TURFGRASS WINTER STRESS MANAGEMENT

Golf course managers' handbook

UPDATED 2025

Sterf

PREFACE

This handbook was first published in 2017. The present, revised version has been updated with results published after that, especially from the projects 'ICE-BREAKER', 'WINTER TURF' and 'Integrated management of turfgrass diseases'.

The main target group for the handbook is golf course managers. However, when working both on the original and the updated version, we consulted many scientific papers, and the list of references became long. We hope this can help turfgrass researchers, agronomists and others who want to dive deeper into the subject.

Ready-to-use information about winter stress management is also available in STERF's updated facts sheets at www.sterf.org and in the Winter Turf blog at www.winterturf.umn.edu

We thank Dr. Eric Watkins, leader of the USDA-funded project WINTER TURF for valuable comments to the updated version of this handbook.

NIBIO Landvik, October 25, 2017

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Updated version
NIBIO Landvik, December 22, 2025

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CONTENT

TURFGRASS WINTER STRESS IN THE NORDIC COUNTRIES

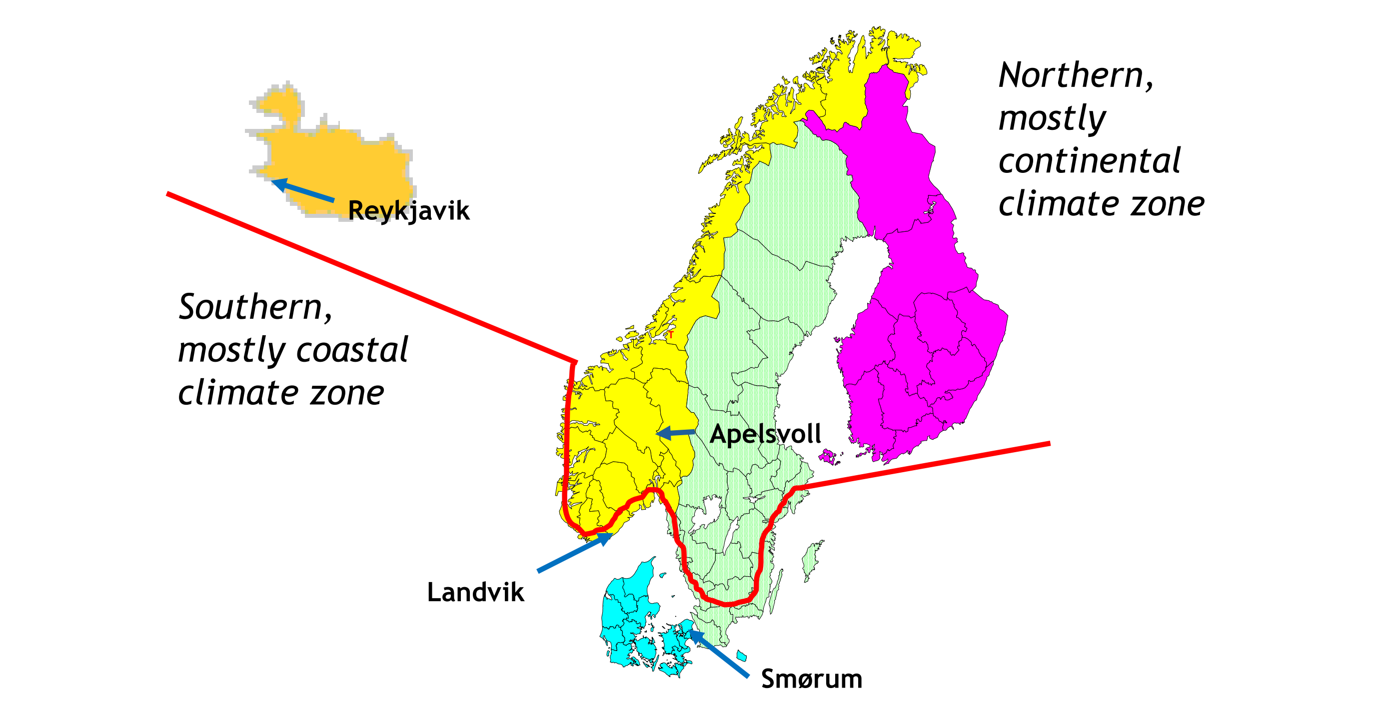

***Figure 1**.The two climatic zones and test locations that are used in SCANGREEN variety trials.*

The Nordic countries include Iceland, Norway, Sweden, Finland (with Åland) and Denmark (with Greenland and the Faroe Island). Some Estonians also claim to be Nordic, and from a winter turf perspective, all three Baltic States should be included.

The climate varies between and within countries. The warm Golf stream makes the coastline of Norway much milder than would be expected from the high latitude. Predominantly western winds deliver large amounts of precipitation to Western Norway, and there is a sharp contrast between the west coast which receives 3-5000 mm/yr and the valleys on the eastern side of the mountains which receive only 2-300 mm/yr.

Coastal climates with small variations between summer and winter temperatures are very different from inland climates where the winter temperature can go below -40 °C. Stable snow covers used to protect turfgrasses from the extreme winter temperatures in these areas. The most challenging climate, from the turfgrass point of view, is unstable snow cover, warm spells during winter and the risk of ice encasement. Because of global warming, such unstable winters are now becoming more and more common in Finland, Sweden, Norway and Iceland.

The turfgrass variety testing program for golf course putting greens, SCANGREEN, delineates the Nordic countries into two climatic zones (Figure 1). This may well be an oversimplification as there are huge differences between the maritime climate of Iceland and coastal areas of Northern Norway and the mostly continental climate in Finland, Central and Northern Sweden and Central and Northern Norway. With global warming, the borderline between the two zones might well move further north, away from the coast and to higher elevations, but the overall risks for turfgrass winter damages is not expected to decline.

STERF's R&D program for Winter stress and Integrated pest management (2025) lists the complexity of winter stresses that grass plants encounter and outlines the factors that are important for successful winter survival. In this handbook, we will group the winter stresses into three: (1) biotic (winter active diseases) (2) abiotic (physical) and (3) stresses related to reestablishment of winterkilled turf. But first we start with plant acclimation before the winter and the winter stress tolerance of the cool-season grasses used on Nordic golf courses.

Turfgrass acclimation (hardening) and deacclimation (dehardening)

Perennial grasses change between two different physiological phases. In the growth phase, cell membranes are impermeable, meaning that cells can absorb water and put pressure on the cell wall so that the cells expand. The definition of plant growth is 'irreversible increase in plant volume', and impermeable membranes are a prerequisite for such growth.

When grasses have acclimated before winter, they contain more water-soluble carbohydrates, and cell membranes have a higher proportion of unsaturated fatty acids allowing water to percolate more easily through the cell membranes (e.g. Hoffman et al. 2010). This allows ice crystals to form and expand mainly outside the plant cells. Higher concentrations of sugars and other osmolytes lower the freezing temperature inside the plant cells, and anti-freeze proteins effectively limit ice crystal growth (Griffith & Yaish 2004, Kalberer et al. 2006).

There seems to be a general contradiction between plant growth and winter stress tolerance. Perennial ryegrass (*Lolium perenne* L.) and annual bluegrass (*Poa annua* L.) tend to continue growing in the autumn and are therefore the least winter tolerant cool-season grasses used on golf courses.

Turfgrass managers should keep in mind that any action that stimulates growth, like nitrogen fertilization, irrigation or covers that increase temperature, might increase the risk of winter injuries. This is the case both in the autumn and in the spring.

Temperatures, and to a lesser extent photoperiod [1], are the key signals for plant acclimation or deacclimation to occur. Periods with daily mean temperatures below 5 °C and, even better, nights below 0°C (Espevig et al. 2011, Acharya & Fei 2025) are signals leading to growth cessation and acclimation. Shade during cold acclimation reduces the freezing tolerance of creeping bentgrass (*Agrostis stolonifera* L.) and annual bluegrass (Dodson et al. 2018). See also Figure 2.

In the northern hemisphere, cool-season turfgrasses usually reach their maximum acclimation status in late December or January (Dionne et al. 2001, Thorsen & Höglind 2010). Depletion of carbohydrates (because of darkness, anoxia, diseases and other causes) and warm spells will eventually reduce the acclimation status as winter passes (Figure 2). After mild spells, plants may be able to reacclimate to a certain extent, but they seldom reach the same level as they had before deacclimation (Tompkins et al. 2000, Espevig, Höglind & Aamid 2014, Hoffman et al. 2014). Read more about acclimation and deacclimation in STERF's fact sheets Acclimation and winter stresses and Warm spells during the winter.

***Photo 1**. Acclimated and frozen turf of annual bluegrass. Several studies (e.g. Espevig et al. 2011, Acharaya & Fei 2025) indicate that a period at subfreezing temperature is necessary to achieve maximal freezing tolerance. Photo: James Bentley.*

1) Unlike trees and shrubs which often respond of photoperiod, temperature is usually the most important signal for cold acclimation of cool-season grasses. Yet, there are differences between northerly and southerly adapted varieties in this regard (Malyshev et al. 2014, Dalmannsdottir et al. 2017, Photo 2). Dalmannsdottir et al. (2017) suggested including photoperiod-induced cold acclimation into breeding programs for more winter-hardy perennial grasses since photoperiod, unlike temperature, remains unaffected by climate change.

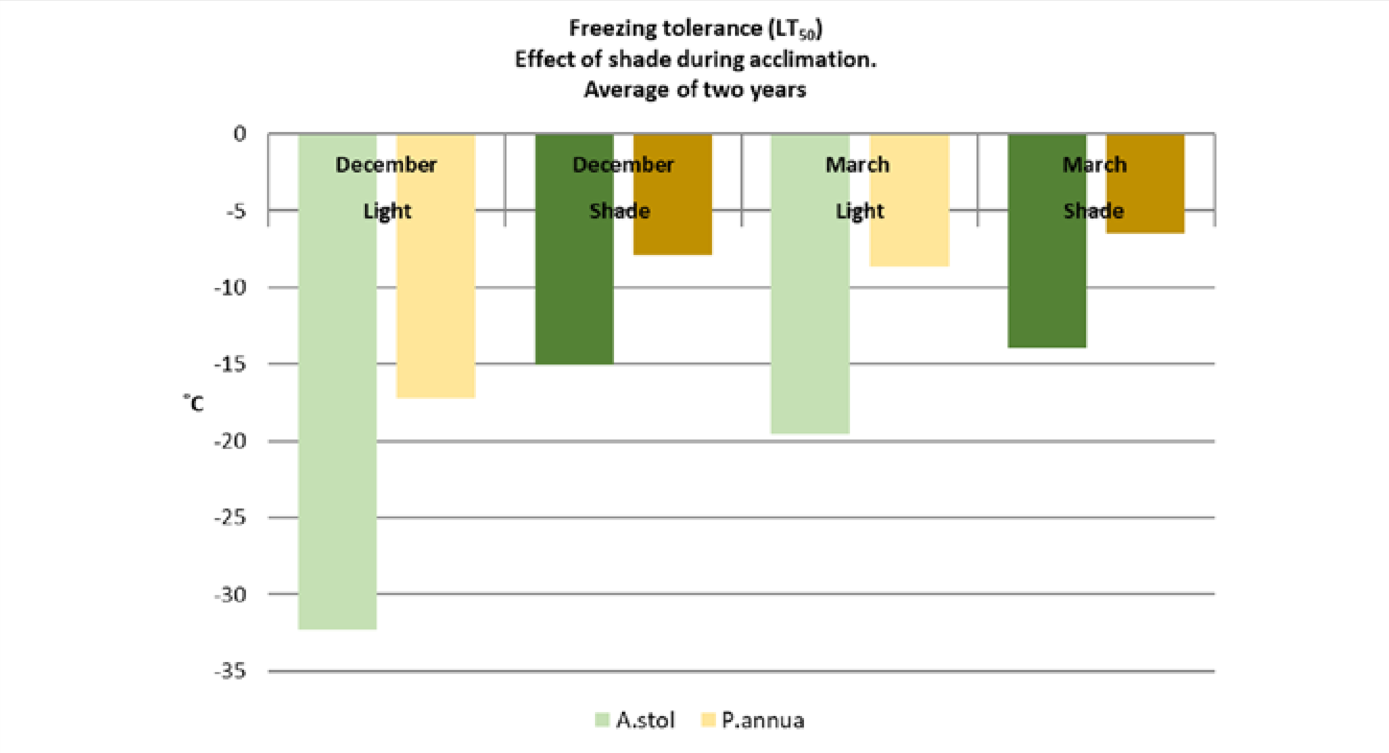

Figure 2. *Freezing tolerance of creeping bentgrass (A.stol.) and annual bluegrass (P.annua) grown in shade (30 % of natural daylight) compared to grass in natural autumn light at NIBIO Apelsvoll. Freezing tests were conducted in early December 2014 and 2015 and in March 2015 and 2016.*

Acclimation to winter stresses affects not only turfgrass tolerance to abiotic winter stresses such as low freezing temperature, ice encasement and desiccation, but also their resistance to biotic stresses, i.e. winter-active diseases (Ergon et al. 1998, Kuwabara & Imai 2009). Tronsmo et al. (2013) showed that velvet bentgrass (*Agrostis canina* L.) was more vulnerable than creeping bentgrass to microdochium patch during the growing season, but resisted microdochium patch better than creeping bentgrass when both species had been acclimated.

Photo 2. *An experimental green at Gjennstad, southeast Norway (59°N) seeded with different mixtures of red fescue (Festuca rubra L. and colonial (browntop) bentgrass (Agrostis capillaris L.). To the right is a mixture of varieties from lower latitudes. To the left a mixture of northerly-adapted Norwegian varieties. Photo taken 18 December 2003 by Agnar Kvalbein.*

GRASS SPECIES FOR NORTHERN CLIMATES

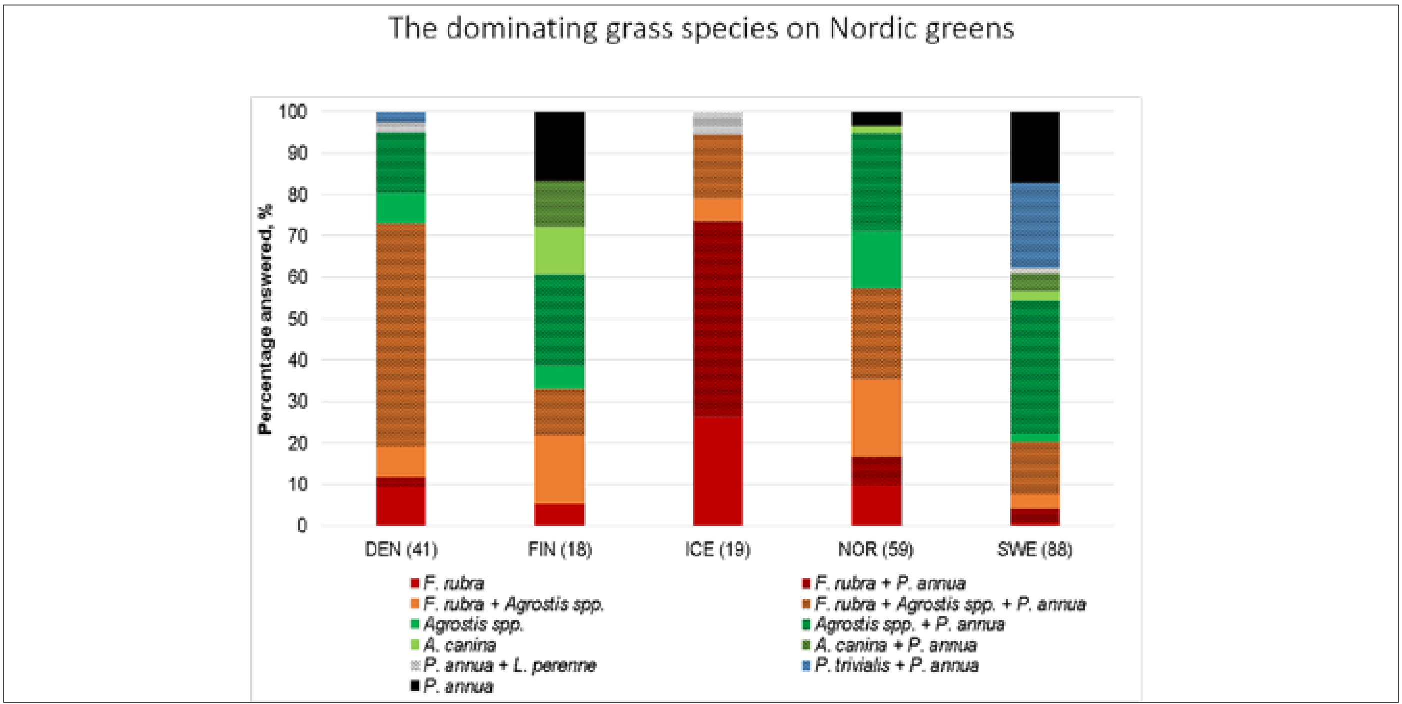

Figure 3. *Data based on a survey on Nordic golf courses in 2015.The number of respondents in parentheses (Kvalbein et al. 2017).*

An overview of this topic is presented in STERF's handbook The Grass Guide 2015 - Amenity Turf Grass Species for the Nordic Countries. The fact sheet Grass species and varieties for severe winter climates (2024) gives more specific information. Within each species, varieties for green and fairway (short cut lawn) can be ranked for winter hardiness at www.scanturf.org.

Species used on golf courses

Nordic golf courses grow many different grass species on their greens, and there are interesting differences between countries. While red fescue (*Festuca rubra* L.) is the predominant species in Iceland, bentgrasses are more widely used in the other countries. Since annual bluegrass usually invades by itself, it is important to know the actual species composition, and not only the species that were included in the seed mixture. Although Figure 3 is based on a survey among golf courses in the five Nordic countries in 2015, we think it is still representative, perhaps with the exception of Finland which only had responses from 18 golf courses in 2015 (Kvalbein et al. 2017).

We have no corresponding data about grass species on fairways and tees, but based on information from seed suppliers, the most commonly used mixture on fairways is red fescue and Kentucky bluegrass (*Poa pratensis* L.). Perennial ryegrass (*Lolium perenne* L.) is sometimes included in Southern Sweden and Denmark in an attempt to outcompete annual bluegrass and broadleaved weeds, and in narrow sections and approaches that are vulnerable to wear and tear. Tees are usually established with Kentucky bluegrass and red fescue and overseeded with perennial ryegrass. Creeping bentgrass fairways and tees are found only on a few high-budget golf courses.

Winter stress tolerance species by species

The species are presented in alphabetical order for botanical names, irrespective of adaptation to green, fairway or rough mowing height.

Velvet bentgrass (*Agrostis canina* L.)

Velvet bentgrass performed equal to (Espevig et al. 2011, Tronsmo et al. 2013) or slightly behind (Espevig, Höglind & Aamlid 2014) creeping bentgrass for freezing tolerance, but better than creeping bentgrass for tolerance to ice encasement (Waalen et al. 2017, Watkins et al. 2025). The latter can probably be explained by a lower respiration rate when the grass has acclimated properly. In that stage, velvet bentgrass also has the same tolerance to snow molds as creeping bentgrass (Tronsmo et al. 2013). There are, however, a number of disadvantages with velvet bentgrass such as extremely high tiller density resulting

Photo 3. *Ultradense green of velvet bentgrass. Photo: Trygve S. Aamlid.*

in thatch accumulation and problems to incorporate top-dressing sand (Photo 3), high susceptibility to in-season microdochium patch (unacclimated plants, Tronsmo et al. 2013) and low recuperative capacity should some kind of damage occur (Ebdon & DaCosta 2020).

We recommend STERF's handbook **Potential for velvet bentgrass on Nordic golf greens** which discusses advantages and disadvantages of using this species. Due to limited seed production acreage in North America, the availability of velvet bentgrass seed on the Nordic market has been rather unpredictable in recent years, but this situation appears to be a little better as of October 2025. The most winter-hardy variety listed by www.scanturf.org is 'Vesper'.

Colonial (browntop) bentgrass
(*Agrostis capillaris* L.)
There are fewer varieties within this species compared to creeping bentgrass, and the winter stress tolerance is more variable. Gregos & Castler (2011) reported overall better resistance to snow mold in US varieties of colonial bentgrass than in creeping bentgrass, but this is not in agreement with SCANGREEN variety testing which usually shows opposite (e.g. Aamlid, Thorvaldsson et al. 2012, Hesselsøe, Borchert, Aamlid et al. 2023). Top-performing varieties in the UK (BSPB/STRI, Bingley) such as 'Saulsbury' and 'Charles' cannot be recommended in the Nordic countries because of high susceptibility to microdochium patch. The Danish varieties 'Jorvik' and 'Cleek', and even more so, the North American varieties 'Heritage' and especially 'Puritan' are better adapted to Nordic conditions and represent a good compromise between high tiller density, fine leaves and acceptable winter hardiness. Superior tolerance to abiotic winter damages can be found in the Norwegian variety 'Leirin', although many greenkeepers will find its tiller density and leaf fineness to be unacceptable for putting greens (www.scanturf.org).

Creeping bentgrass
(*Agrostis stolonifera* L.)
Creeping bentgrass is the main cool-season turfgrass for golf course putting greens in Europe and North America, and new varieties are coming to the market almost every year. North American golf courses commonly use creeping bentgrass even on fairways mowed at 8-10 mm, but this rather costly practice has been adopted only by a few golf courses in the Nordic countries. Creeping bentgrass breeders usually include disease resistance and stress tolerance to their breeding programs, but resistance against microdochiuim patch and Typhula blight usually has less priority than resistance against dollar spot (*Clarireedia* sp.).

Compared with other cool-season grasses, creeping bentgrass is usually ranked no 1 for freezing tolerance. Waalen et al. (2017) also ranked it as the second most tolerant to ice encasement, only exceeded by velvet bentgrass. There is, however, a recent report showing faster oxygen depletion in creeping bentgrass than in red fescue under simulated ice encasement at +0.5°C (Hesselsøe et al. 2025), and this was also partly confirmed in a recent field study in Minnesota (Watkins et al. 2025). Hesselsøe et al (2025) found the old variety 'Penncross' to have better tolerance to ice encasement than newer and denser varieties. The best compromise between turfgrass quality and overall tolerance to winter stresses in the most recently completed SCANGREEN test round was 'L93XD'.

Photo 4. *SCANGREEN variety testing at NIBIO Apelsvoll, northern climatic zone. Bentgrasses to the right and red fescues to the left. Unlabelled plots in the middle are Norwegian ecotypes of red fescue and colonial bentgrass. Photo taken in May 2008 by Bjørn Molteberg.*

Tufted hairgrass / tussock grass (*Deschampsia caespitosa* L.)

This is one of the most winter hardy and microdochium-resistant species on the market. We have seen native genotypes surviving as the only species on severely winter damaged (often poorly drained) fairways. Tufted hairgrass has been recommended for shaded lawns, but it is not a good alternative for tees and football stadiums due to limited wear tolerance and capacity to recover. Some golf courses that seeded this species on roughs and green surrounds ran into severe problems because tufted hairgrass formed dense tufts and the playing quality was not acceptable.

Hard fescue (*Festuca brevipila* Tracey) and sheep fescue (*Festuca ovina* L.)

The traditional use of these fine-leaved, but slowly growing grasses is in roughs, on road verges and in other low-maintenance areas, particularly under dry conditions and at low soil fertility. Both of them, and sheep fescue in particular, are slower in establishment and have less wear tolerance than the three subspecies of red fescue. There is little documentation of the winter stress tolerance of hard and sheep fescue under Nordic conditions, but US research has shown that both hard fescue and, to a lesser extent, sheep fescue are more tolerant than red fescue to microdochium patch, gray snow mold (Koch et al. 2024) and ice encasement (E. Watkins, pers. comm., Dec. 2025). Like red fescue, hard and sheep fescue are rapidly outcompeted on wet soils. The characteristics that have caused renewed interest in these species in recent years is better resistance to dollar spot and better ability to retain green coverage under prolonged and extreme drought. For these reasons, researchers have tested inclusion of hard fescue or sheep fescue in seed mixtures for fairway, but with limited success so far (e.g. Reiter et al. 2017). Unlike tall fescue, hard and sheep fescue do not have an extensive root system, and we don't know if they will resist the combination of strong sunshine, low temperatures and desiccating wind sin spring better than red fescues.

Red fescue (*Festuca rubra* L.)

We divide this species into three subspecies based on chromosome numbers and the existence and length of rhizomes. Strong creeping red fescue *(F. rubra* ssp. *rubra)* is native to northern Scandinavia and local genotypes are well adapted to cold winters. The Norwegian variety 'Frigg' has superior winter stress tolerance, but this comes at the expense of a brownish and rather dull winter color (Photo 5). Like other varieties of creeping red fescue, the tiller density of 'Frigg' is not acceptable on greens, but it is a good alternative in seed mixtures for fairways and semi-roughs in winter-cold areas.

Chewings fescue (*F. rubra* ssp. *commutata*) does not produce rhizomes, but a denser sward than strong creeping red fescue. It grows wild in Denmark and Southern Sweden where it has usually been considered more 'cold tolerant' than strong creeping red fescue and slender creeping red fescue (*F. rubra* ssp. *littoralis*), the latter with a more

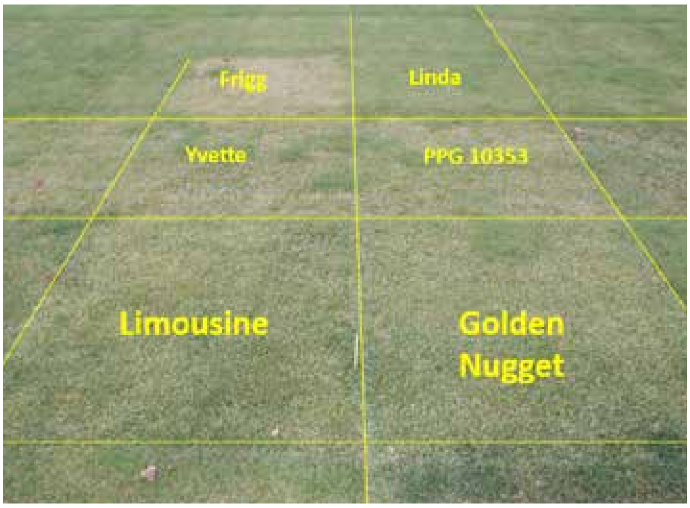

Photo 5. *Color in November of strong creeping red fescue 'Frigg', Chewings fescue 'Linda' and four varieties of Kentucky bluegrass in variety testing at 30 mm mowing height at NIBIO Landvik. Photo:Trygve S. Aamlid.*

coastal adaptation (Petersen 1981). In the early SCANGREEN trials the different adaptation of Chewings fescue and slender creeping red fescue was often characterised by a less dormant winter color and more microdochium patch and overall winter damage in the slender creeping type (e.g. Aamlid, Thorvaldson et al. 2012). However, in a dataset covering 20 years of turfgrass variety testing in the Nordic countries (mowing height 15-35 mm), Aamlid & Gensollen (2014) documented better genetic progress for microdochium resistance in slender creeping red fescue than in Chewings fescue, and this has later been confirmed by the most recent test round in SCANGREEN showing little difference in the average scores of the two subspecies, but significant differences between varieties within each subspecies, for winter color, microdochium patch and total winter damage (Hesselsøe, Borchert, Aamlid et al. 2023). In North America, Chewings fescue has usually been considered to have the least snow mold resistance (both Typhula blight and microdochium patch) among the fine fescues (Braun et al. 2020, Koch et al. 2024). Recently, Watkins et al. (2025) also found better ice encasement tolerance in slender creeping red fescue than in Chewings fescue.

For golf course putting greens in the Nordic countries, our current recommendation is to use a 50/50 seed blend between Chewings fescue and slender creeping red fescue in the southern climatic zone, but a Chewings fescue dominated blend (75/25) in the northern climatic zone (Aamlid, Hesselsøe & Pettersen 2025). Always include at least two top-ranked varieties of each subspecies according to www.scanturf.org.

Red fescue is a low input grass, which means that the need for fertilizer is 50-70 % compared with creeping bentgrass and annual bluegrass. This holds true also for autumn fertilization. Although spring growth was significantly improved when red fescue received late nitrogen fertilization before winter (Kvalbein & Aamlid 2012), we recommend that 2/3 of the annual N input to red fescue putting greens is given during the first half of the growing season (Chen et al. 2024).

Red fescue is significantly more resistant to snow molds than bentgrasses (Gregos & Casler 2013). For this reason, it often ranks higher than bentgrasses for overall winter hardiness in the SCANGREEN trials, which are not sprayed with fungicides. However, even red fescues can be infected with microdochium patch, especially if not acclimated.

Red fescue's tolerance to low freezing temperatures on unprotected greens is inferior to that of creeping bentgrass (Espevig, Höglind & Aamlid 2014, Waalen et al. 2025). Traditionally, it has also been considered less tolerant to ice encasement than creeping bentgrass (Waalen et al. 2017), but recent research showed red fescue to be on level with (Waalen et al. 2025) or better than (Hesselsøe et al. 2025, Watkins et al. 2025) creeping bentgrass under extreme anoxic conditions. On fairways, red fescue varieties except 'Frigg' are usually less winter hardy than Kentucky bluegrass, especially if the fairway is poorly drained (Espevig, Kvalbein & Aamlid 2014).

Guidelines for red fescue management and discussions about fescue/ bentgrass mixtures can be found in STERF's handbook Red fescue management (2016).

Tall fescue
(*Schedonorus arundinaceus* (Schreb.) Dumort. syn. *Festuca arundinacea*)

Tall fescue has a deep root system providing better drought tolerance than any other cool-season turfgrass. Its traditional use has been in home lawns in southern

Photo 6. *Variety testing of perennial ryegrass (4 rows to the left), Kentucky bluegrass (1 ½ row in the middle) and tall fescue (2 ½ rows to the right) at Landvik on 2 April 2016. Photo: Trygve S. Aamlid.*

Europe and North America, but we currently see more interest in this species even in northern Europe because of its superior drought tolerance. Many breeding companies are currently investing heavily in tall fescue in order to overcome disadvantages such as slow establishment, coarse leaf texture and limited wear tolerance. For this species to become an alternative in seed mixtures for (semi)roughs or even fairways on golf courses in the southern climatic zone of the Nordic countries, there is also a need for improved resistance to microdochium patch and abiotic winter damage. So far, the overall winter stress tolerance of tall fescue has mostly been behind that of perennial ryegrass in variety testing at Landvik, southern Norway (Photo 6). In Northern US, tall fescue is usually considered susceptible to snow molds, but more tolerant to abiotic winter stresses than perennial ryegrass (E. Watkins, pers. comm., Dec. 2025).

Perennial ryegrass
(Lolium perenne L.*)*

The winter survival of perennial ryegrass on greens and fairways is unpredictable in the northern climatic zone, but it is usually fairly persistent in the southern zone. Breeding for freezing tolerance in turf-type perennial ryegrass has been going on for quite some time (e.g. Hulke et al. 2008, Iraba et al. 2013, Vossen 2023), but the genetic progress for overall winterhardiness in European variety testing was limited at least up to 2010 (Aamlid & Gensollen 2014). Nowadays, the perennial ryegrass genome has been mapped more thoroughly then in any other turfgrass species, (Vines et al. 2023) and this will hopefully result in more progress for winter-related characters in the future. Tetraploid varieties of turf type perennial ryegrass represent an improvement in resistance to winter diseases (Photo 7), but we doubt that a similar advantage exists for abiotic winter damages since tetraploid varieties have larger and more succulent cells.

Photo 7*. The tetraploid variety 'Fabian' of perennial ryegrass (left row, no 2 from bottom) is less susceptible to microdochium patch than diploid varieties. From variety testing at Landvik in spring 2018. Photo: Trygve S. Aamlid.*

Smaller cat's tail
(*Phleum bertolonii* DC.)

Our experience with smaller cat's tail is very limited as one variety of this turf type timothy is only tested for the first time in SCANGREEN 2023-2026. As of October 2025, winter survival has been good with no microdochium patch in the southern climatic zone, but smaller cat's tail has suffered more total winter damage than red fescue and bentgrasses in the northern zone.

Annual bluegrass
(*Poa annua* L.)

This unseeded, but genetically flexible and highly adaptive species is probably the most common grass on golf courses in northern parts of Europe and North America. Canadian researchers found that the most winter-hardy genotypes came from areas with variable winter temperatures, not from in the colder inland areas with stable snow covers (Dionne et al 2001, 2011). Despite this we usually rank annual bluegrass as the least winter tolerant species on sports fields and golf courses. It is highly susceptible to snow molds, has lower freezing tolerance than bentgrasses and fescues, and does normally not survive more than 30-45 days of ice encasement (Tompkins et al. 2004, Aamlid et al. 2009, Schmid et al. 2010, Waalen et al. 2025). The shallow root system also provides little water during the critical dry periods in spring. Annual bluegrass greens with acceptable quality in spring are seldom in northern parts of Scandinavia, and access to effective fungicides is necessary for good spring performance even in the southern climatic zone.

Annual bluegrass is the only grass that produces seed at green's mowing height. Because a certain percentage of the seeds are dormant, the species usually forms a prolific seed bank (Thompson & Grime 1979). Together with perennial ryegrass, annual bluegrass usually germinates at lower temperatures than other species used on greens. These characteristics contribute to the species' invasiveness, implying that the percentage of annual bluegrass usually increases every time the green dies because of winter stresses. For this reason, it is important to avoid maintenance practices that promote annual bluegrass. This handbook is not about annual bluegrass control, but headlines would be:

- Avoid mechanical disturbance of the green surface
- Keep the rootzone dry
- Limit fertilizer rates, especially at the edges of the growing season when annual bluegrass has an advantage (Chen et al. 2024)

On the negative side, there is always a risk that a strict regime following these recommendations can reduce the playing quality of an annual bluegrass dominated sward because of anthracnose (*Colletotricum graminicola*) and seed head production. This makes annual bluegrass reduction a delicate balance.

'True Putt' and 'Two Putt', two commercial varieties of annual bluegrass coming out of Minnesota, have been tested in the SCANGREEN trials. Unfortunately, none of them can be recommended. Greenkeepers who want annual bluegrass on their greens should rather maintain and develop their local ecotypes. New annual bluegrass greens can be established by taking material from vertical mowing or hollow tine coring of neighbour greens.

Kentucky bluegrass (*Poa pratensis* L)
Early research showed that Kentucky bluegrass mowed at 37.5 mm and with an annual fertilizer input of 35 kg N/ha/yr) had better tolerance to ice encasement than annual bluegrass maintained at 12.5 mm and 70 kg N/ha/yr), but less tolerance than creeping bentgrass maintained at 5 mm and 140 kg N/ha/yr (Beard 1964, 1965). Despite that, Nordic variety testing rarely shows any problems with Kentucky bluegrass winter survival at 15-35 mm mowing height (Photos 5 and 6). In some cases, we have even found surviving plants of Kentucky bluegrass on otherwise winterkilled greens.

Kentucky bluegrass is an obvious choice in seed mixtures for Nordic fairways and tees. For the past ten years, it has also been included in the SCANGREEN trials at 5 mm mowing height. Here, it usually survives the first two or three winters, but we have not measured the playing quality on the rather course, stiff and upright leaves.

Because of slow emergence, Kentucky bluegrass will rarely establish when interseeded into established turf (Aamlid et al. 2012). Sodding of Kentucky bluegrass dominated turf may be an option on bunker edges and other areas that are prone to soil erosion.

Supina bluegrass (*Poa supina* Schrad.)
This shade- and wear tolerant species also has superior winter stress tolerance (Stier et al. 2003). It grows aggressively and the rather coarse, light green plants have a tendency to spread vegetatively into areas where they are not supposed to be. We are therefore reluctant to recommend this species except in special cases, e.g. for enclosed soccer fields and on isolated and shaded tees. Finnish experiences suggest that supina bluegrass can replace annual bluegrass on greens where winterkill occurs regularly (Hakamäki 2014), and this has been confirmed by SCANGREEN variety testing at Apelsvoll (Photo 8).

Rough bluegrass (*Poa trivialis* L.)
Based on the freezing tests conducted by (Beard 1966), US textbooks have often ranked rough bluegrass as one of the most cold-tolerant grasses, only exceeded by creeping bentgrass. Nordic trials have not confirmed these results (Photo 8) and we usually rank it slightly more winter tolerant than perennial ryegrass. In the SCANGREEN trials, especially in the southern climatic zone, pure stands of rough bluegrass often have low density and a purple or almost brownish color, although this is less apparent in mixtures with creeping bentgrass and other species. (See following paragraph about the use of rough bluegrass as a nursery grass.)

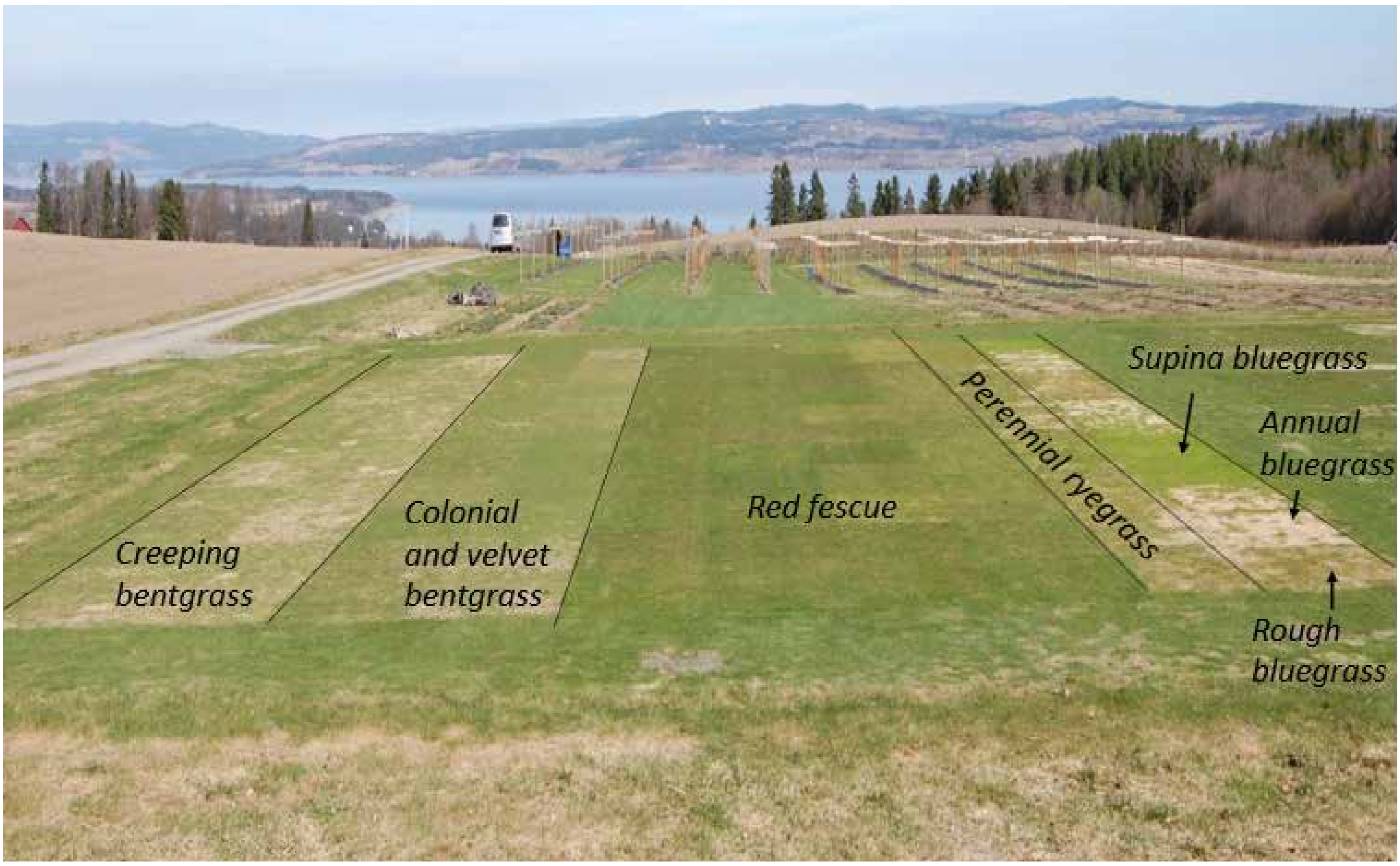

***Photo 8.** SCANGREEN trial at NIBIO Apelsvoll in spring 2013. Supina bluegrass had better winter survival than annual bluegrass and rough bluegrass. Photo: Trygve S. Aamlid.*

Photo 9a-d. *Snow molds right after snow melt. Photos: Tatsiana Espevig*

Plant defence

Recent research on plant genetics has provided new insights into the complex battle between plants and fungi. Plants can recognize invading fungi and activate several defence systems, including building stronger cell walls and producing chemicals that are toxic to the pathogens. The intruders, in turn, are often able to overcome these defence mechanisms. Plant scientists agree that sugars are important in this fight between the host and the fungi, and many greenkeepers are aware of their role as 'carbohydrate managers'. We think this approach is useful, as it provides a key to understanding some of our observations on golf greens.

Horsfall & Dimond (1957) distinguished between 'low sugar diseases' and 'high sugar diseases'. They showed that plants with low sugar levels are more susceptible to certain diseases, and they used Fusarium wilt (the former name for Microdochium) as an example of a 'low sugar disease'. In contrast, rust (*Puccinia* sp.) and powdery mildew (*Blumeria graminis*) were used as examples of 'high sugar diseases'.

Although interactions between plant sugar status and winter diseases are not fully understood, it has been shown that the resistance to snow molds increases with higher levels of sugars in the plant tissue (Vanderplank 1984, Gaudet et al. 1999) and that this is induced by cold acclimation (Tronsmo et al. 2001). Hardened plant species and varieties with a high sugar content usually exhibit good resistance to snow molds. Furthermore, snow mold resistance is influenced not only by the total sugar content, but also by the amount of reserve carbohydrates - fructans (see next paragraph) and by slower rates of sugar metabolism in the more resistant species and varieties (Yoshida et al. 1997, Gaudet et al. 1999, Bertrand et al. 2011).

Sucrose produced through photosynthesis serves as the primary energy source for plant growth and survival. Sucrose can be converted into other sugars or linked together in long chains to form compounds such as cellulose, fructans, starch and the more complex lignin molecule. Fructans are the most important sugars for long term energy storage in grass plants of temperate origin (Smith 1972). The ratio between sucrose and fructans in grasses is dynamic and depends on photosynthetic rate and growth rate. In the absence of photosynthesis under snow, fructans will be converted back to sucrose to provide energy for respiration and defence against snow molds.

Sucrose does not only provide energy, but together with other sugars, it also acts as an important cryoprotectant (Olien 1967, Anchordoguy et al. 1987). It serves as a controller and a signalling molecule (Rolland et al. 2006, Ruan 2014) activating genes that set up plant defence systems (Morkunas & Ratajczak 2014, Moghaddam & van den Ende 2012). When a fungus invades a plant cell, the cell becomes a battlefield. Quick transport of energy into the fight is crucial, and the content of water-soluble sugar in the neighbour cells is important. Plants that are low in sugars become the losers.

Low sugar content can have many reasons. Shade clearly reduces sugar production, while oxygen shortage in the soil (due to

compaction, thatch problems, poor drainage or ice encasement) can make the root cells burn sugar inefficiently by anaerobic respiration. Too much nitrogen, especially in the late summer and early autumn, stimulates growth and directs sugars toward new cell production and elongation rather than storage.
During cold acclimation, grass plants nearly stop growing, allowing sugars to accumulate in their cells. This buildup increases their resistance to winter fungi and other stresses during the cold season.

The most common winter diseases

Some fungi are active at low temperature and can attack plants in the humid microclimate under snow. These pathogens are commonly referred to as **snow molds**, as they often leave white mycelium on the turf when the snow melts (Photo 9). Some of these pathogens can remain active even without snow.

It is important to keep in mind that you may find other fungi attacking plants at low temperatures than those described below. Snow molds are considered to be weak pathogens, meaning they are primarily active when there is little or no competition from other fungi.

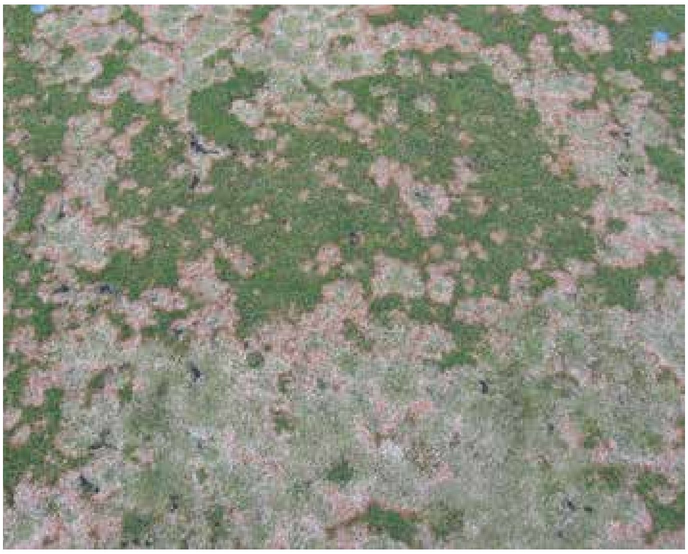

Photo 10. *Microdochium patch on annual bluegrass green at Landvik in the spring 2017 after a mild winter with six snow falls lasting from 2 hours to 2 days. Photo: Tatsiana Espevig.*

Microdochium patch

Microdochium patch caused by *Microdochium nivale* (named *Fusarium nivale* from 1901 to 1983) is the economically most important turfgrass disease in the Nordic countries (Tronsmo et al. 2001, Kvalbein et al. 2017, Melbye 2019). Different from the other snow molds, it can attack the grass without snow cover. During moist and cool periods, even in summer and typically in autumn, microdochium patch can destroy the putting quality of golf greens. Well-fertilized turf can also suffer from massive attacks in spring, even at temperatures above 10 °C. After snow melt, the middle of the microdochium patches often have a tan color while the margins are reddish brown or even pink (Photo 10). This is due to the spores of *M. nivale* being borne in sporodochia (fruiting structures consisting of clusters with a mass of spores and mycelium) which are orange in color (Photo 11). Pink snow mold is the name of these “spring symptoms”.

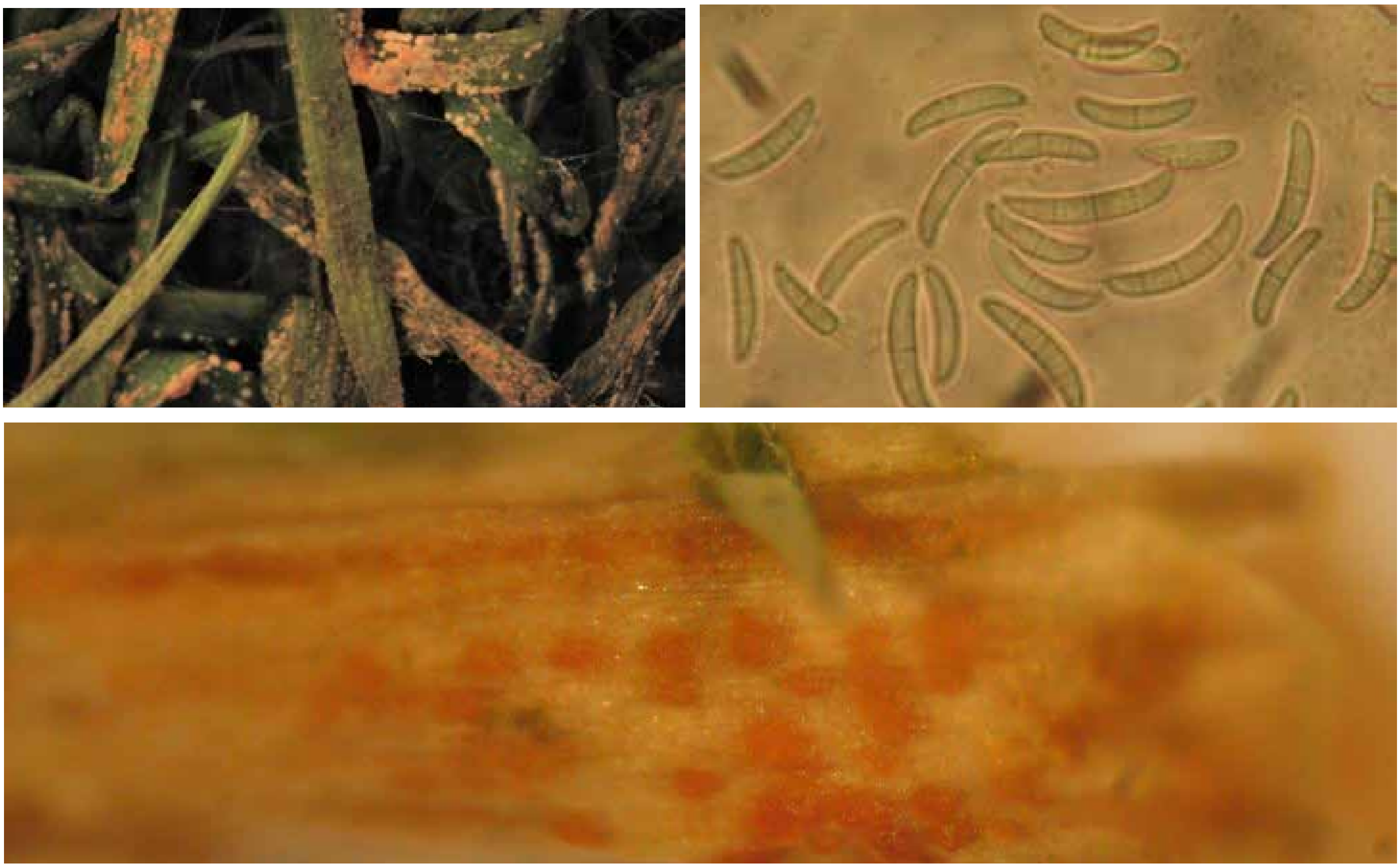

Photo 11a-c. . *Sporodochia of Microdochium nivale on leaves of annual bluegrass (top left and bottom) and spores of M. nivale at 400x magnification (top right). Photos: Tatsiana Espevig.*

M. nivale attacks all grass species used on golf greens. Annual bluegrass is the most susceptible, followed by colonial (browntop) bentgrass, creeping bentgrass and red fescue (Photo 12). Velvet bentgrass is susceptible in the growing season, but becomes more resistant than creeping bentgrass after cold acclimation in the autumn (Tronsmo et al. 2013).

M. nivale spreads with spores, but the fungi can survive in the thatch and attack the grass from growing mycelium. Spores spreading from contaminated thatch are supposed to be the main infection source (Tronsmo et al. 2001). This probably explains why some greens have a higher disease pressure than others. Shade or a higher percentage of annual bluegrass are factors increasing the microdochium patch infection.

Microdochium patch is a typical low sugar disease. In the late summer high soil temperature will enhance the mineralization of nitrogen from the thatch, stimulate growth and lower the sugar content in the plant tissue. In combination with dewfall and moist leaves which allow spores to germinate, the environment becomes perfect for development of microdochium patch. Excessive nitrogen fertilization in the autumn will further stimulate disease development. See the following chapter on fertilization.

Photo12a-d. *Microdochium patch on annual bluegrass in July 2011 (top left) and in November 2018 (top right), on red fescue in October 2013 (bottom left) and on velvet bentgrass in October 2007 (bottom right). All photos are from NIBIO turfgrass research center Landvik. Photos: Tatsiana Espevig.*

Typhula snow molds

The snow molds caused by *Typhula* species are often superficial in the sense that they kill the grass leaves only. However, the crowns may also be injured, and the turf may die in in districts with a certain period of snow cover. *Typhula* snow molds are snow dependent and the severity of damage depends on the duration of the snow cover (Årsvoll 1973). *Typhula ishikariensis* (speckled snow mold) needs at least three months of snow cover to cause significant damage. The snow requirements of *Typhula incarnata* (gray snow mold) are lower, and sclerotia can be produced even after 3 weeks of snow cover (Photo 13). Thus, in the turfgrass fields at Landvik on the Norwegian south coast (on/off winters, often with only a few weeks of snow cover), we often see superficial attacks of *T. incarnata* in perennial ryegrass and creeping bentgrass, but *T. ishikariensis* has not been detected to date. In contrast, both *Typhula* species can be present at Apelsvoll.

Common to the two *Typhula* species is that that they develop grayish patches in spring (Photo 13). It can be difficult to distinguish between them in the field unless you find the sclerotia (a compact mass of hyphae that are formed by the fungi to survive the summer). The sclerotia are reddish brown in *T. incarnata* (Photo 14, 15) and nearly black and smaller in *T. ishikariensis*, and they are embedded in the dead grass leaves in the spring (Photo 14). In the autumn the sclerotia geminate into fruiting bodies which are pink in *T. incarnata* (Photo15, 16) and white in *T. ishikariensis*. If you see these fruiting bodies, it tells that the fungus is present, but the weather conditions and the acclimation status of your turf determine whether there will be an outbreak of disease or not.

Together with mushrooms, *Typhula* belongs to a group of fungi called *Basidiomycetes*, while *Microdochium* belongs to the *Ascomycetes*. This means that some fungicides that are effective to control *Microdochium* will not affect *Typhula* (Hsiang et al. 1999).


Photo 13a,b. *Landvik, February 2019: Gray snow mold (darker patches at the bottom of the photo) and microdochium patch (lighter patches at the top of the photo) (left). Sclerotia of Typhula incarnata were produced after 3 weeks of snow cover (right). Photos: Tatsiana Espevig.*


Photo 14. *Gray snow mold on velvet bentgrass in April 2010 at Kongsberg GC, Norway (left photo). Reddish-brown sclerotia of Typhula incarnata (to the right) and smaller, black sclerotia of T. ishikariensis embedded in dead leaves (to the left) in lawn at Apelsvoll in April 2018 (right photo). Photos: Tatsiana Espevig.*

Photo 15. *Typhula incarnata: Sclerotia (left), sclerotium germinating into fruiting body (middle) and fruiting bodies in late autumn on a creeping bentgrass green. Photos: Tatsiana Espevig (left & middle) and Terje Haugen (right).*

Photo 16. *Fruiting bodies of Typhula incarnata in the late autumn. Photo: Tatsiana Espevig.*

Photo 17. *Active Rhizoctonia (top) and superficial fairy rings (bottom) after snowmelt. Photos: Per Bengtsson (top) and Tatsiana Espevig (bottom).*

Other winter diseases

Some other fungi can also attack turfgrasses under snow cover (Photo 17). *Typhula phacorrhiza* exists in Northern Europe. The oomycetes (not true fungi) *Phythium iwayamai* grows quickly in ice-cold water under snow. *Sclerotinia borealis* can kill the grass if the snow cover lasts about half a year. *Laetisaria fuciformis* which causes red tread, can also be active in early spring following snowmelt. Be aware that rare and new diseases may occur. If you have any doubt, please, send samples to our disease laboratory for identification. More information on biotic winter damage can be found in STERF's fact sheet Winter diseases: Biotic winter damage (Espevig & Aamlid 2018).

INTEGRATED MANAGEMENT APPROACHES TO PREVENT WINTER DISEASES

Fertilization

Our fertilization strategy for the past twenty years, has been based on some simple principles learned from a team of plant nutrition researchers at the Swedish University of Agricultural Sciences. They worked on this for three decades. In short, the key principles were:

- All plants need the same mix of nutrients throughout the year, and the optimal ratio between these nutrients is well defined (Table 1)

- Nutrients, with nitrogen as the minimum factor controlling growth, should be applied frequently in rates corresponding to the plants' growth potential, determined by the turf grass species (genetics) and environmental conditions such as temperature, light and water availability.

Plants are extremely flexible and able to adapt to variations in nutrient availability by rebuilding the ports and pumps in their root cell membranes. This adaptation is, however, an energy consuming process. In order to save energy (sugar) you should keep the nutrient mix in the soil stable and as optimal as possible. On a USGA-spec. green the easiest way to fertilize is to spoon-feed weekly with 'the optimal fertilizer' (Table 1).

The weekly application should be adapted to the grass species' growth capacity (on greens: Poa > bents > fescues) and the environmental conditions. Mineralization of nutrients from thatch degradation will fill some of the plants' needs when the soil temperature is high (Figure 4). The plants' growth potential will be reduced in summer if the mean diurnal temperature is higher than 20 °C. Provided adequate water supply, we have rarely experienced severe summer decline because of heat stress in the Nordic countries up to now, but this might change with global warming in the future.

You can read more about optimal fertilization in STERF's Precision fertilization handbook (Ericsson et al, updated version 2021).

***Table 1.** The optimal plant fertilizer. Each element by weight relative to nitrogen (=100)*

Nitrogen	100
Potassium	65
Phosphorus	14
Sulfur	9
Magnesium	6
Calcium	7
Iron	0.7
Manganese	0.4
Boron	0.2
Zink	0.06
Copper	0.03
Chlorine	0.03
Molybdenum	0.003
Nickel	*

* *Lack of reliable data*

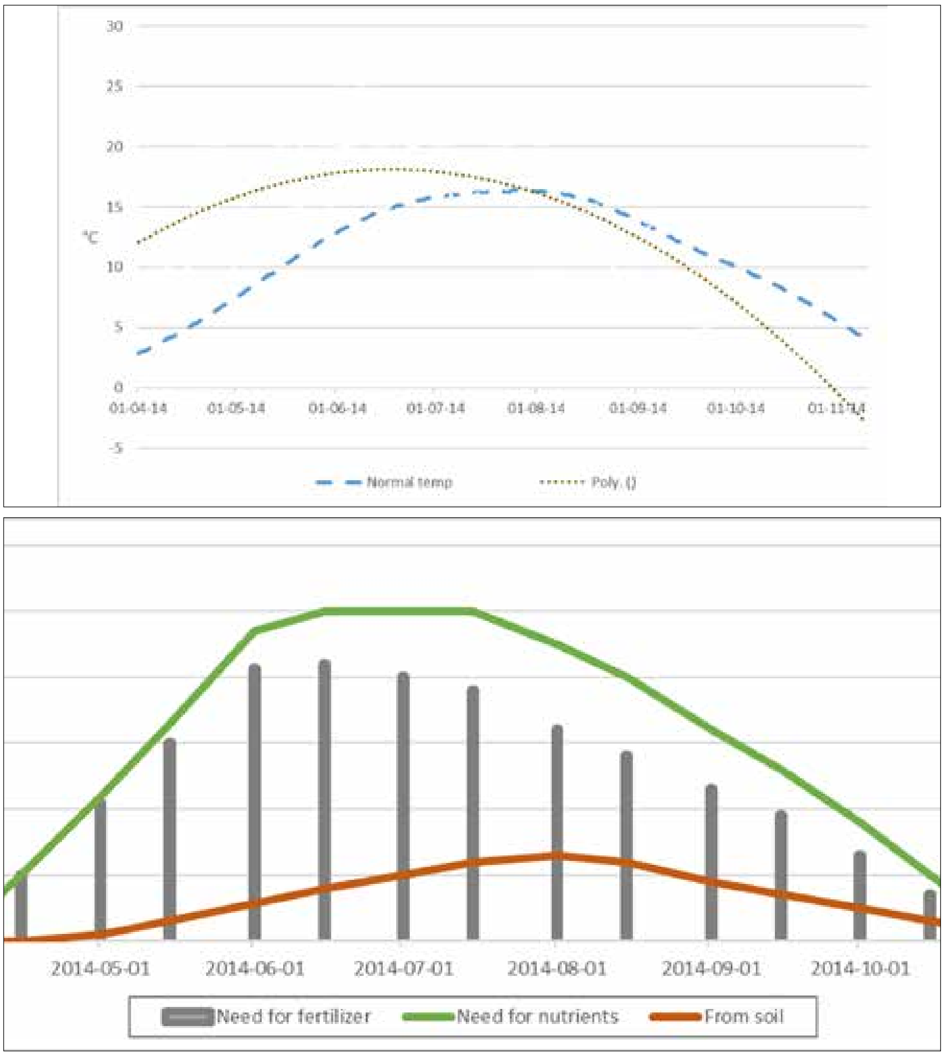

***Figure 4.** Above: Normal irradiance and air temperature in South Norway. Below: Recommended fertilizer distribution as determined by growing conditions and soil fertility (mineralization of soil organic matter).*

Autumn fertilization experiment

In 2014-2016 we conducted fertilization experiments in annual bluegrass and creeping bentgrass at NIBIO Landvik and NIBIO Apelsvoll. Detailed information can be found in Appendix 1. Figure 5 shows microdochium patch development at Landvik during the winter 2014-15. The two higher nitrogen rates (55 and 84 kg N/ha) from medio September to late November) caused significantly more disease in spring in both species. In contrast, the low N rate (28 kg N/ha) tended to have less disease than in the treatment that was only fertilized with other nutrients than nitrogen. We applied no fungicides in these trials.

The positive effects of nitrogen in the autumn are good color and growth until low temperatures trigger cold acclimation. Autumn fertilization also accelerates spring growth (Kvalbein & Aamlid 2012). Several studies, nicely reviewed by Bauer et al. (2012), confirm these positive effects. However, the experimental evidence from Landvik presented in Figure 5 clearly shows that the nitrogen rate in autumn ought to be low. In a new experiment on an annual bluegrass green at Landvik, an increase in nitrogen in November from 0 % to 3 % of the annual rate (292 and 313 kg N ha^{1} yr^{-1} in 2020 and 2021, respectively) resulted in 38 % and 10 % more microdochium patch in the springs of 2021 and 2022 (manuscript in preparation).

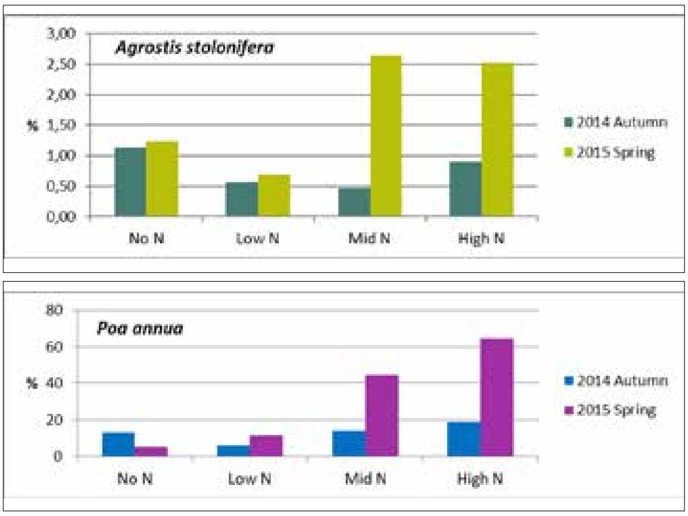

Figure 5. *Microdochium patch (% of plot area) in autumn and the following spring at Landvik in response to four nitrogen levels from medio September to the end of November. Note the different scales on Y-axis.*

Some other nutrients

Potassium

In STERF's survey among Nordic golf courses in 2014-15, ≥25 % of the respondents in Denmark, Norway, Sweden and Finland reported that they usually applied extra potassium in autumn (Figure 6.). In our opinion, this reflects one of the most common misunderstandings in turfgrass management, namely that high rates of potassium in autumn will improve turfgrass tolerance to both biotic and abiotic winter stresses. Autumn-type fertilizers from different fertilizer companies typically contain 3-5 times more potassium than nitrogen, but we are not aware of any research documenting the benefit of such low N:K ratios. As for turfgrass winter diseases there are two US papers showing the opposite result, i.e. more microdochium patch and Typhula blight with constant N but more K from N:K = 2:1 to 1:8 (Moody & Rossi 2010) or from 1:0 to 1:2.5 (Bier et al. 2018). Although plants may have a certain luxury uptake of K, analyses of water leaking from our sand-based lysimeters leave no doubt that most of the potassium given in 'autumn fertilizer types' eventually ends up in the drainage system. We therefore conclude that STERF's optimal ratio between N and K, 100: 65 (Table 1), holds true even when it comes to prevention of turfgrass winter diseases.

Sulfur / Sulfate

Elementary sulfur is an old fungicide. Rausch & Wachter (2005) reviewed the role of sulfur in plants' defence mechanisms and used the term 'sulfur-induced resistance'. However, the experiments at Landvik and Apelsvoll showed no effect on microdochium patch in either autumn or spring of excessive sulfate application in the autumn (N:S rate = 100:160) compared to no sulfate or the recommended rate (N:S= 100:9, Table 1). Based on this, we do not recommend to exclude sulfate from the autumn applications, but the higher rates should be avoided. Our experiments also gave some indications that excessive amounts of sulfate may reduce spring growth.

Iron and iron sulfate

Many Nordic greenkeepers apply extra iron in the autumn (Figure 6). Although the rationale for this may vary, there is no doubt that iron improves color. Mattox et al. (2017) reported that iron sulfate helped to control *M. nivale* if combined with other management strategies, but iron sulfate alone did not provide acceptable winter quality on annual bluegrass greens in the North-West United States.

Excessive use of iron can have serious negative impact on USGA greens. Between the rootzone mixture and the gravel, iron can be oxidized and form a rust layer which can effectively prevent drainage from the green. We have seen this in Norway, and there is at least one report from the US showing similar results (Obear & Soldat 2014).

Using iron sulfate on a colonial bentgrass/annual bentgrass greens in a trial at the Sport Turf Institute research facility in Bingley, UK, reduced microdochium patch incidence when applied preventatively and during periods of early disease pressure. The effective dose of iron sulfate depended on disease

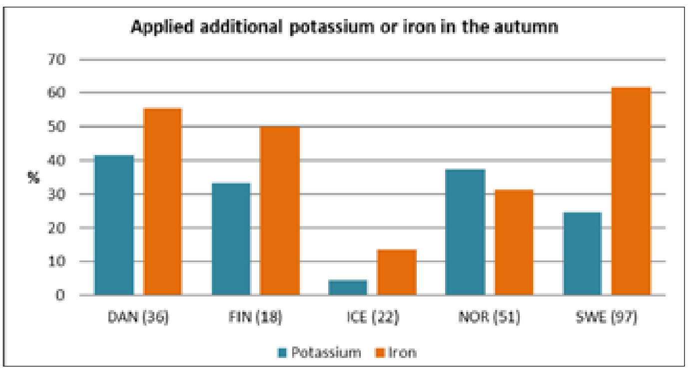

Figure 6. *Results from a survey among Nordic golf courses 2015. The number of respondents in parenthesis (Økland et al. 2018).*

pressure throughout the season, reaching as high as 8 kg iron sulfate/ha per week without causing turf thinning. However, the same suppressive effect was not observed in a parallel trial at NIBIO Landvik, Norway, where the weekly application rates were lower - only 2 or 4 kg iron sufate/ha per week from August to November. Citric acid application in this trial did not reduce the incidence of microdochium patch, indicating that the suppressive effect of iron sulfate at Bingley was most likely due not only to the pH of the spray solution (Hesselsøe et al. 2024).

Copper and pigments

Copper-solutions were considered fungicides many years ago. Some copper products provide an intense bluish to green color of the turf. One such product is the copper-containing pigment 'Harmonizer', which, in Canada and many US states, is approved for use in tank mixture with the mineral oil 'Civitas' for disease control. Field trials with the combined formulation 'Civitas One' in the Nordic countries showed that this combination had the same efficacy as fungicides in controlling microdochium patch. However, we don't know if the suppression of disease was due to resistance induced by the mineral oil, protection by the copper-containing product or a combination of the two (Aamlid et al. 2018). On the negative side, the combined product turned the turf into an almost black color that delayed spring green-up in trials with a long snow cover or ice encasement. It is well known that copper can be toxic to plants, and greenkeepers should be aware of long-term effects of using copper products. The first indication of copper intoxication is reduced root growth (Adrees et al. 2015).

We have also tested fall applications of the alternative colorant Transition against microdochium patch. In this case, the product resulted in less visible patches in the fall, but it had no effect in the following spring (Aamlid & Pettersen 2013). A critical question to the use of colorants is if they have a true preventative or curative effect or if they only mask the symptoms of disease. Some colorants may also have an effect on soil temperature and evapotranspiration (McCarty et al. 2013).

Silicon

Silicon is not yet recognized as an essential nutrient for plant growth and development, but it is not unlikely that it will become so in the future. Grass dry matter can contain up to 8 % Si. The very winter stress tolerant species tufted hairgrass has a very high content of silicon, but this is likely a coincidence. Experiments with cool-season turfgrasses are few and the results inconsistent, but there are reports of positive effects of silicon on stressed plants (e.g. Balakhnina & Borkowska 2013).

Bioproducts

Compost

Inclusion of compost in the rootzone or topdress on USGA greens can reduce injuries from snow mold (Boulter et al. 2002, Espevig & Aamlid 2012). This is an example of biological control because the compost contains a high number of microorganisms. It has also been reported that other fungi, like *Typhula phacorrhiza*, can suppress the snow mold pathogen *T. ishikariensis* (Nelson 1997, Wu et al. 1998).

Compost dressing improves the water holding capacity at the top of the rootzone. This results in less air in the mat. Some of our observations from golf courses indicate that *Microdrochium nivale* depends on air filled pores to develop microdochium patch. A positive effect of compost may therefore have alternative explanations than a high content of microbes.

Because our experiments with nitrogen applications in the autumn showed that high N-rates gave more microdochium patch, we are reluctant to advise compost applications in the autumn without including its nitrogen content into the fertilizer balance.

Biostimulants

There are several definitions of the term 'biostimulant'. We use this one: 'A plant biostimulant is a non-nutritive substance, microorganism or mixture of substances and/or microorganisms applied to plants with the aim to enhance nutrition efficiency, abiotic stress tolerance and/or crop quality traits' (du Jardin 2015)

Stressed plant have shortage of resources, grows under unfavourable conditions and/or faces diseases, pests or toxic chemicals. Biostimulants can make plants more tolerant to such conditions. Experiments have proven positive effects of biostimulants on turf exposed to heat, drought, herbicides, UV-light and some pests. Some products have been shown to improve the cold tolerance of warm season grasses (Munshaw et al. 2006). Although there is no evidence of biostimulants improving winter survival in cool-season grasses, studies on the model plant *Arabidopsis thaliana* have shown that algae extracts from *Ascophyllum nodosum* can enhance freezing tolerance and alter plant cell properties (Rayirath et al. 2009, Nair et al. 2012). Signalling molecules from biostimulants may regulate plant stress responses and defense mechanisms by activating genes that produce protective enzymes (del Rio, 2015). These are intriguing aspects of biostimulants that call for further research.

From 2012 to 2014 we tested commercial products containing the fungus *Gliocladium catenulatum* and/or bacteria in the genus *Streptomyces* for biological control of microdochium *in vitro* (i.e. on agar in the laboratory) and in five field trials on putting greens in Denmark, Sweden and Norway. Results showed good suppression of *M.nivale* in the laboratory, but no effect in the field trials (Aamlid, Espevig et al. 2017). A similar lack of consistency between field and laboratory trials was reported by Nelson (1997). The explanation might be that it, despite multiple applications, is more difficult to maintain sufficient populations of beneficial fungi and bacteria in the field than in the laboratory.

The effect of the biostimulant Hicure (a product containing amino acids and peptides) against microdochium patch and anthracnose (*Colletotrichum cereale*) was tested in two trials on annual bluegrass greens at NIBIO Landvik and STRI Bingley, UK, from May 2020 to May 2022. The biostimulant was applied weekly for 5 weeks and 7 weeks prior to two applications and one application, respectively, of fungicide tank mixes and the colorant Ryder. Five applications of the biostimulant at two-week intervals enabled a reduction in the number of fungicide applications from three to two without compromising turfgrass visual quality or control of microdochium. The authors concluded that Hicure and Ryder show promise in reducing fungicide use on golf courses (Frisk et al. 2023).

Adjuvants

An agricultural adjuvant is a supplemental substance added to a spray mixture to enhance the performance and/or physical properties of a pesticide. In 2018 and 2019 we tested the adjuvant NanoPro™ which contains humic acids from leonardite, an organic substance made up by fossilized remains of ancient plants, in tank mixtures with the fungicides Delaro (prothioconazole + trifloxystrobin) and Medallion (fludioxonil). Our research showed that addition of NanoPro™ to the tank mixture reduced the need for fungicide active ingredient by 30-60 % without losing any control of microdochium on an annual bluegrass green (Espevig, Pettersen & Aamlid 2020). Together with the earlier results presented in this chapter, this shows a potential for a reduced fungicide use on Nordic golf courses.

Plant growth regulators
The only plant growth regulator approved in turf on the Nordic market is trinexapac-ethyl. In our experiments with Primo Maxx® from 2007 to 2013 we found that applications reduced the occurrence of pink snow mold, but not to an extent that made fungicides application redundant when growing susceptible grass species. The effect was explained by the increased carbohydrate level in turf treated with trinexapac-ethyl (Aamlid & Pettersen 2013a).

CULTURAL PRACTICES IN AUTUMN TO REDUCE WINTER DISEASES

Photo 18. *Mycelium of Microdochium nivale around aeration holes on a red fescue green. No fungicide was applied on this green. Photo: Wendy Waalen.*

Mowing height
We examined the effects of increased mowing height in autumn on golf course putting greens in Finland, Sweden and Norway from 2008 to 2010 (Kvalbein & Aamlid 2012). The results showed slightly more winter disease with increased mowing height in red fescue, but not in creeping bentgrass or annual bluegrass. Since increased mowing height resulted in faster green-up and better turfgrass quality of red fescue and annual bluegrass in spring, we concluded that the mowing height of those two grasses should be increased in the autumn to about 150 % of summer height. A similar advantage of increased mowing height in autumn was not detected in creeping bentgrass.

Aeration and topdressing
Hollow tine coring or spiking often creates a compact layer at 6-12 cm depth on putting greens. Deep aeration with solid tines (Vertidrain or similar) in the late autumn is useful to penetrate and loosen this compacted layer. Aeration can, however, have adverse effects where microdochium patch is the major type of winter injury. We base this on observations that the driest part of a green with the highest air-filled porosity is often the most susceptible to pink snow mold. For the same reason, there are at least some observations that heavy topdressing in autumn might lead to more microdochium patch during the winter (Frank et al. 2024) and that the highest density of microdochium patches can be found around the holes after deep aeration (Photo 18).

Taken together, these observations suggest that late autumn is not the optimal time for aeration and topdressing on golf courses that are more susceptible to biotic than to abiotic winter damages.

Photo 19. *Application of UV-C radiation with SGL UVC 180 unit on the putting green of Osnabrück GC. Photo:Wolfgang Prämaßing.*

Rolling
Experiments in Oregon, USA, have shown that rolling can reduce microdochium patch during the growing season on annual bluegrass greens (Mattox et al. 2018, 2020). The authors attributed the effect to dew removal causing a drier canopy. Findings from an experiment at Royal Copenhagen Golfclub in 2020 and 2021 support these results. Rolling twice per week from August to November was sufficient to reduce microdochium patch on a red fescue dominated green (Espevig et al. 2020, Hesselsøe et al. 2022). However, in a parallel trial at NIBIO Landvik on an annual bluegrass dominated green, the effect of rolling was inconsistent (Hesselsøe et al. 2024).

UV-C radiation
UV-C (100–280 nm) is the most energetic part and the shortest wavelength of the ultraviolet spectrum. While it does not naturally reach the Earth's surface, it has strong germicidal properties when applied with lamps at 254 nm (Urban et al. 2016). In plants, UV-C exposure can alter gene expression and induce reactive oxygen species (ROS), triggering various stress responses, but it can also directly kill fungal hyphae on leaf surfaces (Berkelmann-Löhnertz et al. 2015).

In a 2-year study on a green in Osnabrück, Germany (Photo 19), high UV-C doses (35–40 mJ/cm² or more) effectively suppressed dollar spot on golf greens, reducing disease severity and variability between plots, whereas lower doses had little effect. However, none of the UV-C treatments significantly suppressed microdochium patch outbreaks, although the highest dose slightly reduced disease levels. These results indicate that while UV-C can help manage dollar spot, its effect on microdochium patch is limited (Hesselsøe et al. 2024, Hunt et al. 2025).

Tree removal
Huner et al. (1998) explained the effect of temperature and light intensity on cold acclimation, and our experiments have confirmed how harmful shade can be to the turfgrass. Our conclusion is that a chain saw might be the most efficient tool for improving winter stress tolerance.

In the experiment at Apelsvoll with increasing nitrogen rates in autumn to creeping bentgrass and annual bluegrass greens (Photo 20), we did not use any fungicides in the first year. By the end of October, the annual bluegrass green in shade had 28 % microdochium patch as opposed to 7 % in the control treatment with natural light. Corresponding numbers for creeping bentgrass were 2.5 and 0.5 %, respectively.

Photo 20. *Participants at a turfgrass winter stress seminar visiting the experimental green at NIBIO Apelsvoll in November 2014. Microdochium patch nearly destroyed the shaded plots in this experiment. Photo:Agnar Kvalbein.*

Fungicides

The access to fungicides varies and will probably continue to vary among the Nordic countries. Even though EU has introduced the principle of mutual recognition, it is still up to the national authorities to decide which fungicides shall be on the market. A proposal by the EU commission to ban all pesticide use in so-called ‘sensitive areas’, including golf courses, was barely rejected by the European Parliament in November 2023. However, there will probably be more rounds on this issue in years to come.

According to the European Food Safety Authority (EFSA), Plant Protection Products (PPPs) are pesticides that are mainly used to keep crops healthy and prevent them from being destroyed by disease and infestation. One problem with this definition is that it not only includes chemical pesticides and growth regulators, but also microorganisms, biostimulants and additives that contain at least one active substance used with the intention of controlling weeds, insects, mites and/or diseases. EU’s pesticide database includes a special category for ‘low risk products’ that should qualify for a faster, simpler and less costly approval in the member countries, but the implementation of this legislation varies among the Nordic countries. This is a problem, especially for smaller companies that have developed and want to start marketing alternative products that may lead to less use of chemical fungicides.

The golf federations in the Nordic countries have also chosen different strategies regarding fungicide approval. Some have accepted that only formulations with a specific turfgrass label shall be used on golf courses. Others have applied for and received permission for ‘minor use’ of agricultural products. This has a great impact on the cost of fungicide application in the various countries.

Common to the five Nordic countries is that they have implemented EU’s directive on ‘Sustainable pesticide use’. This directive is based on the principles for ‘Integrated Pest Management (IPM)’ which means that fungicide shall only be applied when other methods cannot provide adequate protection, and when damage from disease is expected to be unacceptably high.

Preventive fungicide applications in the autumn against winter diseases always imply environmental risks because of high precipitation and retarded uptake due to low temperature. Undulated greens, short distance to waterways, low organic matter in the rootzone and localized dry spots increase these environmental risks (Larsbo et al. 2007, Aamlid et al. 2009). Other experiments have shown high concentrations of fungicides and their metabolites in surface runoff (Aamlid et al. 2020). Hence, it is important to control thatch and keep up the infiltration rate as the turf ages.

Although STERF’s survey from 2014—15 showed that 84 % of the golf courses in Iceland and 38 % of the golf courses in the five Nordic countries taken together, did not use fungicides (Økland et al. 2018), there is a wealth of practical experiences and experimental evidence documenting the need for fungicide applications in the autumn. *Microdochium nivale* and other winter fungi will seriously injure especially annual bluegrass, but also colonial bentgrass and creeping bentgrass, where fungicides are not applied. But there is no need, and it is also illegal, to apply higher rates or make more applications than permitted on the label. Provided preventative applications or application at the first sign of disease, our experiments have usually shown equal protection if the rate of the product is reduced by 1/3 relative to the maximum rate on the label. One preventative application of a systemic fungicide when the turf is still growing in October usually provides 60-80 % disease reduction and the level of control is usually increased to 90-95 % with an additional application of a contact fungicide three weeks later. Only golf courses accepting nothing, but the highest level of control will have to go for a third application before snow fall (Aamlid et al. 2015). Based on nine years of research in Wisconsin, Koch (2025) was not able to see any difference in protection if the last application was done two days or two weeks before snow fall.

Repeated use of the same fungicide always implies a risk for pathogens to develop resistance, hence, there is a maximum number of applications per year (usually between 1 and 4) stated on the label. Fungicide application normally protects the grass for several weeks and applications during mild winter periods are not necessary if the grass has been protected by 2-3 applications in autumn. Early spring applications can be considered if the grass has started to grow and there is a risk of weather conditions promoting *Microdochium nivale*, but our experiments have seldom shown better disease control or faster green-up after such applications. In one case we saw a severe outbreak of microdochium patch after a late snow fall on deacclimated turf that has started to grow and received the first application of fertilizer (Photo 21), but the attack was superficial and the turf recovered within one to two weeks.

Photo 21*. A late snowfall caused a severe outbreak of microdochium patch in the SCANGREEN trial at NIBIO Landvik in April 2008. Photo: T. Espevig.*

ABIOTIC WINTER STRESSES

Low temperature freezing stress

Freezing injury is the result of stress caused by ice formation in plant tissues (Jespersen et al. 2023). Intracelluar ice ruptures cell membranes which is lethal to plant tissue, and excessive extracelluar ice formation can result in dehydration of cells. Freezing of meristematic tissues, especially in turfgrass crowns, is always more critical than freezing of mature leaves. Early studies in annual bluegrass and winter barley showed that that root meristems are more frost sensitive than meristems forming new leaves and tillers (Beard & Olien 1963, Olien & Marchetti 1976), and this was later confirmed in perennial ryegrass and Supina bluegrass using infrared termography (Stier et al. 2003). Cold acclimated winter wheat and winter rye do not freeze before the temperature at crown level is down to -5-6 °C (Pukachi & McKersie 1990, Brush et al. 1994) and we assume this is the case also for most cool-season turfgrasses.

When turfgrass textbooks rank species or varieties for 'cold tolerance', they usually refer to studies of freezing tolerance under controlled condition. Plants are typically acclimated in the field or in a greenhouse or growth chamber before exposure to different freezing temperatures in a programmable freezer (e.g. Dionne et al. 2001, 2011; Espevig et al. 2011, 2014). Results are expressed as LT50 values, i.e. the temperature killing 50 % of the plants. Although the exact methodology varies among researchers/laboratories, the ranking of species or varieties is usually fairly consistent which gives confidence in these freezing tests (Jespersen et al. 2023). However, it is important to remember that the exact LT50 values obtained in the laboratory are never representative for field conditions. There are also conflicting results as to whether ranking for freezing stress is representative for other types of abiotic winter stresses such as ice encasement (Gudleifsson et al. 1986, Hofgaard et al. 2000, Höglind et al. 2010).

Frost heave

Frost heave is when the soil surface moves upwards because of ice formation. It is common on silty soils with high capillary capacity, especially if the soil temperature drops slowly. Frost heave can tear off grass roots and increase the risk of desiccation. In the worst case, parts of a green can be lifted up to 20 cm. Many Icelandic greenkeepers have experienced this problem and try to repair the damage by rolling the greens when the frost is about to thaw in the spring (B. Hannesson, pers. comm., Danneberger 2023)

Ice encasement and melt water

The risk for ice and water injuries depends on geography and golf course architecture. Global warming seems to expand the risk for ice encasement into areas that used to have a stabile continental winter climate. The districts around and north of the Nordic capitals Oslo, Stockholm and Helsinki have many golf courses, and many greenkeepers in these areas now report on severe problems with water and ice.

The golf course architects are responsible for some of the problems because they often underestimate the importance of surface water runoff from the greens. Some also construct green areas where melting water can flow from the surrounds on to the green. Golf course owners often pay a high price for rebuilding badly constructed greens areas after some years.

The following sections explains what's going on when the grass is covered by ice.

Lack of oxygen and/or accumulation of toxic gases
Plants need oxygen for respiration. Respiration is very low when the temperature is below -3°C, but significant around 0°C. Under ice (or impermeable covers), accumulation of CO_2 will usually occur in parallel with the depletion of oxygen. Experiments in controlled environments have shown that the combination of low O_2 and high CO_2 is more detrimental to the grass than if only one of the two gases is changed separately (Castonguay et al. 2009). In the worst case, ethanol, organic acids and other toxic by-products of anerobic respiration my accumulate in addition to CO_2 and cause a bad smell at ice melt (Gudleifsson 1994). Microbial activity in the soil also contributes to this unfavorable gas composition, especially on soil-based greens high in organic matter (Rochette et al. 2006). Important implications of declining O_2 concentrations under ice are less freezing tolerance (Waalen et al. 2025) and a drop in plant carbohydrate (fructan) status due to inefficient, anaerobic respiration (Andrews & Pomeroy 1990, Bertrand et al. 2003, Gudleifsson 2013, Gendjar et al. 2024). Both responses are likely to have the strongest impact shortly before and just after ice melt in spring. Low freezing night temperature may be the last nail in the coffin for weak grass coming out of ice encasement, and low carbohydrate levels are likely to delay turfgrass green up and golf course opening in spring.

From 2011 to 2024, the three years with most damage from ice encasement in southeast Norway were 2013, 2018 and 2023. Figure 7 shows that these were also the years with the lowest mean monthly temperature in March and therefore the latest snow and ice melt in spring. In other words, increasing duration of ice covers will normally increase the risk for turfgrass winterkill due to O_2 depletion and accumulation of toxic grasses. Yet, it is hard to predict the critical duration of ice cover in various grass species as the conditions under ice covers depend on so many factors. Estimated tolerances in the field vary from 20-80 days in annual bluegrass to more than 150 days in velvet bentgrass and creeping bentgrass (Tompkins 2004, Aamlid 2009, Waalen et al. 2017, 2025).

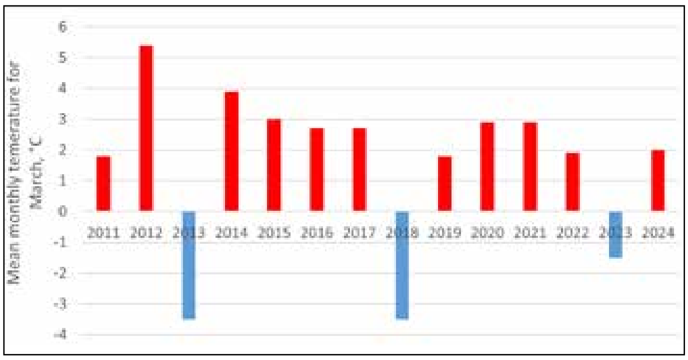

__Figure 7.__ Mean monthly temperature in March from 2011 to 2024 at NIBIOs weather station Lier, about 30 km southwest of Oslo. 2013, 2018 and 2023 were the years with most winterkill on golf courses.

A likely reason for the highly variable reports on tolerance to ice cover within the same turfgrass species is the huge variation in the nature of ice. We often distinguish between compact, black ice (Photo 22) and gray ice which is more porous. In the laboratory studies, Beard (1965) and Tompkins (2004) found more damage from 'ice encasement' in which pots were saturated with water before ice formation, than from 'ice cover' where the pots had a lower soil water content and were not as deeply frozen. Similarly, Andrews & Pomeroy (1990) and Gendjar & Merewitz (2023) found the greatest damage from ice encasement when the soil moisture was high at ice formation.

The formation of ice on putting greens may occur during mild spells when it rains gently on bare, frozen greens in the absence of snow cover. While this is the method used when we intentionally create ice covers in field experiments, a more common

Photo 22. *Compact ice on a putting green at Asker GC, Norway. Photo: James Bentley.*

situation is that ice is formed as snow melts and penetrates to the frozen surface during mild periods. In this case, snow depth, and thus the ability for the snow to absorb water before it hits the frozen surface, may have an important effect on the thickness and compactness of the ice layer. Figure 8 shows how ice accumulated under snow in the control treatment (natural winter conditions, no covers and no snow removal) on a putting green at NIBIO Apelsvoll, Norway, in 2021-22 (Waalen et al. 2025).

The turfgrass literature often distinguishes between hypoxia (reduced oxygen concentration relative to the normal atmospheric concentration of 21 %) and anoxia (total lack of oxygen, i.e. close to 0 %. Oxygen sensors under ice or plastic covers in the ICE-BREAKER experiments occasionally showed O_2 concentrations down to 1-2 % towards the end ice encasement period, but 5-10 % was far more common (Waalen et al. 2025, Watkins et al. 2025). Our results support the Canadian conclusion that altered gas composition is not likely to kill the grass on putting greens unless the O_2 concentration is less than 5 % (Dodson et al. 2017).

Crown hydration and membrane damage

One of the most noteworthy results in ICE BREAKER project was that, despite similar gas compositions, golf course putting greens survived significantly better if an impermeable plastic sheet was inserted between grass and ice than if the ice was in direct contact with the grass (Waalen et al. 2025). This shows that there are other aspects of ice cover that may be equally, if not more, important than the gas composition. A stable and dry environment at the turfgrass crown level seems very important. Beard (1963, 1965) talked about the detrimental effects of 'crown hydration' in combination with freezing temperatures. The physiological reason is usually damage to cell membranes, causing leakage of metabolites from inside cells to the extracellular environment (Heatherington et al. 1987, Chalise & Merewitz 2025a). At least in annual bluegrass, this injury often occurs in the early winter regardless of the duration of ice encasement (Valverde & Minner 2007).

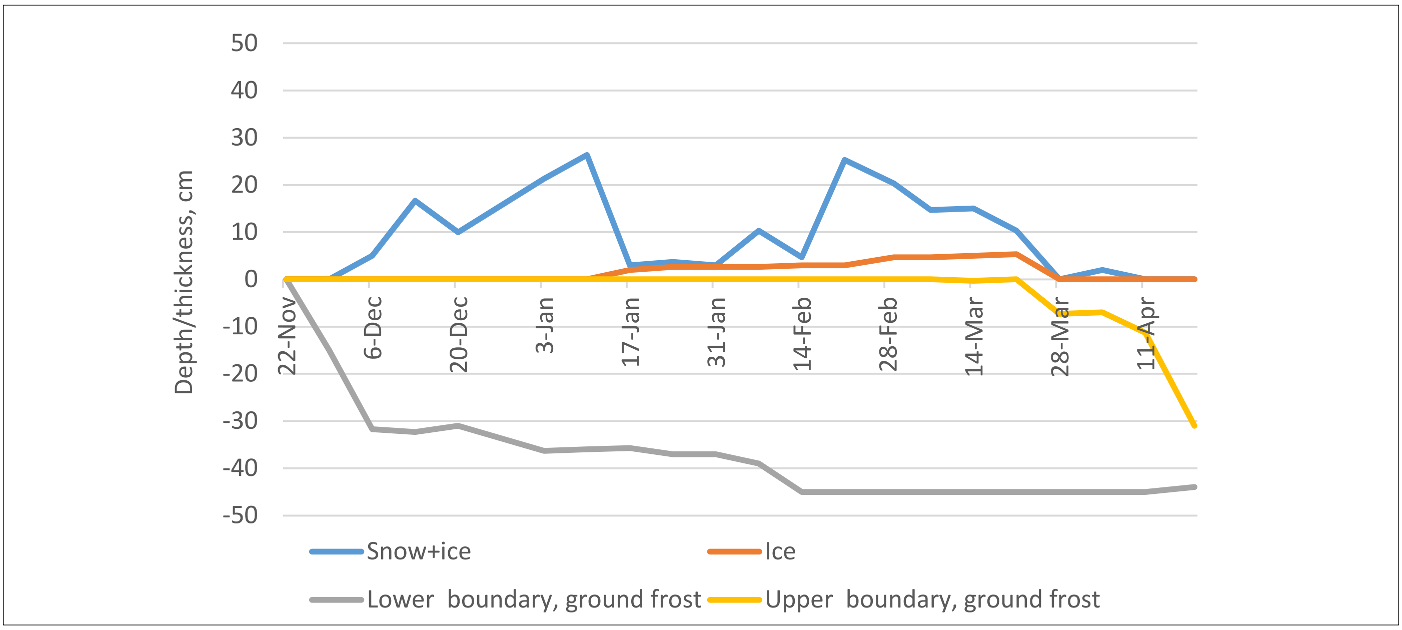

Figure 8. *Snow and ice cover on a sand-based putting green at NIBIO Apelsvoll during the winter 2021-22. Snow depth was never more than 25 cm and ice started to build up on the deeply frozen ground during a mild period with ice melt in mid-January already. Spring came early with snow and ice melt in late March resulting in a total duration of ice cover of 77 days. Red fescue and creeping bentgrass survived, but annual bluegrass suffered more than 50 % winterkill (Waalen et al. 2025).*

MANAGEMENT IN AUTUMN AND WINTER TO REDUCE ICE AND WATER INJURIES

Fertilization

On sand-based putting greens, our recommendation for small and decreasing nitrogen inputs from August to November (Figure 4) will also contribute to increased tolerance to ice encasement, melt water and other abiotic winter stresses. As discussed for winter diseases in the previous chapter, we are not aware of any experimental evidence suggesting that autumn fertilization with more potassium than nitrogen will make the grass more robust before the winter. The first researchers to study this relationship were Beard & Rieke (1966) who found that the best survival of creeping bentgrass and Kentucky bluegrass under any nitrogen rate occurred at a potassium rate one-half of that of nitrogen. Schmid et al. (2016) reported 32 % damage from 47 days ice cover on an annual bluegrass green that had not received potassium for three years, but no injury in treatments that had received annual inputs varying from 53 to 220 kg K/ha. The corresponding concentration of potassium in plant dry matter varied from 1.3 % K on unfertilized plots to 2.6 % K at 53 kg K/ha and 3.1 % K at 220 kg K/ha. These results are in general agreement with Dodson et al. (2016) who found that the maximal freezing tolerance of annual bluegrass was achieved at tissue concentrations between 2.5 and 3.0 % N and between 2.25 and 2.75 % K. Dodson et al. (2016) recommended fertilization with equal rates of N and K to achieve this balance. i.e. a little more K than recommended by Beard & Rieke (1966) and STERF (Table 1). A similar conclusion was reached by Webster & Ebdon (2005) who argued that the optimal N:K ratio for freezing tolerance could be a little lower than the optimal ratio for growth.

Aeration

Deep aeration with solid, course tines (Vertidrain or similar) is usually one of the last maintenance operations on a golf course before winter. This will improve the drainage of surface water to a depth at which the soil is often unfrozen. Although there will be less benefit of the holes if they are filled with ice, we recommend this practice also because deep aeration once a year loosens the compacted zone at 8-12 cm depth created by spiking and other maintenance operations. As mentioned in the previous chapter there is, however, a risk for more snow mold around the holes (Photo 18).

Topdressing

Frequent topdressing with sand is the most important way to control thatch. Dressing should normally be accomplished during the growing season when the grass grows and produces thatch. Keeping the organic matter content in the 25 mm top layer between 3.0 and 4.5 % is a goal. STERF's handbook [Potential for velvet bentgrass on Nordic golf greens] discusses several aspects of thatch control.

Heavy topdressing with sand covering grass leaves in late autumn might reduce photosynthesis severely in a period when little sunlight is available at high latitudes. On the other hand, it is often argued that heavy topdressing will protect turfgrass crowns from desiccation and winter play (if the summer greens remain open during winter) and lead to faster green-up in spring due to higher soil temperatures. After studying this relationship on golf courses in Wisconsin and Minnesota, Taylor (2001) concluded that about 2 mm of sand would be beneficial on most greens, but that doble rates would be counterproductive on wet and shaded green with late snow melt. Late fall topdressing is currently being investigated as part of the project WINTER TURF, and results are so far inconclusive.

Temporary water control

Many greenkeepers in areas with frequent occurrence of ice build-up have developed their own strategies for surface water control. Here are some suggestions:

- Fences of plastic can lead incoming water around the green. The fences must be kept low to avoid shade on the green. Some use a turf cutter to open a ditch and place the sod on the downside to create an 8 cm high wall leading water around the green.
- Temporary ditches from lower parts of the green may work for a while. On flat greens, ice will probably fill the ditches, and care must therefore be taken to keep them open (Photo 23)
- Frost heave in silty soils outside the green can create a dam by blocking surface runoff (Photo 24). Open ditches through the green surrounds may therefore be required.
- If you will make a temporary ditch, remove the turf with a (modified, narrow) sod cutter. The turf should be stored on plastic in roughs where the spring comes early, not in the bunkers which are often the last to get free of snow.
- At low spots on USGA-greens the water can be drained vertically. Make deep holes down to the gravel with your golf-hole cutter. A cup in the hole will prevent sand erosion. An insulating material over these holes can be necessary to protect the gravel from freezing.
- A mobile water pump can be an additional tool (Photo 25) .

***Photo 23.** Temporary ditches in greens need maintenance during the winter. An asphalt cutter in use. Photo: Ole Albert Kjøsnes, Byneset GC, Norway.*

Photo 24. *Frost heave outside this USGA green prevented surface water runoff. Photo: Steinar Selle, Grenland GC, Norway.*

Photo 25. *Removal of melt water from a green with a mobile pump. Photo: Allan Ferm, Grønmo GC, Norway.*

Impermeable winter covers

The protection of putting greens, mostly annual bluegrass, with impermeable covers has a long tradition in Canada (Dionne 2000). Inspired by the Canadians, Oslo Golf Club tested this practice on its – at that time – annual bluegrass greens in the early 1990s. The overall conclusion was positive: As long as fungicides were applied until covering and water was prevented from seeping under the covers, the winter survival of annual bluegrass was mostly better on the covered than on the uncovered greens. However, it was also emphasized that greens should not be covered before the grass had hardened in the fall, and that the covers should not be left on so long in the spring that temperatures started to rise under them (Midtvåge 1996). Some years later, Tronsmo & Tronsmo (2004) conducted trials at five Norwegian golf courses using black fiber fabric as a base layer and dense plastic as a top layer. The grass under the fiber fabric and plastic was noticeably greener when the covers were removed, but two weeks later the effect had disappeared. The authors also reported more winter diseases under the covers.

STERF has funded several projects on winter covering. One such project took place in Finland and northern Sweden from 2007 to 2010. In Finland, no advantage could be demonstrated from covering creeping bentgrass and velvet bentgrass greens, but in Sweden, there was mostly better survival of greens with annual bluegrass and/or rough bluegrass. The need for ventilation under the covers was highlighted, although in one trial, there was more winter disease on the covered than on the uncovered part of the green (Rannikko & Petterson 2011).

In Norway, trials with impermeable plastic covers on greens with six different grass species were conducted at NIBIO Apelsvoll during the winters of 2011-12 and 2012-13. Plastic covers did not improve winter survival compared with natural winter conditions (no amendments), but the plastic-covered treatments had significantly better survival than a treatment with 98-119 days of man-made ice cover directly on the green (Waalen et al. 2017).

As part of the same project, plastic covers were used during three winters at Miklagard GC, Norway, Timrå GC, Sweden, and Oulu GC Finland (a total of nine trials). All the greens contained some annual bluegrass, but were otherwise dominated by creeping bentgrass (Miklagard) or velvet bentgrass and red fescue (Timrå and Oulu). Plastic covers resulted in better winter survival in seven out of nine trials. The exceptions were one trial at Miklagard where water seeped in under the covers, and one trial at Timrå with increased fungal growth under the covers (Kvalbein et al. 2015).

After the devastating winter 2017-18, four golf clubs 10-30 km southwest of Oslo decided to cover some of their greens with impermeable covers before the winters 2018-19 and 2019-20. The greens on the four courses had botanical compositions ranging from almost pure annual bluegrass to creeping bentgrass dominance. One golf course invested in durable Green Jacket covers from Canada (Photo 26), taylor-made for the size and shape of each green (10 yr warranty); the others bought new large sheets of agricultural transparent plastic every year to ensure plastic quality and avoid the need for space to store the plastic during summer (Photo 27). In either case, results were so convincing that the four courses decided to cover all greens before the winter 2020-21. During that and the following two winters we tested the need for undercovers and ventilation systems in large scale trials including 15 greens on each course as part of the ICE-BREAKER project. The conclusions were:

- The risk for anoxia increased with soil temperature and the concentration of organic matter in the thatch/mat layer. Use of impermeable covers could not compensate for good drainage and shaping of the greens to ensure surface runoff of melt water.
- A permeable undercover under the plastic/impermeable cover was recommend (Photo 26) as it prevented the plastic from freezing to the grass and was favorable in years with up to 130 days coverage, but made no difference in a year with around 150 days coverage and heavy snow / ice above the plastic on soil-based or inadequately drained greens.

Photo 26. *Durable Green Jacket cover installed at Haga GC, Norway. Drainable pipes for ventilation have been installed under the impermeable cover. Photo: Gavin Jagger.*

- It is critical to dig down collars to avoid melt water from seeping in under the covers from higher areas around the green.
- Sensor-based ventilation through drainage pipes under the impermeable covers improved survival in one year with 140-160 days coverage, but was not necessary in years with less than 130 days coverage. Ventilation before the snow and ice becomes too heavy is recommended as an insurance, especially on annual bluegrass dominated greens and greens with a high concentration of organic matter in the thatch/mat layer (Photo 28).
- The need for preventative fungicide applications before coverage in late autumn is the same as on uncovered greens.

All in all, the results from the four golf courses showed significant benefits of the impermeable covers in four out of five years. These experiences, together with the results from the small-scale experiments at Apelsvoll (Waalen et al. 2025) makes us recommend impermeable covers on golf courses in areas with on/off winters and the risk for ice encasement. More information can be found in STERF's fact sheet Use of impermeable covers for better winter survival of golf course putting greens.

Photo 27. *Covering a putting green at Asker GC, Norway, in late November 2020. A permeable spring tarp was installed before the impermeable plastic. Photo: James Bentley.*

Photo 28. *Ventilation under impermeable covers before the snow layer gets too thick and heavy is a good insurance should the cover period become longer than 130 days. Photo: James Bentley.*

Monitoring turfgrass condition during winter

Visual inspection of the turf is difficult under snow. Therefore, we recommend the installation of sensors in the top 3 cm surface layer on greens that are vulnerable to ice encasement, and especially on greens that are going to be covered. Temperature sensors are the cheapest and most readily available but should, if possible, be accompanied with sensors for O_2 and CO_2 concentration as well. Sensors for CO_2 concentration often have a maximum value of 4 % (40000 ppm), so make sure to buy one that covers higher concentrations if you decide to invest in CO_2 sensors. As already mentioned, there is usually little risk for plants dying from anoxia if the temperature at crown level is in the range -1 - -3°C and the O_2 concentration is higher than 5 % (Dodson et al. 2017).

For those who can't afford sensors, the nose is probably the best tool to monitor turfgrass status under ice. If you break the ice, you will be able to smell some of the chemicals produced under anaerobic conditions. Products like ethanol or lactic acid do not smell much. but larger organic acids may smell like bad silage or sweaty socks, and the highly toxic gas hydrogen sulphide smells like rotten egg or seaweed. Methane gas can, in the worst case, create bubbling 'volcanoes' through the ice if the thatch/ may layer has a high concentration of organic matter (Photo 29).

On uncovered greens we recommend to collect samples in late February or March to get an early indication of winter damage (Photo 30). The samples should not be placed directly into your window at room temperature, but allowed to thaw slowly in darkness in a refrigerator for a day or two. Collecting samples from frozen turf requires special tools. Read more about tools and devices in STERF's fact sheet: **Winter work on greens**.

Photo 29. *When gas comes up through the ice, you are in trouble! Photo: Ole Albert Kjøsnes.*

Photo 30. *Samples taken from different putting greens in March and placed in a small table 'greenhouse' to get an early indication of winter damage. Photo: Trygve S. Aamlid*

Photo 31. *Snow removal on a putting green at Asker GC in March 2020. Photo: James Bentley.*

Snow removal in December, January or February

Dry snow is an effective insulating material and provides excellent conditions for winter survival. Heavy snow falls in November and December may, on the other hand, create problems if the green is not frozen and if the grass has not been acclimated and protected by fungicides. On such unfrozen greens we must be very careful with tractors or other machines that can damage the putting surface.

On frozen greens, the biggest challenge with snow is that it may turn into melt water and then refreeze into ice. In order to avoid this, some greenkeepers prefer to remove snow layers thicker than 5-10 cm throughout the winter and especially if the weather forecast predicts a warm period with rain and/or snow melt in the middle of the winter.

In the ICE-BREAKER experiment on creeping bentgrass, annual bluegrass and red fescue greens at Apelsvoll, we included a treatment with removal of any snow thicker than 5 cm throughout the winter. In this treatment the greens froze more quicky and to a greater depth than in the control treatment covered by snow, but unlike in the control treatment shown in Figure 8 there was virtually no formation of ice during the winter (Waalen et al. 2025). Despite that, there was no benefit of snow removal on winter survival of any of the three species: Annual bluegrass suffered almost 100 % winterkill, while creeping bentgrass and red fescue survived almost 100 % irrespective of snow removal or not. For annual bluegrass, it seems that direct exposure to low freezing and fluctuating temperatures throughout the winter was just as harmful as 77 days of ice cover.

Your will find a more thorough discussion on snow removal during winter in STERFs popular scientific article Spring 2023: Severe winter damage and late opening of golf courses in Norway.

Snow removal in March/April

Three of the four golf courses hosting the demo trials with impermeable covers in ICE-BREAKER blew most of the snow off a couple of weeks before natural snow melt in late March or April (Photo 31). The fourth course would not risk damaging their permanent Green Jacket covers by driving a tractor with snow blower on the greens. Golf course opening was, in most years, a little earlier on the courses practising snow removal, but this may also be explained by local climatic conditions, different practices as to the use of spring tarps, and - not at least – variable pressures from golf club members.

The decision whether or not to remove snow in spring will have to be based on snow thickness, the duration, thickness and porosity of the ice layer under the snow, and the long-term weather forecast. Obviously, on-line temperature and gas sensors on the green surface may be very helpful in making these decisions. Earlier snow removal implies a longer period with the use of spring tarps to protect the grass against low freezing temperatures, desiccating winds and strong sunshine. Some golf courses may occasionally have temperatures down to -15°C or even lower in March, and it is important to remember that grass coming out of snow and ice encasement have less freezing tolerance than in December and January (Photo 32)

Photo 32. *'What did we do wrong? We cracked the ice'. Greenkeepers discussing on a fescue/bentgrass green, probably killed by low freezing temperatures shortly after snow removal and ice cracking. Photo taken at Vestfold GC, Norway, on 13 April 2013 by Agnar Kvalbein.*

Ice cracking

After most of the snow has melted or been removed from the green, the critical question is what to do with the ice layer? One alternative is to crack it mechanically using, for example, a Vertidrain with solid tines. However, in most cases we agree with US turfgrass agronomists (e.g. Nelson 2005, Vavrik 2019), that ice cracking does more harm than good, at least if conducted in January or February already. The situation may be different when we get to late March and the ice is not frozen as tightly to the grass any more. But even then, as the incoming radiation increases, we think it is safer to stimulate ice melt than to break the ice mechanically. The ICE-BREAKER experiment at Apelsvoll included a treatment with cracking of a 10 cm solid ice layer in March, but the winter survival was only marginally better than where the snow and ice melted naturally a couple of weeks later (27 vs 23 % winter survival on average for the three species, Waalen et al. 2025).

Ice melting

Ice can be melted with chemicals that lower the freezing temperature of water. Chlorides of calcium (Ca), magnesium (Mg), potassium (K) or sodium (Na; table salt which is also the most common product used on roads) are efficient in melting ice, but they are also likely to burn the grass, especially if the melt water cannot escape on the green surface, but penetrates into the rootzone. Norwegian laboratory and field experiments with Calcium Magnesium Acetate (CMA) showed no phytotoxic effect in spring, but the mixed creeping bentgrass / annual bluegrass green did not survive any better as the CMA rarely created holes deeper than 2 cm in the ice layer (Kvalbein & Aamlid 2008). We therefore concluded that CMA could not be recommended on putting greens, and this was later confirmed by US trials showing that CMA incurred the same risk for phytotoxicity as NaCl and slightly more than KCl if applied at the same rate (Hollman et al. 2017).

Charcoal, black sand or a thin layer of black organic fertilizer can be very efficient in accelerating ice melt as more energy from the sun becomes available in March. This is a safer option than using chemical de-icers (Hollman et al. 2017), and it corresponds with what three of four greenkeepers did after snow removal in March/April in the ICE-BREAKER project. Dark expanded clay minerals (LECA) can also be efficient in melting ice (Photo 33) although such large aggregates will have to be removed with a leaf blower once the ice has melted.
You will find more information about ice cracking and melting in STERF's fact sheet: Anoxia – when to break the ice ?

Photo 33a,b *LECA® can be used to penetrate ice if there is some solar radiation.These photos are from Sunnfjord GC, Norway. The aggregates melted holes in the ice even though the weather was partly cloudy. Photo: Leiv Årseth.*

SPRING STRESSES

In practical greenkeeping, the ultimate result of turfgrass management during the previous season and the multiple stresses encountered during the winter are usually not seen until 1-2 weeks after snow and ice melt in spring. This is a critical period, as grass coming out of the winter is often weak and need the best maintenance for fast recovery. One of the most frustrating experiences a greenkeeper can have, is that the grass appears green and healthy at snow and/or ice melt, but then collapses in a couple of days.

The spring challenges are often due to a combination of high light intensity, desiccation and re-exposure to aerobic conditions. When the grass is de-acclimated and resumes growth, it also becomes much more vulnerable to low freezing temperatures. You can read more spring stresses in STERF's fact sheet Spring stresses: The difficult transition into a new growing season, and about de-acclimation in Warm spells during the winter.

Desiccation

We have chosen to classify desiccation as a spring stress, but turf that is not protected by snow may dry out during the winter as well. Winter desiccation occurs when the soil is frozen so that the plants can't take up enough water to replenish that lost by transpiration. This is usually related to little or no snow cover, sub-zero temperatures, winds and sunny days that promote stomata to open.

Photoinhibition and oxidative stress

When re-exposed to ambient oxygen concentration, there is a risk that turfgrass that has been exposed to hypoxia or, in the worst case, anoxia under an ice cover will start producing superoxides (O_{2-}) hydrogenperoxides (H_2O_2) and other Reactive Oxygen Species (ROS) that are toxic to the plants (Blokhina et al. 2003). The risk is exacerbated by increasing duration of ice encasement (Chalise & Merewitz 2025a) and by the combination of high light intensity and low temperature shortly after ice melt. Photosynthesis consists of two reactions, and we use the term 'photoinhibition' when there is a mismatch between the physical 'light reaction' which captures energy from the sunlight and the chemical (enzymatic) 'carbon reaction' which converts this energy into sugar. On cool and bright spring days, the light reaction often runs at maximal speed and produces excessive energy that – in the presence of O_2 – ends up as ROS because the carbon reaction is limited by low temperature (Huner et al. 1998). The plant's defence mechanism against ROS is the production of antioxidants, which, however, is often inadequate in annual bluegrass, thus leading to spring death in that species. Associated physiological and morphological reactions going on in annual bluegrass, but to a much lesser extent in creeping bentgrass, are increased production of the growth-suppressive hormone ethylene (Laskowski & Merewitz 2021) and a thinner wax layer in the cuticula on leaves and crowns (Chalise & Merewitz 2025b), that have been under ice cover, the oxidation of lipids making cell membranes more saturated and thus vulnerable to leaching after ice melt (Laskowski & Merewitz 2021).

Previously in this handbook we have discussed plants' acclimation to cold, but plants will also acclimate to different light conditions. Intense light, and especially UV-radiation, can severely harm the leaf cells. Overwintering leaves formed at low light intensity in October can easily be shocked by the intense sunlight when the snow and/or ice melts in April. Annual bluegrass maintains the formation of new leaves for a longer period in autumn than creeping bentgrass and these late-formed leaves are especially susceptible to degradation of amino acids leading to loss of photosynthetic capacity during ice encasement (Gendjar et al. 2024). The authors found no similar degradation of amino acids in creeping bentgrass which was therefore able to resume photosynthesis using leaves formed in the autumn.

Some grass species are able to cope with the light stress in spring by producing anthocyanin or other color pigments that shade the vulnerable parts for the cells. Some misinterpret this purple color as phosphorus deficiency. We have seen the anthocyanin color especially in velvet bentgrass (Photo 34) and rough bluegrass. For the latter species it has even been speculated that the production of pigments under high light intensity may be large enough to be utilized industrially (Petrella et al. 2016). Likewise, the dark off-season color of some varieties of red fescue (Photo 34) may well be due to the production of protective pigments.

Photo 34a,b. *Early spring green-up on a green with various grass species at NIBIO Landvik in 2009. Top photo taken on 31 March, two weeks after the melting of a two months' snow cover. Lower photo taken on 6 April. Photos: Trygve S. Aamlid.*

Maintenance of surviving turf in spring

Low soil temperature is the main growth-limiting factor in spring. After spring equinox on 21 March the days are longer the further north you go, and the longer days will, to some extent, compensate for the lower temperature when it comes to plant growth at high latitudes (Hay 1990).

Spring covers

There are many different types of spring covers. Light transparency, persistency and resistance to water and gas diffusion vary among the products, and so does the price. Some greenkeepers prefer the low-weight, white fibrous tarps (Agryl, Lutrasil) commonly used in Nordic horticulture. Others prefer the more open 'Norgro' covers (Photo 35) or the 'Evergreen' cover consisting of woven plastic (Photo 36) .

Spring covers usually increase the mean (diurnal) surface temperature by 1-2°C. There is little effect on cloudy and rainy days, but the temperature can increase up to 5°C on sunny days in May. Too high temperature increase may be stressful for plants coming out of snow or ice cover, and for that reason many greenkeepers use spring covers as a protection against night frost, but take them off during daytime. While a single one-layered spring cover may not suffice to bring the surface temperature above freezing in the coldest nights, the grass will often be protected because vapor condensates under the cover. Use of spring covers usually makes the turf look greener and stimulates leaf elongation. In addition to temperature, the latter may also be a response to partial shade and different light quality under the covers. Other advantages are the protection against strong wind and harmful desiccation, especially if the irrigation system is not yet up and running.

Recent research in the projects ICE-BREAKER and WINTER TURF have revealed that the light effect, i.e. avoidance of photoinhibition, of spring tarps may be just as important as the temperature effect. More information about this can be found in following section on turfgrass (re)establishment from seed. However, although both temperature and light effects are relevant for turf that has survived the winter, we recommend greenkeepers to be careful not overusing spring covers on mature grass. We have often seen that the nicely green, but weak turfgrass plants coming out covers are overtaken by uncovered plants before the golf course opens.

Spring irrigation

Transpiration from surviving turfgrass starts early in the spring and drought can limit turfgrass green-up and recovery. We therefore recommend that turfgrass managers get their irrigation systems up and running as early as possible in spring. Irrigation will lower the canopy temperature because of evaporation, but the temperature of the irrigation well is not important. With sprinkler irrigation and small droplets, the temperatures of the irrigation water will usually adjust to air temperature before it hits the ground (Hannesson 2009).

Because plant uptake is limited by low soil temperature, excessive irrigation is likely to wash out nutrients more easily in the spring than in the summer. Keep in mind that leakage can be considerable from greens with poor grass coverage.

Photo 35. *The relatively open spring cover 'Norgro' used by many Norwegian greenkeepers. The temperature increase is less than for Agryl/Lutrasil (Photo 37) or Evergreen (Photo 36) covers. Photo: Trygve S. Aamlid*

Photo 36. *Faster green-up with Evergreen spring tarp at Haga GC, Norway in late April 2021. Photo: Trygve S. Aamlid.*

REESTABLISHMENT OF DEAD TURF

STERF has defined reestablishment after winter injuries as a part of winter stress management and published in 2025 the updated fact sheet Reestablishment after winter damage.

Reestablishment from seed is always difficult (Photo 37). Low temperature slows germination. Too much or too little thatch in the dead spots can impair the seed's access to moisture and oxygen, which are both basic requirements for germination. Partly dead greens are perhaps the most challenging because surviving turf and juvenile grass seedlings require very different input and maintenance.

Inhibitors to germination and seedling growth after ice encasement?

Many greenkeepers assume that greens killed by ice encasement contain toxic substances and are therefore more difficult to reestablish than greens killed by freezing temperatures or snow molds. Although supported by Norwegian greenhouse studies (Brandsæter et al. 2005) and practical observations in Icelandic hayfields (Gudleifsson 1994), our studies of seed germination and seedling root growth of creeping bentgrass and red fescue on germination paper soaked with water extracts from ice-covered greens have not been able to confirm this assumption. We identified butyric and acetic acids and their esters in the thatch layer shortly after ice melt, but these compounds were very volatile and evaporated in a day or two. In a follow-up experiment conducted by German students, the concentration of butyric and acetic acids had to be at least ten times higher than that detected in the ice-covered greens to have any negative effect on germination. Based on these findings we concluded that there is no scientific evidence for inhibition of germination or seedling growth by toxic substances remaining in the thatch or soil after ice covers on putting greens (Waalen et al. 2018 and unpublished results 2024).

Turfgrass species, varieties and seed treatments

Annual bluegrass forms a huge seed bank on many golf greens (Lush 1988), but it often takes two to three of months for this seed bank to reestablish acceptable putting quality on winterkilled greens. Greenkeepers might take advantage of this as an opportunity to change the botanical composition of their greens by reseeding with creeping bentgrass (Stier 2005) or some other durable species. Several researchers have ranked creeping bentgrass varieties for germination rate and ability to develop turf cover at low soil temperatures (Heineck et al. 2019, Carroll et al. 2020, Ebdon & Dacosta 2021, Lönnberg & Blusi 2023, Dacosta et al. 2025). The most consistent result across these studies is that the varieties 'Independence' and 'Memorial' are more severely delayed by low soil temperatures than newer varieties such as '007', 'Luminary', 'Declaration' and 'Pure Select'. In agreement with Waalen & Kvalbein (2016), Ebdon & Dacosta (2021) also found that colonial bentgrass germinated faster at low temperature than many varieties of creeping bentgrass, whereas velvet bentgrass was significantly slower. The fastest cool-season grasses to establish turf cover from seed at low temperature are perennial ryegrass followed by rough bluegrass. For this reason, some greenkeepers use these species as temporary nurse crops (cover crops) when reestablishing winterkilled greens at low temperature in spring. The nurse crop may either be seeded alone, e.g. on winterkilled annual bluegrass greens (Lönnberg & Aamlid 2022), or it may be mixed with creeping bentgrass or another durable species. Heltoft et al. (2021) found that perennial ryegrass seeded as a nurse crop was a little faster than rough bluegrass, but also more competitive to creeping bentgrass.

Some researchers have tried seed priming or repeated application of various plant health products after seeding to speed up emergence and the development of turfgrass coverage on winterkilled greens (DaCosta et al. 2025). While some of these products may shorten the germination period by 2-3 days in the laboratory (e.g. DaCosta et al. 2015), there are few reports showing consistent improvements under practical field conditions. An interesting compound that warrants further research is the plant hormone gibberellic acid (GA3) which, in one out of two years, doubled turfgrass coverage after four weeks when being used for seed priming of creeping bentgrass 'Luminary' at NIBIO Landvik (Dacosta et al. 2025). However, this result was not confirmed when reestablishing winterkilled greens in Central and Northern Sweden (Lönnberg & Blusi 2023).

Seeding date

Waalen & Kvalbein (2016) found that annual bluegrass has a lower optimal temperature for germination and seedling growth than creeping bentgrass. For this reason, it has been argued that reseeding after winterkill should not take place as early as possible, but rather wait until the soil temperature has increased to at least 10°C. Three different seeding dates of creeping bentgrass and a commercial cultivar of annual bluegrass seeded 7-14 days apart were tested against an unseeded control in

Photo 37. *Looking for creeping bentgrass seedings on a winterkilled green at Vestfold GC in spring 2018. Photo: Lily Watkins.*

***Photo 38.** Trial with different seeding dates and creeping bentgrass varieties on a dead annual bluegrass green at NIBIO Landvik, April 2024. Photo: Trygve S. Aamlid.*

parallel field trials in Michigan, USA (Perkinson & Frank 2025) and Norway (Bekken & Aamlid 2025, Photo 38) over two years. Results at both sites agreed that there is no reason to postpone the reseeding in spring. The earliest seeding date, which in Norway was in late March or early April at an average soil temperature around 5°C, not only resulted in the best overall coverage, but also the highest proportion of creeping bentgrass relative to annual bluegrass. The trials included four different varieties of creeping bentgrass, but there were no significant differences between the varieties in reestablishment rate at any of the experimental sites (Perkinson & Frank 2025, Bekken & Aamlid 2025). The commercial variety 'Two Putt' of annual bluegrass performed the worst in the trial in Michigan (Perkinson & Frank 2025).

Preparations and seeding methods

Several field trials on winterkilled annual bluegrass greens in Central and Northern Sweden have shown that slit seeders, i.e. sowing machines that slit the seed into the thatch/mat at around 1 cm depth, usually gives better emergence than drop seeder which place the seed on the surface (Lönnberg & Aamlid 2022). The obvious explanation for this is that seeds need soil contact to imbibe water and start the germination process. Turfgrass slit seeders are available at row spacings down to 3 cm, and they should always be used in two different directions to avoid unnecessary gaps and promote faster recovery (Photo 39).

Use of covers

Cool-season grasses usually have a higher optimal temperature for germination than for tillering. This explains why we are more positive to using spring covers when (re)establishing new turf from seed than for early green-up of surviving turf. Besides the positive effect on soil temperature and soil moisture, spring covers may play an important role in avoiding photoinhibition of newly emerged seedings. Photos 40 and 41 show that the two covers Evergreen and Evergreen Radiant resulted in the most healthy seedings and the fastest development of turfgrass coverage in a trial at Landvik in spring 2025 (Aamlid, Borchert et al. 2025). These results are preliminary, but they provide a good example of how spring cover may protect new seedings from light stress.

***Photo 39.** Result of three years repeated reseeding / overseeding of three different creeping bentgrass varieties (one with both primed and unprimed seed) with a slit seeder on an annual bluegrass green in Northern Sweden. Photo: Carl Johan Lönnberg.*

***Photo 40a,b**. Field trial at NIBIO Landvik seeded 4 April 2025 with various spring covers for faster establishment of creeping bentgrass, immediately after seeding (left) and 18 days later (right). Photos: Trygve S. Aamlid.*

***Photo 41 a-d.** Close-up of creeping bentgrass seedlings from uncovered plots and plots covered with Agryl fibre tarp, Evergreen Original and Evergreen Radiant covers. Photo taken at the final removal of covers on 29 April 2025. Photos: Ove Hetland.*

'The bad spot syndrome'

For to the one who has, more will be given, and from the one who has not, even what he has will be taken away. Mark 4:25.

To our knowledge, 'the bad spot syndrome' has not been described in international turfgrass literature before. This chapter is an attempt to create a model that can help turfgrass managers understand why reestablishing dead greens sometimes is extremely difficult.

We have earlier argued that a high content of organic matter in the rootzone will exacerbate the risk of hypoxia and winter injuries under impermeable covers (Rochette et al., 2005), and probably also under ice encasement. Now we will argue that low organic matter content because of poor growth, often caused by drought, increases the risk for winter injuries and makes it very difficult to reestablish turf and produce a consistent green of good playing quality.

Bad spots start with poor growth

The turfgrass growth rates on greens vary for many reasons. One is suboptimal green construction. We often find that lack of vertical barriers around USGA-constructed greens makes the edges dry, especially close to green bunkers or when the green is elevated from the surroundings (Photo 42).

Wear and compaction from golfers and machinery are other reasons for reduced plant growth. The amount of wear is often reflected in the organic matter content on various parts of the green. On undulated or renovated greens, scalping might occur, or double mowing reduce the cutting height in the clean-up round. Triplex mowers also result in compaction at the green edges (Photo 43).

A third reason for reduced plant growth are fairy rings or take all patch (*Gaeumannomyces graminis*). Microdochium patch seems to be more frequent on the drier parts of the greens and is sometimes related to localized dry spots. While the reasons for poor growth can be several, our main point here is that reduced growth implies too low production of thatch, and that the stress which reduces growth at the same time increases the risk of winterkill and makes it more difficult to reestablish new turf from seed.

Photo 42. *Dry edge of a green caused by water retention from the soil outside the green and the deep bunker drain. Photo: Agnar Kvalbein.*

Photo 43. *A typical pattern on a poorly reestablished green. Picture taken in Northern Norway in August. The bad areas can be related to wear (clean up round) and drought. Photo: Agnar Kvalbein.*

When consulting golf courses where the reestablishment of greens has not been successful, we often measure very low soil water contents in the top 5 cm, typically 4-8 % by volume. When examining the soil profile carefully, the organic matter content is very low in the upper centimetres. The course pores near the surface are not able to retain water, which therefore very rapidly moves into the finer pores further down in the profile (Photo 44).

Photo 44. *Profile under bad spot to the left and under acceptable turf to the right. These profiles received the same rates and types of topdressing sand. Poor growth the spring 2013 caused layering at the bad spot. On the top of the sand, there is a thin layer of organic matter from summer 2013. The putting surface was nice in the autumn). In spring 2014 the turf was dead, probably killed by Microdochium nivale. The sand was hydrophobic, and the green was very difficult to reestablish due to the pure sand layer on the top. Photos: Agnar Kvalbein*

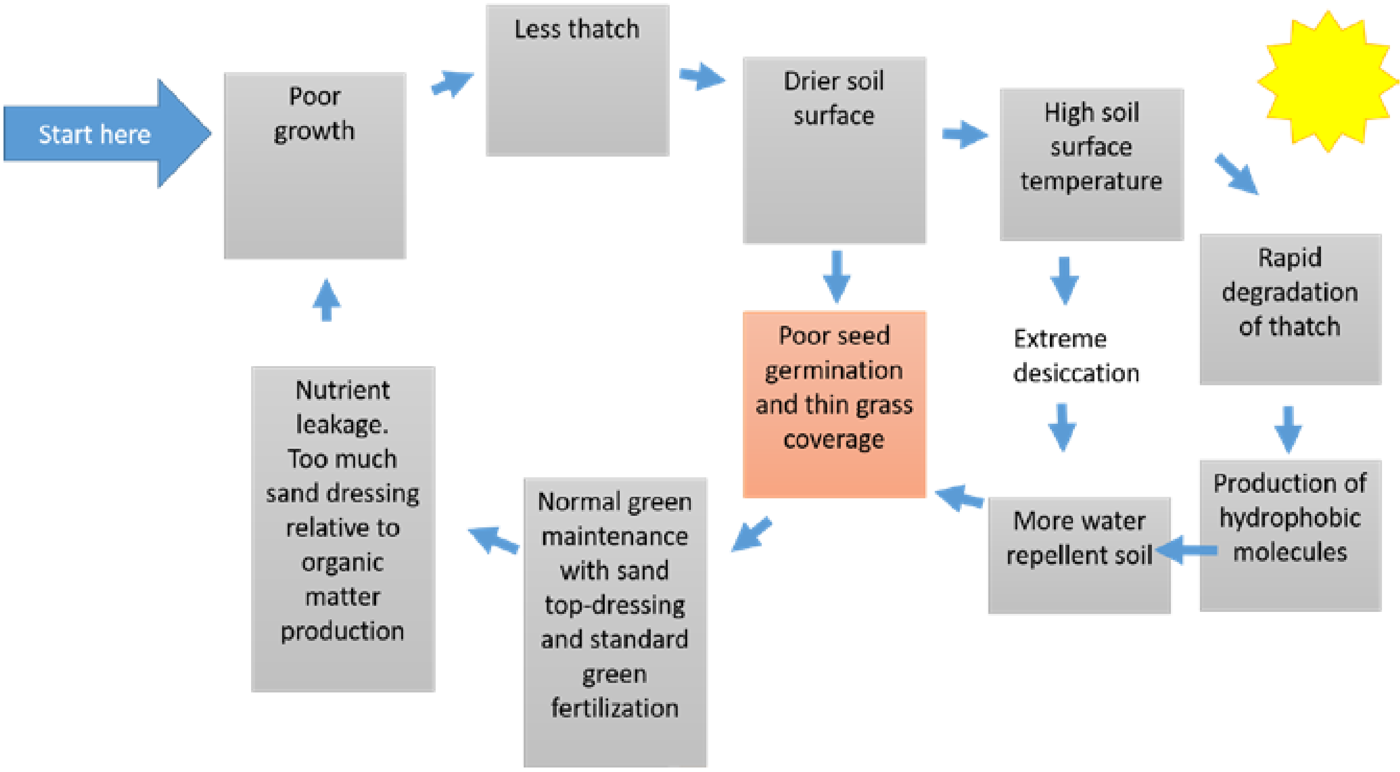

Figure 9. *The bad spot syndrome. The model explains why some winterkilled spots on a golf green are extremely difficult to reestablish.*

The location of the bad spots will usually coincide with localized dry spots. They are on the highest parts of the green, at the edge of the green, or where irrigation coverage or overlap is poor. Hydrophobic soil develops from degradation of organic matter (Doerr et al. 2000, York & Canaway 2000) and the occurrence of "fatty", water-repellent compounds increases over time (Spaccini & Piccolo 2009). On bad spots, the degradation of organic matter goes fast because less thatch results in fast replenishment of oxygen and the low sward density increases soil temperature. 'Bad spot' development is summarized in Figure 9.

How to cure bad spots?

There is no simple answer. The goal is to build up the water holding capacity in the bad spots without producing too much thatch under the surrounding turf that survived the winter.
If the spots are large and you have a skilled staff and access to high quality sod produced on a compatible sand, the easiest solution is probably to reestablish the winterkilled areas with sod. We do not think of this as an easy way out of the problem. Sodded parts of a green often becomes hydrophobic, and uniform playing quality is hard to achieve (Photo 45).

Photo 45. *Winter injuries repaired with sod in spring. Picture taken on 9 September 2006. Photo: Agnar Kvalbein.*

The alternative to sod is meticulous handwork on the spots: Removal or break-up of thatch, incorporation of good, mature compost into the top layer, spot sowing with a hand spiker, uniform and frequent application of fertilizers and hand irrigation with a nozzle that create fine droplets. Manual irrigation (Photo 48) is particularly advantageous because the coarse and heavy droplets from the sprinkler system tend to move seed and dressing material into the surrounding turf, thus leaving the dead spots as low bump with coarse sand. In such cases, dressing with a mixture on sand and organic material, such as finely granulated garden compost or low-fertility manure, is likely to raise and stabilize soil moisture around the seeds and to provide nutrients for seedling growth.

Mowing partly dead greens is also difficult. The newly seeded areas are often unstable, and even single mowers and footsteps will easily destroy the seedlings (Photo 46, 47).

If you manage to get some new plants germinating, the seedlings need much fertilizer to exploit their maximum growth capacity. A rule of the thumb is that establishing turf on greens requires three times more fertilizer than established turf. This is also reflected in a higher risk for nutrient leakage from greens under establishment (Aamlid, Kvalbein & Pettersen 2017), and frequent (at least weekly) applications are therefore essential to achieve a high growth rate while minimizing nutrient losses. Spot fertilization is recommended as long as the bad spots are visible.

Is the application of clay mineral dressings or water holding polymers on the bad spot an alternative? Such a practice will create a permanent variation in rootzone properties, and most turfgrass managers will hesitate to use such minerals unless they are incorporated into the rootzone of the entire green.

Photo 46. *Footsteps on seedlings in unstable rootzone material. Photo: Agnar Kvalbein.*

Photo 47. *How can these seedlings survive in an environment with adjacent mature grass, playing golfers and daily mowing? Photo: Agnar Kvalbein*

Photo 48. *Irrigation by hand with hose and small droplet nozzle is necessary when reestablishing partly dead greens after winter injuries. Picture from grow-in experiments at NIBIO Landvik. Photo: Agnar Kvalbein*

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APPENDIX 1. AUTUMN FERTILIZATION EXPERIMENTS 2014-2017

***Table A1.** Concentration of nutrients (g/l) in the six different fertilizers.*

Treatment	N	P	K	Mg	Ca	S	Fe	Mn	Zn	Cu	Mo
1. No N	0.00	0.16	0.76	0.08	0.09	0.11*	0.011	0.0043	0.0023	0.0005	0.00036
2. Low N	0.40	0.16	0.77	0.08	0.09	0.14	0.011	0.0043	0.0023	0.0005	0.00036
3. Med N	0.80	0.16	0.77	0.08	0.09	0.14	0.011	0.0043	0.0023	0.0005	0.00036
4. High N	1.20	0.16	0.77	0.08	0.09	0.14	0.011	0.0043	0.0023	0.0005	0.00036
5. No S	0.80	0.16	0.77	0.08	0.09	0.0	0.011	0.0043	0.0023	0.0005	0.00036
6. High S	0.80	0.16	0.78	0.08	0.09	1.27	0.011	0.0043	0.0023	0.0005	0.00036

* *No ammonium sulfate in this fertilizer*

The project was funded by the Scandinavian Turfgrass and Environment Research Foundation (STERF), Research Council of Norway and The Norwegian Golf Federation. The aim of these experiments was to test the effects of nitrogen and sulfate on winter stress tolerance of green grass.

Two experimental USGA-greens were established in late June 2014 and reestablished in 2015. The grass species were creeping bentgrass ('Independence') and annual bluegrass (local ecotype). The green at NIBIO Landvik was on a lysimeter facility and drainage water was collected for nitrogen analyses. At NIBIO Apelsvoll half of the green was shaded to 30 % of natural daylight during the experimental period, lasting from the beginning of September until the end of November. During these weeks the greens were fertilized with 6 different treatments (Table A1).

Nitrogen and sulfate were the experimental variables. All fertilizers were applied weekly at decreasing rates (Figure A1). The total amount of nitrogen applied during the 13 weeks were 0, 28 (low), 55 (medium) and 84 (high) kg/ha.

During the establishment period in July and August, the greens were fertilized frequently with a complete fertilizer, 140–160 kg N per hectare during 11 weeks. The greens were mowed three times weekly at 5 mm. Mowing continued at this height but less frequently until the grass stopped growing in late autumn. (We measured height growth every week).

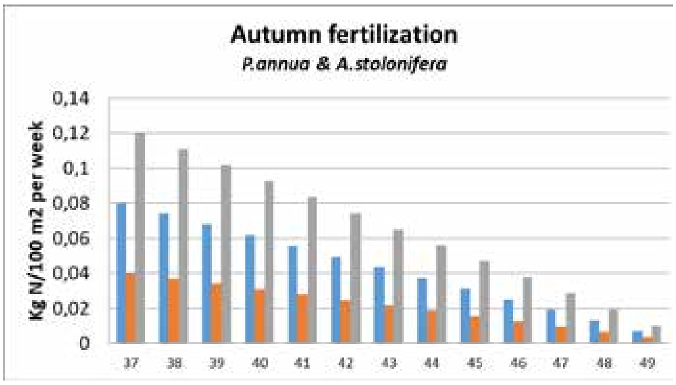

***Figure A1.** Weekly fertilizer applications followed a declining curve. Blue=medium, orange = low, gray = high rates.*

In the first year we applied no fungicides, and a severe attack of microdochium patch occurred early in the autumn, especially on annual bluegrass. The shaded green on Apelsvoll was very bad. The second year we applied Delaro (trifloxystrobin + prothioconazole) to get more healthy plants for the laboratory experiments.

Some results are presented in the main text. Below you will find some additional data.

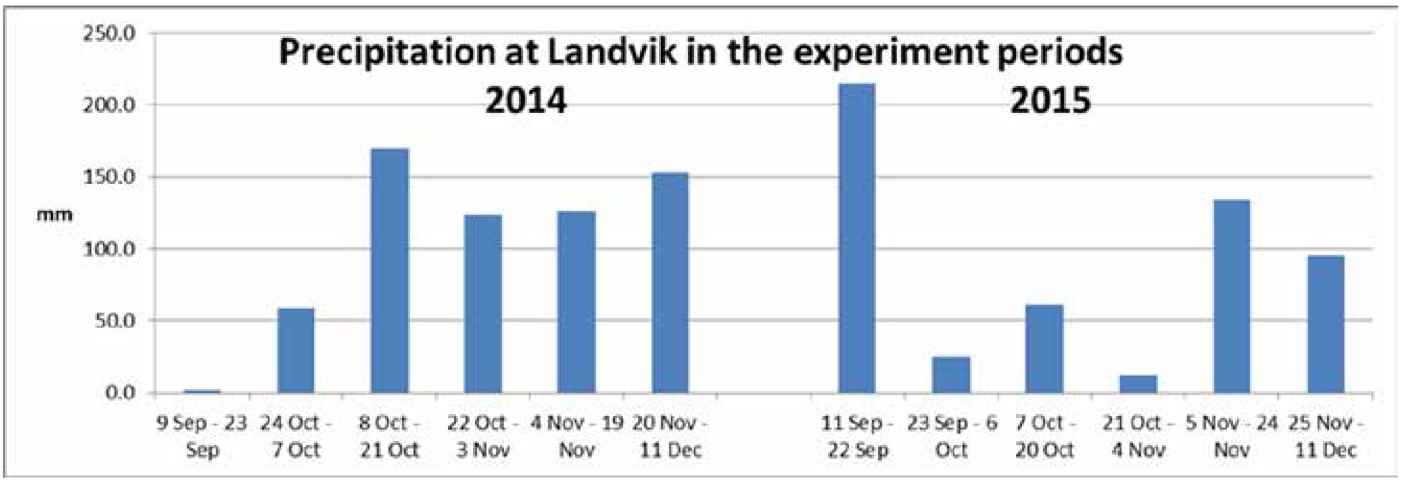

***Figure A2.** Natural precipitation at Landvik in the experimental periods in 2014 and 2015.*

Nitrogen leakage

Drainage water was collected from plots where half of the area was creeping bent and the other half was annual bluegrass. The natural precipitation was higher than normal in the first experimental year (Figure A2).

The collection of drainage water showed, on average for two years, that 49 % of the highest nitrogen rate leaked from the green (Figure A3). The nitrate limit for drinking water in EU is 50 mg/litre. The drainage water did not exceed this limit, but we think the loss was unacceptably high. The leakage was highest when the soil temperature was below 5 °C. Based on this we cannot recommend 'late autumn fertilization', i.e. giving high fertilizer rates at soil temperatures below 5 °C, as a sustainable strategy.

Freezing test

Grass samples were collected from the two experimental greens and brought to laboratory tests in the beginning of December and by the end of February/beginning of March. The test was performed according to our standard protocol (Espevig et al. 2011), and LT50 values calculated. The test showed that there were significant differences between the two species, and they also reacted differently on nitrogen fertilization in the autumn. Higher nitrogen applications reduced the freezing tolerance of creeping bent. For annual bluegrass there was no significant effect of autumn fertilization. Results from the last experimental year, which confirmed the first year's results, are shown in Figure A4.

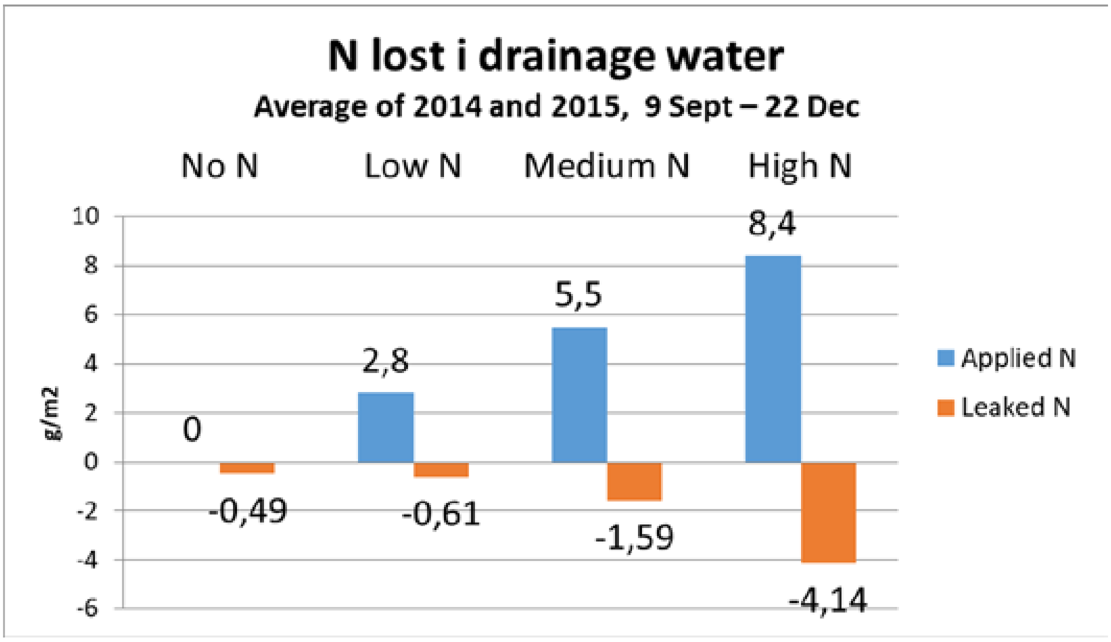

Figure A3. *Nitrogen applied and lost in drainage water from the experimental green at Landvik. See Figure A1 for weekly application rates.*

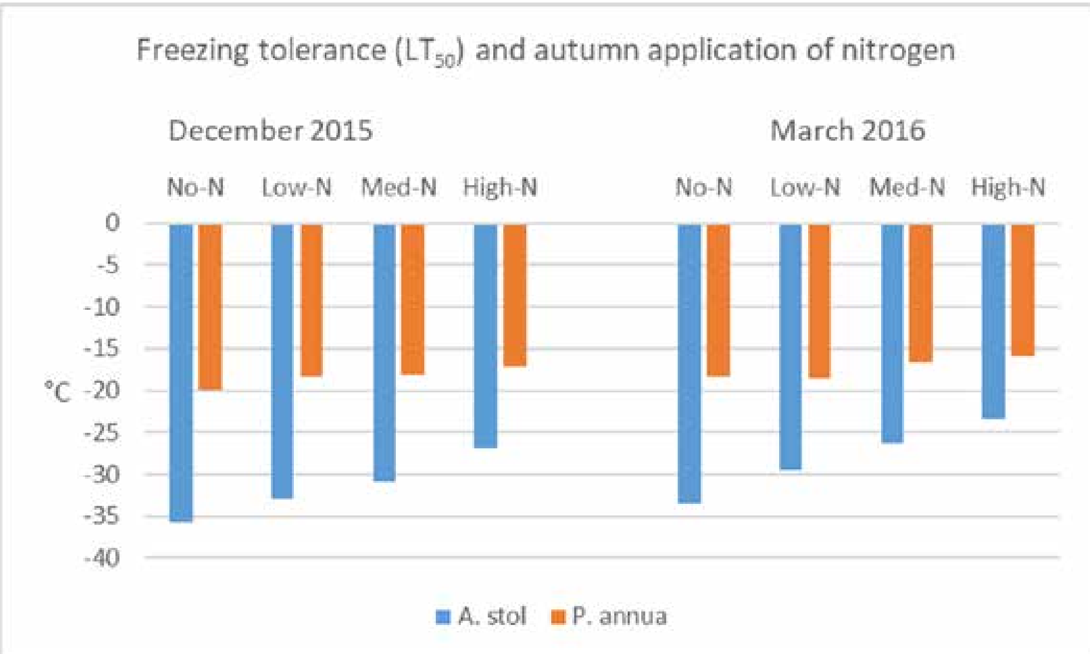

Figure A4. *Temperature (°C) that killed 50 % of the test plants (LT50). Creeping bentgrass and annual bluegrass were sampled from a golf green fertilized with four rates of nitrogen (0, 2.8, 5.5, 8.4 g/m2) in the autumn.*

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2017

Updated version 2025

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