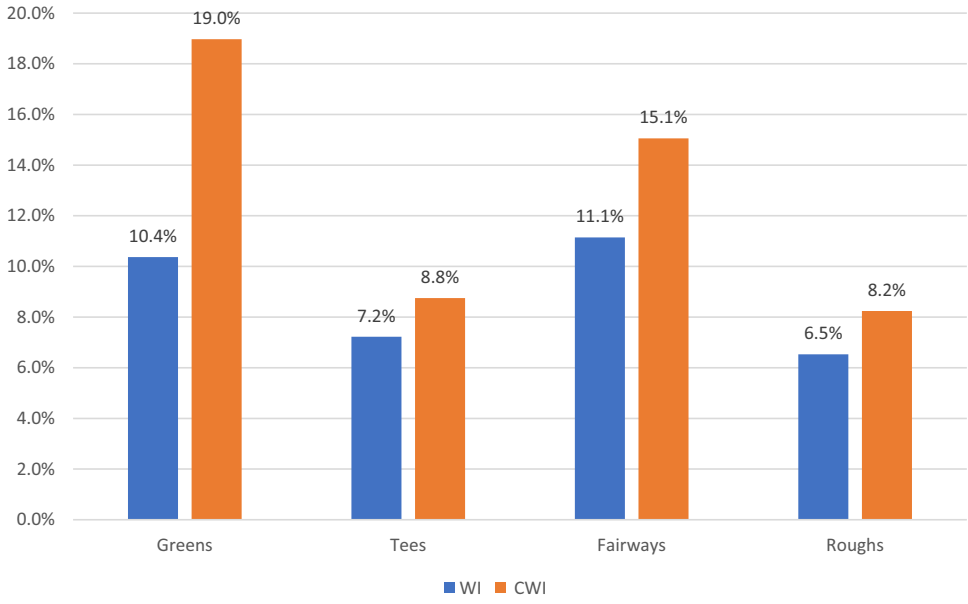

Fig. 4. Weighted average percentage of area (in acres) affected by winter injuries in North America based on survey data from golf course superintendents in the United States and Canada (N = 96). Winter injuries comprise years with normal winter injuries and considerable winter injuries when there were more than normal winter injuries to the golf course. CWI = considerable winter injuries; WI = winter injuries.

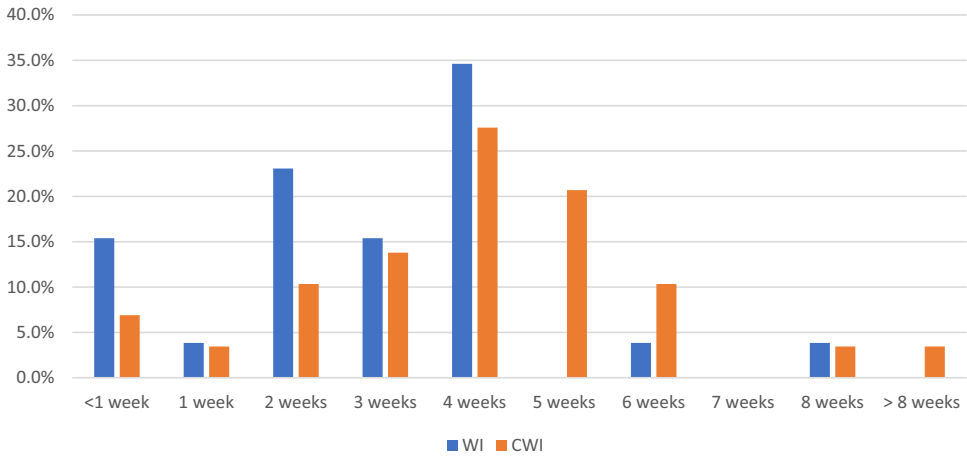

Fig. 5. Distribution of the time duration of the use of temporary greens to prevent delayed openings in North America during years in which winter injury occurred based on survey data from golf course superintendents in the United States and Canada (N = 29). Winter injuries comprise years with normal winter injuries and considerable winter injuries comprise years when there were more than normal winter injuries to the golf course. CWI = considerable winter injuries; WI = winter injuries.

who showed that annual bluegrass was very susceptible to injury from ice encasement, while creeping bentgrass was more tolerant. Recent work in Minnesota showed that annual bluegrass died under ice encasement durations more than 90 d, while creeping bentgrass was not affected at 90 d and was only partially damaged after 120 d of ice encasement (Watkins et al. 2025). Similarly, Valverde (2007) evaluated how creeping bentgrass and annual bluegrass survived under 10 possible winter scenarios in a controlled experiment and found that creeping bentgrass was not killed under any treatment, while annual bluegrass incurred injury during the first 15 d after ice encasement. Our survey results support previous findings and suggest that turfgrass management experts should develop strategies for either promoting annual bluegrass health to minimize the risk of winter injury, or management practices that reduce or eliminate annual bluegrass on golf course greens and fairways. We found that winter injury can impact greens and fairways up to 19% and 15%, respectively, depending on the severity of winter stresses.

A typical golf season in North America (excluding southern states that play year-round) spans approximately 7 months, from April to late October. Every day a golf course stays closed due to winter injuries can mean losing up to $7900 in revenue. Furthermore, courses also face recurring expenses—both to prevent winter injury and to recover from the damage caused by winter injuries. Our findings estimate the economic cost of winter injury to golf courses in North America. For the golf courses in our sample, the average cost to prevent winter injuries was between $12,000 and $17,999. The average cost to recover from winter injury when winter injury occurred was between $6000 and $8999. In addition, averaged across all years when there were delays in golf course opening due to winter injury, additional revenue loss per course was $3000–$8999 per year. To put this into perspective, the average economic impact of winter injuries is between $404 and $506 per acre for a golf course in North America. For instance, an 18-hole golf course with about 75 acres of maintained turfgrass this would be approximately $30,300 to $37,950 annually. The mean operational budget of the sample was between $400,000 and $424,999, the total cost of winter injury accounted for roughly 7.5% to 9% of the total operating budget.

We also found differences in the economic impact of winter injuries between public and private courses. On average, public golf courses spent less to prevent winter injuries, between $9000 and $11,999 compared to private courses that spent between $12,000 and $17,999 per year. However, public courses incurred higher costs and revenue losses from damage due to winter injury compared to private courses. The total annual cost to a public course ranged from $27,000 to $35,997, and the annual cost to a private course ranged from $21,000 and $32,997.

The study also examined the indirect effects of winter injuries on golf course in terms of staff reductions and salary reductions as a result of revenue losses due to winter injuries. While most courses did not lay off employees, about 7% reported eliminating three to four positions each year due to budget constraints. Salary reductions were also reported by nearly 10% of superintendents, with reductions ranging from 6% to 15%, depending on the severity of the injury. Many courses responded to the financial pressure by restricting budgets and scaling back on new investments.

There is a lack of information regarding the economic impact of winter injuries in North America and the differences and effectiveness of various turfgrass management practices. This research is a step forward in trying to fill this gap in the literature by understanding the economic impact and management practices associated with turfgrass

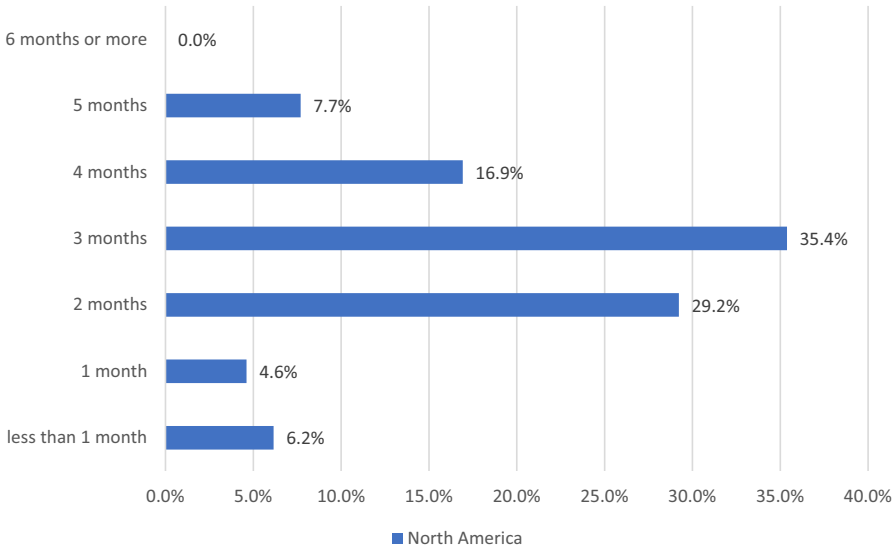

Fig. 6. Time duration of ice cover in severely affected areas in North America based on survey data from golf course superintendents in the United States and Canada (N = 96).

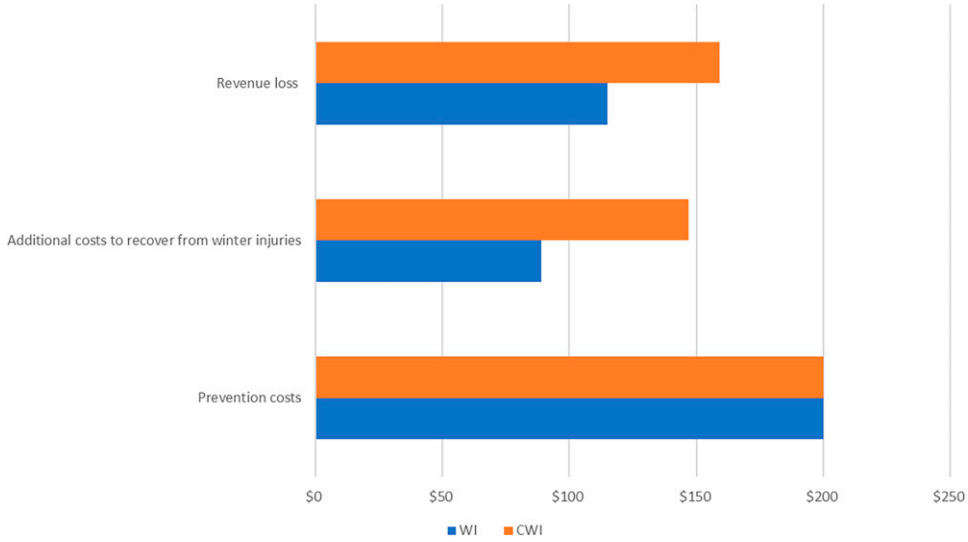

Fig. 7. Distribution of the costs and revenue losses attributable to winter injuries in years with normal winter injuries (WI) and years with considerable (more than normal) winter injuries (CWI) (N = 96).

winter injuries in golf courses across North America.

These results have important policy and managerial implications. The estimated economic cost of $404 to $506 per acre can help golf course superintendents account for possible risks of winter injuries on their annual budgets. The differences between public and private courses in terms of winter injury's impacts suggest that management strategies should be tailored to each type of golf course. Given the direct and indirect impacts of winter injury like revenue losses, additional costs of inputs to recover from winter injury, and employment reductions, there is a need for more industry-led grant programs to research winter injury prevention. As various climate models suggest changes in weather patterns in the coming years, funding for infrastructural investment (e.g., drainage systems and protective covers) will become even more important to maintain the economic and operational viability of golf courses in North America.

Our findings suggest that the industry can proactively adopt grass species that are more tolerant of winter injuries. For example, creeping bentgrass can be adopted to reduce the injury from ice encasement. Strategic planning is needed and should focus on preventive measures such as drainage systems, protective turfgrass covers, and appropriate fertilization regimens.

Fig. 8. Management practices by public golf course superintendents in North America based on survey data from golf course superintendents in the United States and Canada (N = 43).

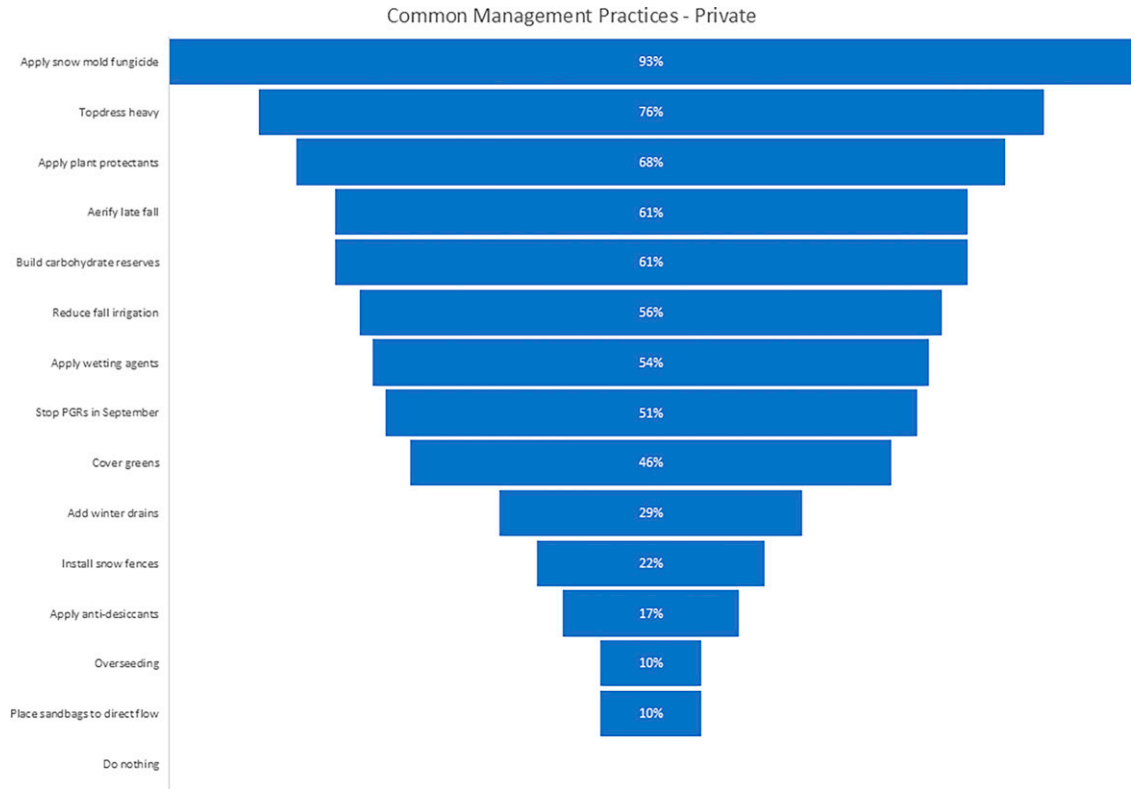

Fig. 9. Management practices by private golf course superintendents in North America based on survey data from golf course superintendents in the United States and Canada (N = 41).

While this research provides an overview of the extent and impact of winter injuries, future research can use sophisticated econometric models to examine the exact relationship among the various factors of winter injuries and the extent of damage observed to better inform industry stakeholders. For future surveys, data representativeness can be improved by increasing the sample size and including a more geographically diverse sample and additional turfgrass management practices.

References Cited

Beard JB. 1969. Winter injury of turfgrasses, p 226–246. In Proceedings of the First International Turfgrass Research Conference, Sports Turf Research Institute, Bingley Yorkshire.

Beard JB. 1964. Effects of ice, snow and water covers on Kentucky bluegrass, annual bluegrass and creeping bentgrass. Crop Sci. 4(6):638–640. cropsci1964. https://doi.org/10.2135/cropsci1964.0011183X000400060026x.

Beard JB. 1972. Turfgrass: Science and culture. Prentice-Hall, Englewood Cliffs, NJ, USA.

Frank KW. 2015. Winterkill of turfgrass. Michigan State University Extension, East Lansing, MI, USA. https://www.canr.msu.edu/resources/winterkill-of-turfgrass.

Gelernter WD, Stowell LJ, Johnson ME, Brown CD. 2017. Documenting trends in land-use characteristics and environmental stewardship programs on US golf courses. Crop Forage & Turfgrass Mgmt. 3(1):1–12. https://doi.org/10.2134/cftm2016.10.0066.

Karl TR, Melillo JT, Peterson TC. 2009. Global climate change impacts in the United States. Cambridge University Press, Cambridge, UK.

Kreuser B. 2019. Prevent winter desiccation on creeping bentgrass. Golfdom. https://www.golfdom.com/prevent-winter-desiccation-on-creeping-bentgrass/. [accessed 26 Jun 2025].

Kvalbein A, Waalen WM, Bjørnstad L, Aamlid TS, Espevig T. 2017. Winter injuries on golf greens in the Nordic countries: Survey of causes and economic consequences. Intl Turfgrass Soc Res J. 13(1):604–609. https://doi.org/10.2134/itsrj2016.09.0826.

Landschoot P. 2023. Winterkill of turfgrasses. Penn State Extension, University Park. https://extension.psu.edu/winterkill-of-turfgrasses.

Rantanen M, Karpechko AY, Lipponen A, Nordling K, Hyvärinen O, Ruosteenoja K, Vihma T, Laaksonen A. 2022. The Arctic has warmed nearly four times faster than the globe since 1979. Commun Earth Environ. 3(1):1–10. https://doi.org/10.1038/s43247-022-00498-3.

US Environmental Protection Agency. 2025. Technical documentation: Freeze-thaw conditions. https://www.epa.gov/system/files/documents/2025-01/freeze-thaw-conditions_td.pdf. [accessed 26 Jun 2025].

Valverde FJ. 2007. Field evaluation of winterkill in annual bluegrass (*Poa annua* L.) and creeping bentgrass (*Agrostis stolonifera* L.) (PhD Diss). Iowa State University, Digital Repository, Ames, IA, USA. https://doi.org/10.31274/rtd-180813-17110.

Wang Y, Yue C, Watkins E, Straw C. 2023. How do risk preferences affect golf course superintendents' adoption of precision irrigation technologies? Implications from prospect theory. J Agric Appl Econ. 55(3):516–535. https://doi.org/10.1017/aae.2023.28.

Watkins E, Petrella Dp, Aamlid T, Christensen DC, Dalmannsdottir S, Hollman AP, Deters G. 2025. Recovery of five cool-season turfgrasses following long-term ice encasement. Crop Sci. 65:e70053. https://doi.org/10.1002/csc2.70053.

Wells S, Martinson KL, Undersander D, Sheaffer C. 2014. A survey investigating alfalfa winter injury in Minnesota and Wisconsin from the winter of 2012-2013. Forage grazinglands. 12(1):1–7. https://doi.org/10.2134/FG-2013-0051-RS.