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Turf grass winter survival

Book of abstracts from international seminar

11-12 November 2014

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Front page illustration:
Winter sampling at Apelsvoll. Photo: Wendy M. Waalen
Winter covers at Miklagard golf. Photo: Stefan Schön
Lab work at Landvik: Photo: Anne M. A. Steensohn

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Preface

Bioforsk Turfgrass Research Group, STERF and The Research Council of Norway would like to welcome you to the seminar "Turf grass winter survival" in Gjøvik on November 11-12th, 2014. This seminar presents results of vital interest for golf courses in the Nordic countries regarding turf grass winter survival. About 70% of golf courses in this part of Europe suffer from winter damages every year and that the associated average annual costs per golf course are €35 000-40 000 (STERF, 2014). An enquiry performed by the Norwegian Golf Federation in 2013 showed that golf course managers throughout Scandinavia consider 'Winter Stress Management' to be the most important thematic area for STERFs research and development.

One of the aims of this seminar is to build a network between golf course managers, turf grass researchers, consultants, agronomists and people from the turf grass industry who have interest in turf grass winter hardiness. This seminar also sums up the results from the research project 'Turfgrass winter survival in a changing climate' (2011-2014). The principal objective of this project was to reduce winter injury of grasses for golf courses, recreational areas and pastures through better understanding of dehardening reactions and appropriate management in a wetter and less stable winter climate. The project included experiments in the field and under controlled conditions which were carried out at Bioforsk's research facilities at Apelsvoll, Landvik and Særheim. The project did also include large-scale experiments with protective winter covers of golf greens at Oulu Golf Club (Finland), Timrå Golf Club (Sweden) and Miklagard Golf Course (Norway) during the three winters 2011-2014.

The project was funded by STERF and The Research Council of Norway (Project 208010). We thank The Research Council of Norway for additional support for this seminar (Project 241323). We sincerely thank the speakers for their presentations and for writing the abstracts to this Bioforsk Focus booklet. Thanks to the project reference group members for fruitful meetings and discussions.Thanks to staff at Bioforsk Særheim, Bioforsk Apelsvoll and Bioforsk Landvik for excellent technical assistance and to Elise Krey Pedersen for the practical organization of this seminar.

We hope you will enjoy the meeting and discussions on challenges, future perspectives and new collaborations in the field 'turfgrass winter survival'.

Tatsiana Espevig and Agnar Kvalbein

Program:

Tuesday, November 11th

11.00	STERF's Program on Winter Stress Management. Maria Strandberg, STERF, and Tatsiana Espevig, Bioforsk
11.20	Physiology of cold acclimation and deaccimation of cool-season grasses. Michelle DaCosta, University of Massachusetts
12.30	Lunch
13:30	Acclimation, deacclimation and reacclimation capacities in various turfgrass species used on golf greens. Mats Höglind and Tatsiana Espevig, Bioforsk
14:15	Scandinavian testing of turfgrass species and varieties for winter hardiness. Trygve S. Aamlid, Bioforsk
15:00	Coffee break
15:30	Carbohydrate changes in turfgrasses during winter. Tatsiana Espevig, Bioforsk.
16:00	Questions and discussion
19:00	Dinner at hotel

Wednesday, November 12th

08:00	Poor drainage and winter hardiness of grasses used on lawns/fairways. Agnar Kvalbein and Tatsiana Espevig, Bioforsk
08:30	Ice encasement of grasses: Preventative measures and injury repair. Bjarni Gudleifsson, Agricultural University of Iceland
09:15	Coffee break
09:45	Result from large scale demonstration trials with protective covers on golf greens. GC managers Juha Karsikko (Finland), Håkan Blusi (Sweden) and Stefan Schön (Norway)
10.30	Winter covering strategies for golf courses. Jim Ross, Olds College, Canada
11:15	Ice encasement and protective covers on golf greens. Wendy M. Waalen, Bioforsk.
11:45	Questions and final discussion
12:30	Lunch
13: 15	Visit to ongoing turfgrass trials at Bioforsk Apelsvoll
14:30	Bus departure for Oslo Airport Gardermoen, arrival 16:00.

STERF's Winter stress management programme

Maria Strandberg[1*] **and Tatsiana Espevig**[2*]

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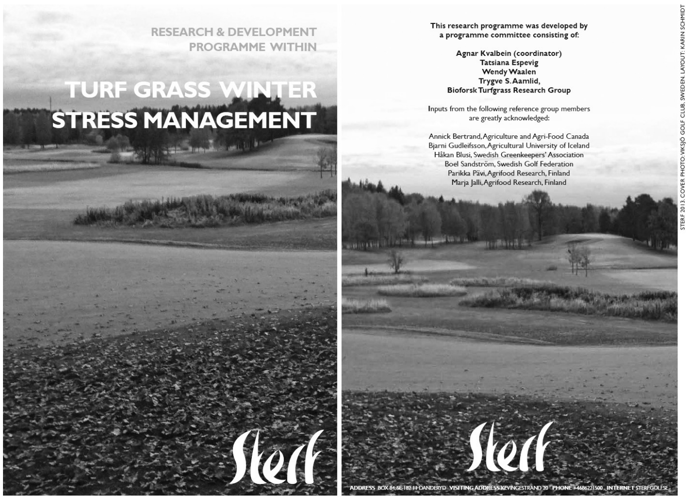
It is apparent that the golf and turf grass industry faces a number of local and international challenges, all of which will need concerted and collective solutions, underpinned by robust, applied science. To meet the challenges the sector has to face, the Scandinavian Turfgrass and Environment Research Foundation (STERF) has created four international and trans-disciplinary Research and development (R&D) programs, including:

- Sustainable water management
- Turf grass winter stress management
- Integrated pest management
- Multifunctional use of golf facilities

Progress in these programme areas will collectively lead to improvements in the quality of managed turf grass areas as well as economic and environmental gains for the industry. The key objectives of the programmes are to coordinate design and running of R&D activities, and to coordinate effective dissemination of the resulting new knowledge through channels and formats that are easily accessible to end-users. STERF will play a key role in expanding the programmes on an international level. All four STERF R&D-programmes can be found at: http://sterf.golf.se.

The programme within Turf grass winter stress management was published early 2014 and is a joint R&D programme between STERF and Canadian Turfgrass Research Foundation. Winter damage is the foremost reason for dead grass in the Nordic countries, reducing the aesthetic and functional value of turf. UN-IPCC climate scenarios predict that due to high precipitation and unstable temperature, ice and water damage will become the most important cause of winter damage in the future. The programme within winter stress management defines winter stress management as 'All actions taken to prepare the plant for the winter, avoid winter-related damage and re-establish high quality turf in the spring'. This is a complex but high priority area for STERF, as it has been estimated that about 70% of Nordic golf courses suffer from winter damage every year, and that the associated average annual costs per golf course are €35,000-40,000. The programme was created by a STERF appointed committee consisting of Agnar Kvalbein (leader), Tatsiana Espevig, Wendy Waalen and Trygve S. Aamlid from Bioforsk Turfgrass Research Group. To provide inputs and assure the scientific quality and practical relevance of the programme, the committee received assistance from an international reference group consisting of researchers, consultants and practitioners from Canada, Iceland, Sweden and Finland.



RESEARCH & DEVELOPMENT
PROGRAMME WITHIN

TURF GRASS WINTER
STRESS MANAGEMENT

This research programme was developed by
a programme committee consisting of:

Agnar Kvalbein (coordinator)
Tatsiana Espevig
Wendy Waalen
Trygve S. Aamlid,
Bioforsk Turfgrass Research Group

Inputs from the following reference group members
are greatly acknowledged:

Annick Bertrand, Agriculture and Agri-Food Canada
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Marja Jalli, Agrifood Research, Finland

STERF 2013. COVER PHOTO: VIKSJÖ GOLF CLUB, SWEDEN. LAYOUT: KARIN SCHMIDT

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Physiology of cold acclimation and deacclimation in cool-season turfgrasses

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ABSTRACT

Increases in soil and air soil temperatures during the overwintering period may trigger metabolic and physiological changes leading to cold deacclimation and loss of freezing tolerance in cool-season turfgrasses. Elevated temperatures followed by freezing events can result in increased sensitivity of grasses to direct low temperature kill, particularly for species such as annual bluegrass (*Poa annua* L) and perennial ryegrass (*Lolium perenne* L.). Additional research is necessary to understand the factors that trigger deacclimation in grasses and to identify plant traits that contribute to enhanced deacclimation resistance and freezing tolerance. The specific objectives of our research were to determine the effects of different above-freezing temperature and duration combinations that induce deacclimation of annual bluegrass (AB) and creeping bentgrass (CB), and to examine early physiological changes associated with deacclimation of these two species, with a focus on carbohydrate, protein, and hormone metabolism parameters. Additional studies were also undertaken to study deacclimation responses in perennial ryegrass (PR), with a focus on identifying genes that may be differentially expressed between genotypes of PR contrasting in freezing tolerance and deacclimation resistance.

In our initial studies, we compared one AB ecotype (previously shown to exhibit freezing sensitivity) and one CB cultivar (‘L-93’). Plants were exposed to a cold acclimation at 2°C followed by -2°C in controlled environment chambers. The grasses were then exposed to deacclimation treatments that consisted of warming the chambers until the soil temperatures reached 4°C, 8°C, or 12°C for up to 5 days at each temperature. In all the experiments, we found that annual bluegrass never achieved the same level of freezing tolerance as creeping bentgrass in response to cold acclimation, determined as the lethal temperature at which 50% of plants were killed (LT50). Along with a lower cold acclimation capacity, AB exhibited a 2.5-fold greater loss in freezing tolerance in response to exposure at 4 °C. Conversely, at later stages of deacclimation and greater warming, CB also exhibited significant deacclimation and loss in freezing tolerance. Therefore, although both AB and CB exhibited deacclimation in response to above freezing temperatures, the threshold temperature required to induce greater losses in freezing tolerance was lower for AB compared to CB.

In subsequent experiments, we monitored changes in carbohydrate metabolism in response to exposure to simulated mid-winter warming events. We found AB leaves were greener and had higher water content compared to CB when exposed to deacclimating temperatures. In addition, photosynthesis and respiration rates increased very rapidly during deacclimation for AB, suggesting that metabolic and physiological activities of AB were activated earlier in response to warmer temperatures compared to CB. We next compared creeping bentgrass (‘L-93’) to one freezing-tolerant AB ecotype (AB-T) and one freezing-sensitive AB ecotype (AB-S). Following cold acclimation, plants were exposed to 8°C for 0.5, 1, 3, and 5 d to induce deacclimation. At each duration of deacclimation, plants were assessed for their freezing

tolerance (LT50), concentrations of soluble sugars and amino acids, and changes in dehydrin-like proteins in overwintering crowns. Fully acclimated CB achieved a higher freezing tolerance (LT50 of -21.5°C) compared to AB-T (-19.8°C), followed by AB-S (-15.3°C). Total soluble sugars, mainly high molecular weight (HMW) fructans, increased during cold acclimation for all plants, with higher levels accumulated in CB. Dehydrin-like proteins were present in each species, but were cold-inducible and associated with freezing tolerance changes only in CB. In response to deacclimation, CB maintained higher freezing tolerance compared to both AB ecotypes, which was associated with the maintenance of higher concentrations of total soluble sugars, and in particular the HMW fructans. Lastly, our most recent studies have also helped us to identify differences in the signaling of plant hormones during cold acclimation and deacclimation, such as auxins and abscisic acid, which are further being investigated within our research group.

Dehardening resistance and rehardening capacities of six turfgrasses used on golf greens

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Dehardening is claimed as one of the reasons of poor survival when low freezing temperatures follow warm spells during winter and early spring. Dehardening can be completely reversible, partly reversible or completely irreversible depending on the temperature and duration of the dehardening period (Pomeroy et. al, 1975; Gusta and Fowler, 1976a and 1976b; Rapaz, 2002). Only few studies have been conducting on dehardening of cool season turfgrasses in the field (Hoffman et al., 2014a and 2014b) or under controlled environmental conditions (Tompkins et al., 2000) and these studies seem to be limited to creeping bentgrass and annual bluegrass and except for Tompkins et al. (2000) we are not aware of there is no literature on rehardening capacities of turfgrasses.

This study was conducted to determine hardening ability of six turfgrass species/ subspecies in late autumn/early winter and to compare their dehardening resistance and rehardening capacity. Plants were collected from an experimental green at Bioforsk Landvik (south coast of Norway, 58º N, 97 latitude, 12 m above sea level) in late November 2011 and 2012 and subjected to six or twelve days of dehardening at 10 ˚C in a growth chamber. An additional rehardening treatment at 2 ˚C for 23 days after 12-d dehardening at 10 ˚C was included in 2012. Freezing tolerance (lethal temperature for 50 % plants, LT50) was determined after hardening, two dehardening and rehardening treatments.

The ranking order for lethal temperature for 50 % plants (LT50) in late November was as follows: annual bluegrass (*Poa annua* L.) (−13 to −14 ˚C) < colonial bentgrass (*Agrostis capillaris* L.) (−18 to −20 ˚C) ≤ slender creeping red fescue (*Festuca rubra trichophylla* L.) (−19 ˚C) ≤ chewings fescue (*Festuca rubra commutate* L.) (−21 ˚C) < velvet bentgrass (*Agrostis canina* L.) (−23 to −27 ˚C) ≤ creeping bentgrass (*Agrostis stolonifera* L.) (<−30 ˚C). The main dehardening occurred during the first 6 days at 10 ˚C and dehardening rates (absolute ºC) increased in the order: slender creeping red fescue < chewings fescue < colonial bentgrass < annual bluegrass < creeping bentgrass. Creeping bent dehardened more than the other species, but creeping bent was still the most frost tolerant species after 12 days of dehardening at 10˚C. Velvet bentgrass was also relatively frost hardy, and seem to be relatively resistant to dehardening in spite of the fact that the dehardening rate of velvet bentgrass was inconsistent in the two experimental years.

In spite of the greater absolute dehardening (absolute loss in freezing tolerance, º C) in creeping bentgrass than in annual bentgrass, the relative loss in freezing tolerance in creeping bentgrass was lower than in annual bluegrass. If freezing tolerance of nonhardened creeping bentgrass and annual bluegrass is assumed to be -9.3 ˚C and -8.3 ˚C, respectively (Hoffmann et al., 2014), the hardening capacity of creeping bentgrass was more than 20 ˚C vs. 5 ˚C of annual bluegrass. Thus, the loss of freezing tolerance relative to hardening capacity of creeping bentgrass in our study would amount to 27 % and 38 % in 2011 and 2012, respectively, vs. more than 100 % in annual bluegrass. Thus, the consequences of dehardening for turfgrass winter survival will usually be more critical in annual bluegrass than in creeping bentgrass. Of particular importance is that creeping bentgrass seems to be more resistant than annual bluegrass to dehardening at temperatures as low as 4 °C (Hoffman et al., 2014b). Future studies on dehardening should include measurements of freezing tolerance of non-hardened plants to be able to determine the relative loss of their hardiness.

In perennial grass species there is often a positive correlation between early growth cessation in autumn and winter hardiness including freezing tolerance, although this relationship is not always strict (Brummer et al, 2000). In this study, the leaf growth (mm) of creeping bentgrass, chewings fescue, slender creeping red fescue, colonial bentgrass, and annual bluegrass under hardening in the fall (as of November) 2012 was reduced approximately 59, 42, 26, 27 and 4 times, respectively, compared to their normal growth rate in summer (Aamlid and Molteberg 2011; Aamlid et al., 2012). This can be compared with the freezing tolerance that these species achieved namely -31 °C, -21 °C, -19 °C, -20 °C, and -14 °C, respectively. These findings indicate a positive correlation (r=0.95) between degree of growth reduction in fall and freezing tolerance also for the turfgrass species in this study. Conversely, among species the ability to initiate leaf growth during mild periods seems to be negatively correlated with the species' resistance to dehardening.

All species except annual bluegrass rehardened to some extent at 2°C, but never back to its LT50 level before dehardening. Low overall freezing resistance and less capacity to reharden in annual bluegrass than in the other species was associated with more leaf growth during both hardening and dehardening.

The research was funded by Scandinavian Turfgrass and Environment Research Foundation (STERF) and The Research Council of Norway. Thanks to Trond O. Petterson and Anne M.A. Steensohn from Bioforsk Landvik, Henk Maessen, Geovan Leeuwen, Anne Kvitvær, Isak Drozdik, and Geir Tore Tengesdal from Bioforsk Særheim, and Geir Egil Paulsen from Norsk Landbruksrådgivning Rogaland for excellent technical assistance. Thanks to Grimstad Planter AS for providing of cold store at −2 °C. Thanks to Torfinn Torp (Bioforsk) for advice and helpful discussions on statistical data processing. Thanks to Wendy M. Waalen (Bioforsk) for discussions on physiology of hardening and freezing tolerance.

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Scandinavian testing of turfgrass species and varieties for winter hardiness

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Testing of turfgrass varieties for national listing in the Nordic countries started in the 1960s and increased in importance as European and American breeders brought many new varieties to the market in the 1970s and 1980s. However, between 1995 and 2005, the public funding of this activity was mostly withdrawn as the EU no longer required any testing of the 'Value for Cultivation and Use' (VCU), but only of 'Distinctness, Uniformity and Stability' (DUS) for inclusion on the European list. In Norway, the last turfgrass variety trials with public funding were finished in 2006.

National testing of turfgrass varieties is now largely replaced by SCANTURF, a joint Nordic program for variety testing in short-cut lawn (15-20 mm mowing height) and on football pitches exposed to wear. This program is entirely funded by the plant breeders through entrance fees. SCANGREEN, a corresponding program for variety testing on golf greens mowed at 3-5 mm, was funded by the Scandinavian Turfgrass and Environment Research Foundation (STERF) in 2003 and new trials started in 2007 and 2011. From 2010 the two programs have been coordinated by the Bioforsk Turfgrass Research Group, with new trials starting every second and fourth year, respectively. In both programs the trial period is four years and variety ranking are updated every year at www.scanturf.org. SCANGREEN ranking lists are published separately for a northern and a southern zone due to different requirements to winter hardiness (Fig. 1).

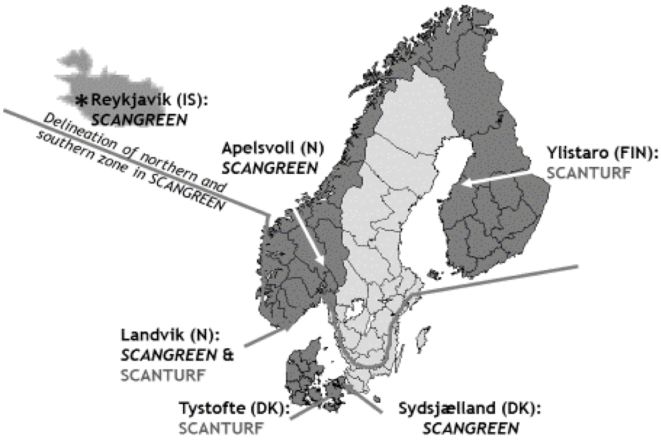

Figure 1. Experimental sites in SCANTURF and SCANGREEN variety testing as of 2014.

Assessment of winter hardiness

Winter damage is a central character in SCANTURF and SCANGREEN, as it was in the former national testing programs. In most trials during the past 30 years, winter damage was assessed as the per cent of plot area with dead turf in spring without specifying the type of damage, but nowadays, species and varieties are also ranked for resistance to *Microdochium nivale* or *Typhula incarnata*. In the ranking list presented at www.scanturf.org, winter kill as per cent of plot area has been converted to winter hardiness on a scale from 1-9, where 9 are the most winter-hardy varieties.

Ranking of species for winter hardiness in the Nordic countries compared with North America ?

Winter hardiness is a complex character. Besides resistance to the winter-active fungi, it includes tolerance to abiotic factors such as level and duration of freezing temperatures, darkness (carbohydrate depletion), ice encasement (suffocation), high soil water tables and submersion (crown hydration), soil upheaval (root abruption), dry winds over frozen soil (desiccation) and the combination of high light intensity and low temperature in spring (photoinhibition). STERF's Grass Guide' (Kvalbein & Aamlid 2012) presents the following ranking of the most common turfgrass species for overall tolerance to the combined impact of these hazards:

Poa pratensis > Agrostis canina = Festuca rubra ssp. commutata > Agrostis stolonifera > Agrostis capillaris > F. rubra ssp. litoralis > F. rubra ssp. rubra > Lolium perenne > Poa trivialis > Poa annua
This ranking is quite different, and for the red fescues more elaborate, than the corresponding North-American ranking for 'Cold tolerance' (Turgeon 2005): Agrostis stolonifera > Poa trivialis > Poa pratensis > Agrostis capillaris > Festuca rubra > Festuca arundinacea > Lolium perenne.

The main reason for the discrepancy between these ranking lists is that the former includes not only to low freezing temperature, but the whole winter complex. Another important reason is that the Nordic VCU trials, unlike most NTEP trials in North America, are not sprayed with fungicides.

Genetic progress in winter hardiness in major turfgrass species

From 1986 to 2007, 56 new varieties of *Festuca rubra* ssp. *commutata*, 20 of *F.rubra* ssp. *litoralis*, 28 of *F.rubra* ssp. *rubra*, 58 *of Poa pratensis* and 42 of *Lolium perenne* were entered into the Norwegian and SCANTURF programs. Throughout this period, 'Center' and 'Conni' were the reference varieties when testing *Festuca rubra* (all subspecies) and *Poa pratensis*, respectively. The same continuity in use of only one reference variety did not exist in *Lolium perenne*, but repeated use and overlaps between 'Barclay', 'Mondial' and 'Ronja' created a secure reference level even in this species. A simple way to estimate the long-term genetic gain was then to express variety performance relative to the reference and to relate these relative figures to the year of entry into the program using linear regression.

These calculations showed that the strongest reduction in winter damage over the 20 year period was obtained in *F. rubra* ssp. *litoralis* (correlation with year: r= – 0.74***), followed by *F. rubra* ssp. *commutata* (r=-0.58***), F. rubra ssp. rubra (r=-0.44**), *Lolium perenne* (r=-0.32*) and *Poa pratensis* (r=-0.05ns) (Aamlid & Gensollen 2014).

Stronger reductions in winter damge of ssp. *litoralis* than in the other subspecies of red fescue are in agreement with similar calculations for resistance to *M.nivale* in the French variety testing program (Aamlid & Gensollen 2014). Scandinavian seed mixtures of red fescue have often included only a minor portion of ssp. *litoralis* due to limited winter hardiness, but this may well change in the future as Danish trials have shown ssp. *litoralis* to be more competitive to *Poa annua* and have better recuperative capacity than ssp. *commutata*.

No reduction in the winter damage of *Poa pratensis* over the last decade is not surprising as winter hardiness is never a limiting factor for the use of this species. In contrast, the relatively slow and unsecure progress in *Lolium perenne* is more of a concern as the use of this species could be widely extended with more winter-hardy varieties coming to the market. During the same period, the correlations between relative tiller density and year of entry was as high as r=0.68***, and between turfgrass height growth and year of entry r=-0.58***, which reflects that other characters than winter hardiness had higher priorities or were easier to breed for. In the ongoing SCANTURF trials started 2011 and 2013, there are, however, indications that the new tetraploid turf ryegrasses are more winter hardy than the traditional diploid types.

Future varieties with superior winter hardiness on greens ?

SCANGREEN has identified a few Norwegian varieties of *Agrostis* and *Festuca* with superior winter hardiness. Most noteworthy is 'Nordlys', a Norwegian bentgrass cultivar, which was in a class of its own at the northern test site Apelsvoll. 'Nordlys' was originally registered as *A. stolonifera*, but the test plots also showed characteristics resembling *A. canina* and *A. capillaris*. The variety owner has therefore produced new prebasic seed and ordered a new DUS test to ascertain the identity of the variety.

The SCANGREEN trial at Apelsvoll from 2007 to 2010 included some additional test plot with entries of *F. rubra* ssp. *commutata* from a Norwegian breeding program that was discontinued ten year ago. Most of these lines show better winter survival than varieties of more southern origin, and the three best ones were therefore included in the still ongoing trials. As of 1 March 2014, 'LøRc 0008' had higher scores for winter hardiness than any other variety *F. rubra* in the northern test zone, and its overall appearance was also better than of the control variety 'Musica'. Provided approval in the DUS test and successful seed production, 'LøRc 0008' the may therefore contribute to more winter-hardy greens with red fescue in northern parts of Scandinavia in the future.

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Carbohydrate changes in turfgrasses during winter in Norway

Tatsiana Espevig[1]*, Wendy M. Waalen[1], Bruno Printz[2], Jean-Francois Hausman[2] and Trygve S. Aamlid[1]

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Lower temperatures and shorter day length in fall trigger changes in the net carbon metabolism in plants. The level of sucrose in herbaceous plants increases as the reduction in plant growth is stronger than the reduction in photosynthesis, and this results in the accumulation of fructans which are the main storage carbohydrates in cool season grasses. The role of non-structural carbohydrates in the freezing tolerance of winter cereals and forage grasses has been extensively evaluated (Tumanov, 1940; Levitt, 1980; Livingston, 1991, 1996). Sucrose and even fructans have been reported as important cryoprotectants (Anchordoguy et al., 1987). The fructans are depleted as they provide a source for respiration during winter and early spring in the absence of photosynthesis. However, compared with the number of investigations in winter cereals and forage grasses, research on carbohydrate changes during winter is very limited in the cool-season turfgrasses (Espevig, 2011; Blombäck et al., 2012). Here we present preliminary results from two studies that were conducted to quantify the carbohydrate content of (1) six turfgrasses on golf greens and (2) four turfgrasses on fairways with low and high water table. Both studies were conducted during the winter under natural weather conditions.

The first experiment was conducted on a newly established USGA-green with colonial bentgrass (*Agrostis capillaris*) 'Jorvik', velvet bentgrass (*A.canina*) 'Villa', creeping bentgrass (*A. stolonifera*) 'Independence', Chewings fescue (*Festuca rubra* ssp. *commutata*) 'Musica', slender creeping red fescue (*F. rubra* ssp. *litoralis*) 'Cezanne' and annual bluegrass (*Poa annua*) at Bioforsk Apelsvoll (61˚N, 250 m a.s.l., continental climate) during the mild winter 2011-12 with 98 days of snow cover and periods of ice encasement, and the normal winter 2012-13 with 141 days of stable snow cover and no ice. Grass samples were collected in November, January and February each winter with the last sampling in March 2012 and April 2013. For more details regarding turf maintenance see abstract of Waalen et al. in this booklet.

The second experiment was conducted on a newly established fairway with perennial ryegrass (*Lolium perenne*) 'Bargold', Kentucky bluegrass (*Poa pratensis)* 'Limousine', strong creeping red fescue (*Festuca rubra* ssp. *rubra)* 'Frigg' and Chewings fescue (*Festuca rubra* ssp. *commutata)* 'Musica' in the field lysimeter facility at Bioforsk Landvik (58° N, 12 m a.s.l., coastal location) during the winters 2011-12 and 2012-13. The soil type was sandy loam. A water table at 0-5 cm from soil surface was maintained by impeding drainage on 50 % of the plots from October 26th to December 12th in 2011 and from October 12th throughout the winter in 2012-13; remaining plots had free drainage. Grass samples were collected on December 12th, January 30th and March 19th during the winter 2011-12, and on December 7th, January 25th and April 5th during the winter 2012-13. For more details regarding turf maintenance see abstract of Espevig, Kvalbein & Aamlid in this booklet.

After thawing for two days at 4 ˚C in the dark, the samples were oven dried for two days at 60 ˚C and stored at room temperature prior to crown separation. The dry crowns (ca. 25 mg) were ground manually using a brass mortar and pestle. Simple sugars and low degree of polymerization (DP) fructans were extracted with 80 % ethanol. Fructans of higher DP were extracted from the initial insoluble residue with boiling water and then hydrolysed using sulphuric acid. The simple sugars from the first and the second extractions were analysed in the Gabriel Lippmann Centre, Luxembourg, using High Performance Anion Exchange Chromatography coupled with Pulsed Amperometric Detection. The data were expressed in µmol per 1 g DW and analysed separately for each winter using the SAS procedure MIXED for a split-plot design in the first experiment (species as whole-plot factor and sampling as sub-plot factor) and for a split-split-plot design in the second experiment (drainage as whole-plot factor, species as sub-plot factor and sampling as sub-sub-plot factor). Both experiments had four blocks that were considered a random effect.

Results, experiment 1. The highest fructan content was found in creeping bentgrass followed by velvet bentgrass, Chewings fescue, colonial bentgrass and slender creeping red fescue. Annual bluegrass had the lowest fructan content in 2011-12 but the highest content in 2012-13. This fact remains unexplained. During the winter 2011-12 the main loss of fructose (55% of initial content), glucose (52%) and fructans (34%) occurred in December-January; the further loss by March 2012 was only 2%, 8% and 19% of the initial content, respectively. During winter 2012-13, the initial loss of fructose, glucose and fructans in December-January amounted to 33%, 33% and 24%, respectively, followed by a further loss of 37%, 42% and 36% by April 2013, respectively. Sucrose was kept at the same level through the whole winter 2011-12 by all species except annual bluegrass. During winter 2012-13, sucrose was gradually lost by all species. The interactions SPECIES*SAMPLING were not significant except for fructose in both years.

Results, experiment 2. Significant interactions SPECIES*SAMPLING revealed that in December both years the initial concentration of fructose and glucose was higher in perennial ryegrass than in other species. Perennial ryegrass had also the highest concentration of fructans in December 2011. In December 2012, the differences in fructan content were not significant among the species. During the winter 2011-12, the highest depletion of fructans (17-29 %) happened from December to January. From January to March 2012, the fructans were kept at the same level in all species. In contrast, ice encasement during the winter 2012-13 resulted in gradual depletion of fructans from December to April. From December 2012 to January 2013, the ranking order for fructan depletion was as follows: strong creeping red fescue (20 % of initial) < perennial ryegrass (22 %, was almost dead in January) < Chewings fescue (32 %) < Kentucky bluegrass (39 %). The further fructan depletion from January to April was as follows: perennial ryegrass (25 %, was completely dead in April) < Chewings fescue (30 %) < Kentucky bluegrass (43 %) < strong creeping red fescue (45 %). Impeded drainage did not influenced accumulation or depletion of fructans in any species.

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Effect of impeded drainage on winter hardiness of four turf grasses used on lawns/ fairways

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Apart from temperature, dehardening of turfgrasses is believed to be related to winter rainfall causing hydration of turfgrass crowns (Roberts 1995). Crown hydration is caused by slush, rain or flooding, often connected to unfavorable soil texture, compaction, organic matter accumulation in the top layer, or frozen layers in the soil profile. Under such conditions, freezing temperatures after mild and wet periods will result in intercellular ice formation eventually leading to membrane dysfunction and plant collapse (Brule-Babel and Fowler 1989). Soil physical properties have also been shown to have large impact on winter damage and growth of perennial forage grasses in Northern Norway (Sveistrup & Haraldsen 1997, Volden et al. 2002). Our hypothesis was that even a moderate (e.g. 5 percentage point) increase in the water content of crown tissues will result in dehardening and trigger metabolic activity regardless of species investigated in this project. Thus, the objective of the study was to monitor cold hardiness levels and crown moisture from December to April of four turfgrasses grown on a fairway with low and high water table maintained during fall and winter and relate this to soil and air temperature.

The experiment was conducted in the field lysimeter facility at Bioforsk Landvik (south coast of Norway, 58° N latitude, 12 m above sea level) during the winters 2011-12 and 2012-13. The facility included 16 stainless steel lysimeters filled with sandy soil, each with a surface area of 1m x 2m and 40-cm depth. The experiment was designed as split-split-plot (SSPD) (the 3 factors were drainage as whole-plot factor, species as sub-plot factor and sampling as sub-sub-plot factor) with 4 blocks. Perennial ryegrass (*Lolium perenne*) ‘Bargold’, Kentucky bluegrass (*Poa pratensis)* ‘Limousine’, strong creeping red fescue (*Festuca rubra* ssp. *rubra)* ‘Frigg’ and Chewings fescue (*Festuca rubra* ssp. c*ommutata)* ‘Musica’ were seeded on July 6th and 7th 2010. The grasses were maintained at 15 mm mowing height from May to November and received annually 1.2 kg N, 0.1 kg P and 0.8-0.9 kg K per 100 m2. The poor drainage (water table up to 0-5 cm from soil surface) was maintained from October 26th to December 12th in 2011 and from October 12th throughout the winter in 2012-13. Grass samples were collected on December 12th, January 30th and March 19th during the winter 2011-12, and on December 7th, January 25th and April 5th during the winter 2012-13. The samples were and tested for freezing tolerance using short-tern freezing tests (lethal temperature for 50 % plants, LT50) and analysed for crown moisture. After the first sampling in December both years the grasses were also exposed to a long-term freezing test to define the lethal duration of -7 to -8 ºC for 50 % of plants (LD50). The data were analysed individually for each winter using the SAS procedure MIXED for a SSPD with random block effect. LT50s were calculated by PROBIT analysis using the logistic distribution in SAS. In addition to weather data received from the local weather station (air temperature and precipitation, http://lmt.bioforsk.no/), we monitored soil temperature at 1-cm, 5-cm and 10-cm depth throughout both winters.

In early December 2011, the freezing tolerance (acclimation ability) of the turfgrasses was as follows: strong creeping red fescue (<-30˚C) > Kentucky bluegrass (-25˚C) > chewings fescue (-19˚C) > perennial ryegrass (-16˚C). As of January 2012, the freezing tolerance was improved by 1-4 ºC and achieved its maximum (lowest LT50) in all grass species. The loss of freezing tolerance from January to March varied significantly among the species. As of March 2012, the freezing tolerance of the grasses was between -13 ºC and -15 ºC. Thus, the most frost hardy species had higher loss of freezing tolerance than frost sensitive species, and the ranking order for the loss of freezing tolerance was the same with acclimation ability of the grasses to frost.

In early December 2012, the ranking order for freezing tolerance and acclimation ability of the turfgrasses was similar as in 2011: strong creeping red fescue (-36˚C) > Kentucky bluegrass (-25˚C) = Chewings fescue (-25˚C) > perennial ryegrass (-18˚C); but almost all species were hardened better in 2012 than in 2011. This was associated with a colder fall in 2012 compared with 2011. It appears that a higher total precipitation in October and November 2012 (457 mm) than in 2011 (128 mm) did not influence acclimation ability of the grasses. This was most likely due to the average photosynthetic photon flux density for the light hours in September, October and November remained similar in both years. In contrast to the first winter, perennial ryegrass, strong creeping red fescue, chewings fescue and Kentucky bluegrass lost their parts of their freezing tolerance from December 7th 2012 to January 28th 2013 and this loss amounted to 16, 7, 3 and 1 °C for the four species, respectively. This dramatic loss of freezing tolerance happened most likely due to one-month of ice encasement (IE) starting prior to Christmas 2012. Then IE conditions lasted until April 5th (more than 100 days) and together with low soil temperatures throughout the winter (down to -5°C at the 1-5-cm depth and down to -4°C at the 10-cm depth under ice/snow from December to March) and exposure to severe night frost after induced ice/snow melting prior to the last sampling on April 5th 2013, it resulted in poor survival of the grasses. In April 2013, LT50s were defined only for strong creeping red fescue (-7 °C) and Chewings fescue (-10 °C).

As determined in December 2011, LT50s were highly correlated with LD50s. In the second fall the grasses were acclimated better and LD50s in December 2012 were not defined as the longest duration was not long enough to kill 50% of the plants. So we have to find another way to express the results, probably a parameter NOED (no observed effect duration) can be used.

Impeded drainage during the acclimation period from October to December 2011 did not significantly affect either crown moisture content or freezing tolerance (LT50s). During winter 2012-13, poor drainage again did not affect the crown moisture content of the grasses, but a negative effect of impeded drainage on freezing tolerance was found in perennial ryegrass, Chewings fescue and strong creeping red fescue in January and in Chewings fescue in April. Moreover, as registered in the field on June 5th 2013, winter survival was negatively affected by poor drainage in Chewings fescue and Kentucky bluegrass. Thus, the live coverage of the grasses in the early summer 2013 was as follows: Chewings fescue (83 % drain vs. 23 % no drain), strong creeping red fescue (28 % drain vs. 35 % no drain), Kentucky bluegrass (44% drain vs. 10% no drain) and no survival in perennial ryegrass.

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Ice encasement damage of grasses: Preventive measures and injury repair

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Agriculture and sport have common interst in reducing winter damage of perennial grasses. Here we will present results of studies on ice encasement damage of grasses in Iceland, presuming that results from agricuiltural fields are at least partly applicable to sports fields. The hayfields in Iceland are mainly permanent fields, dominated by timothy (*Phleum pratense*) and Meadowgrass (*Poa pratensis*) and perhaps Tufted hairgrass (*Deschampsia caespitosa*) and annual bluegrass (*Poa annua*). Perennial plants prepair for winter by hardening which results in increased winter tolerance of the plants. If the winter stress exceeds the tolerance of plants they are injuried or killed. The winter stresses are of different causes; frost heave, drought, freezing, starvation, flooding, ice encasement, snow mould, or damage from ice nucleating bacteria. The type of injury depends on plant tolerance and physical environment such as climate, soil and topography. Our task has been (1) to explain what **kind of damage** is dominating in Icelandic hayfields, and (2) to explain what actually happens, i. e. **how plants are killed**, and (3) what can be done to **reduce** these damages, and (4) how to **repair** damaged fields.

(1) Ice encasement damage

It has been estimated that 90% of winter damage in Icelandic hayfields can be ascribed to ice encasement, only 5% to freezing and the rest to fungy, drought and frost heave. Unfortunately, research on winter survival has mainly focused on freezing and studies of ice encasement damage has been neglected. The main reason for the dominance of ice encasement damage in hayfields in Iceland is the unstable and changeable weather conditions. The damage is correlated to the duration of ice cover, the longer the ice cover lasts the more severe is the injury. The topography is crucial for the stress intensity and sloping areas often escape from ice formation as the melt water runs off the fields whereas the water accumulates in flat areas giving rise to ice. The microtophography can be very important as ice will form in small depressions prolonging the duration of ice cover resulting in ice damage, whereas only few centimetres higher areas will escape the ice and plant injury. The predicted climate change, with increased winter temperatures, will in the future decrease or perhaps eliminate the ice encasement damage in these agricultural areas and other types of stress, such as freezing or fungy might become a greater problem.

Our studies started by surveying the damages in N-Iceland. These sampling studies indicated the dominanse of ice encasement damage, and the importance of topography, soil and plant material. We started with field tests where plants were exposed to ice cover in the field. This method turned out to be unsufficient as intensive thaw periods destroyed the experimet in spite of efforts to protect the ice cover with styrofoam. Then we turned to laboratory experiments in specially equipped freezers where we could control the temperature and duration of ice cover. We measured the ice tolerance of different plant species and impact of many variables such as plant age, soil type, fertilization and cutting. As a general rule in agriculture the winter cereals in Iceland tolerate ice for 1-2 weeks, legumes 3-4 weeks and grasses 8-12 weeks. This all depends on plant species and plant condition. The most tolerant perennial grass species is Thufted hairgrass, Timothy is moderately tolerand and Perennial ryegrass is least ice tolerant. In a laboratory experiment these three spesies tolerated 53, 34 and 26 days respectively.

(2) Cell death

During ice encasement plants respirate using carbohydrates as a source. The respiration is slow as the soil and grass temperature is low, fluctuating around 0°C. As the plants are more or less encased in ice they run out of oxygen and turn to anaerobic respiration producing compounds such as CO_2 , ethanol, lactic acid, formic acid and butyric acid. The content of carbohydrates in ice encased plants decrease solwly as a result of respiration. Simultanously an increasing accumulation of respiration products is detected. The plants, encased in compact ice, can not get rid of these metabolites which may then accumulate to toxic concentrations and subsequently kill the plant cells. Where metabolites protrude through cracks in the ice dark or brown spots may appear on ice cover during ice melt in late winter or spring and a strong odour of these metabolites can be detected. Another cause of cell death might be production of reactive oxygen species (ROS) when plants return to air after long-lasting ice cover.

(3) Preventive measures

In agriculture it is very important to have good slopes on the fields so the melt water can flow away in thaw periods, and farmers try to eliminate depressions in the topography. Because of compact and water saturated soil plants in peat soil are less tolerant than plants in mineral soil. Peats are, because of flat topography, also prone to greater stress than plants in other soil types. It is important to use winter tolerant plant species/cultivars and to increase the tolerance by correct plant treatment during summer and fall. Cutting frequency and fertilisation have great impact on plant tolerance. Frequent cutting, expecially in fall, decrease the tolerance. Unballanced fertilization with high N-content and low P- and K- concentration reduces tolerance as well as low pH does. As the duration of ice cover is crucial, the farmers or sport fields managers might reduce the damage by braking the ice cover in time mechanically with suitable equipment.

(4) Injury repair

When farmers have to respond to extensive ice encasement damage of the fields they either (1) **recultivate** the field by plowing, (2) **sow** new plant material into the sod, or (3) leave the field **unrepaired** and surviving plants or weeds will cover the field in the future. Recultivation is most expensive and one year of yield is lost. Also if the field is left without any repair the yield in the future is mostly composed of weeds and less valuable plant species. In some fields where plants have been sown into the sod with direct drilling, the growth of seedlings has been sucessful in young fields, but failed in old fields dominated by annual bluegrass. It has been postulated that, (A) the metabolites produced by anaerobic respiration under the ice accumulate in the soil surface as **phytotoxins** depressing the germination and growth of the sown seedlings, or (B) annual bluegrass produces chemical compounds generating **allelopatic** impact depressing growth of other plant species. Both these theories indicate that old and badly killed annual bluegrass fields are best repaired by recultivating, but young fields by direct drilling.

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Demonstration trials with protective covers on golf greens

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Full scale experiments were conducted three winters from 2011 to 2014 on three golf courses in severe and variable Nordic winter climates.
One green on each course was divided into four and each part covered with different material in the late autumn.

A. Uncovered (control)
B. Plastic (different quality on each course)
C. Semipermeable tarp (VPM membrane from Palmive Tech Textiles Ltd, Nottingham)
D. 1 cm air space made by a mat of crushed metal strings (Enkamat ®) + plastic as B

The covers were carefully sealed around the edge of each plot to prevent water intrusion. The covers were laid when the soil was about to freeze, before permanent snow, and, if possible, when the greens were relatively dry.

In the spring the turf cover (%), disease (%), colour (1-9) and overall impression (1-9) was recorded 3 times from snow melt with about two weeks intervals.

Oulu golf course

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As far as golf course management is concerned, winters can be very problematic in the Oulu region. In worst case the course may have ice cover from late November until end of April. But fortunately we had one so called normal good winter, with plenty of snow, during the experiment period.

The tests were done at one of our practise greens. It is ca 450 m2 and the sward is a mixture of velvet bentgrass (Vesper, Legendary, Avalon), slender creeping red fescue (Sealink) and remains of creeping annual bluegrass (DW-184 True Putt). The three covers covered about a half of the putting area.

The covering dates were 28.11.11, 29.10.12 and 25.11.13. We removed the covers 4.5.12, 23.4.13 and 16.4.14. The ground was frozen on date of covering. On 2012 and 2013 a light snow cover had to be removed first. Fungicides were sprayed the same time as the rest of the 38 greens due to practical reasons, approximately one week or two before covering. Removals were done right after snow melt.

2011-2012: Ice on greens from late Nov to Apr. Snow removed and ice spiked in February on the control area. Grass survival under covers 60-70%, control area 40-50%. Colour value (scale of 1-10): covered 7, control 5. No difference in survival and appearance between treatment C and D. In the middle of May there was an even colour on the whole green. Green on play 8.6.2012.

2012-2013: Snow cover from the end of Nov to late Apr. Practically no ice on the course and it was as much to a perfect winter as it can be. Grass survival under covers was approx. 80%, on control 50%. More significant difference in appearance. Colour value 8 on the covered area and 2 on the control. Again no differences between the different cover materials. This time it took approximately two weeks more for the control area to catch up with the covered areas in appearance and turf cover. Green on play 20.5.2013.

2013-2014: Ice cover on the whole course from middle Dec to end of March. We broke the ice on the greens in February, (except for the experiment green). About half of the 39 greens were either severely damaged or totally dead. On the test green the control area was dead, whereas the covered area more or less survived. There was however some water damage under the covers where water had leaked in. Not taking account of the water damaged area, the grass survival under the covers was 75%. About 10% difference in favour of treatment C, the permeable tarp. This was a very cold spring, and the control area did not recover from winter damage until early June. Green on play 10.6.2014.

Conclusion: Based on these tests during three winters it would be quite safe to conclude that there are benefits from using winter covers on the greens. Under these circumstances the grass survived better every year under cover than on the control area. There was no obvious difference between the two kinds of covers, Enkamat ®+plastic and semipermeable tarp on grass survival and appearance. In terms of labour Enkamat ® would probably be easier to use, and thus more efficient.

Timrå golf course

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Timrå Golfklubb is located at latitude 63, on the east coast of Sweden, 380 km north of Stockholm.
The club was founded 1985 as a seaside course with 18 holes.

Winter is usually between midst of November until midst of April. There is often ice on the turf for long lasting periods.
The green that was used for the experiment covers 500 m2. The grass species was mix of velvet bentgrass/ fine fescue / Poa annua.

Results: During the years 2011-2014, when the trail was conducted, the winters were very different. Lots of snow or almost no snow. Lots of ice - no ice. We learned that there was a bit more fungi under the covers. If there was snow on frozen ground and lots of snow (no ice), the grass survived (control).The covered grass with fungi damages recovered faster than the control every year. There were almost no fungi under the semipermeable cover during this study. There were fungi under the air+ plastic every year and there were fungi under the plastic in the spring 2013 and 2014.Some ice damages occurred under the air+plastic because of leakage. There were no suffocation damages during this study.

Conclusion: I now feel comfortable to say that ice encasement damages on turfgrass can be prevented with the covers. This is a successful way to have a good playing quality when the season starts. Even if there are some damages under the covers they will always recover faster than the areas that are not covered if it is an icy winter. It’s not important what you cover with – it is important THAT you cover.

Miklagard golf course

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Miklagard golf course is located 35 km north of Oslo city centre on silty soil in the transition zone between coastal and inland climate. Winters with stable, dry snow from end October until April seems to become rarer, and rain during the winter can cause ice or slush under the snow. Grass species on the greens are a mix of creeping bentgrass and annual bluegrass. All greens on the course were sprayed with fungicides before the experiment green was covered (Amistar (azoxystrobin) 3 l /ha and Delaro (prothioconazole / trifloxystrobin) 1.5 l/ha).

2011- 2012: In the autumn 2011 the experiment was set up 11 November (soil temperature 3.4 ˚C) on a chipping green surrounded by slopes. During the winter surface water was collected on the green and party pressed under the covers through the soil. When the covers were removed 15 Martz the plastic covered part looked perfect, but it collapsed after some hours and turned out to be completely dead. The uncovered part was also dead while the air+plastic and the semipermeable tarp had a turf cover over 90%. 10% pink snow mould was found under the semipermeable tarp on the higher (drier) part of the green.

2012 – 2013: The experiment was relocated to a putting green with less surface water problems. This winter there was a relatively stable snow cover from the start of November until end of April there was a lot of ice. Factors C and D gave 100 % turf cover, plastic had 85% while the uncovered control was severely damaged by disease (45%).

2013-2014: The green was covered early in November under wet conditions. The snow disappeared in December/January but came back and until melt down 10th March. One week later the uncovered part of the green had 30% disease and 70 % turf cover. The covered parts had less snow mould patches and the turf cover was rated plastic (93%) < air+platic (96 %) < semipermeable tarp (99%), and the colour was better than the control.

Conclusion: After three years we conclude that winter covers on the poa/bent greens at Miklagard golf course improved the winter survival and reduced the time needed for recovery in the spring. We have not yet decided if winter covers on greens will be the normal procedure at Miklagard.

Winter cover strategies for your golf course

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Annual bluegrass putting greens suffer from winter injury as a result of desiccation, low temperature injury and injury from conditions of anoxia. A recent research project focused on covering strategies using impermeable covers to assist in the overwintering of annual bluegrass putting greens. The trial was conducted at an actual golf course where gas concentrations, temperatures, soil organic matter and soil textures were monitored. This study allowed the researchers to better understand the problem with prolonged lack of oxygen (anoxic) under these covers.

Four different covering strategies were tested and gas samples and temperatures were collected on a weekly basis to determine fluctuations. The gas concentrations were compared with the temperatures reading to attempt to better understand the relationship. Temperatures just above freezing appeared to have the greatest effect on changes in gas concentrations. The cover strategies varied in the amount of ventilation that would occur and it appeared that the strategy that had a continual air flow resulted in the least fluctuation in gas concentrations.

Testing that begun over the summer of 2014 has focused on a methodology to develop ‘hermetically’ sealed chambers so that the researchers can test the effects of anoxia on annual bluegrass turf. From the preliminary results, it appears that annual bluegrass is still alive at the onset of anoxic conditions and that there is a period of time before mortality occurs. This information will help golf course superintendents to develop action thresholds for intervention during conditions of anoxia.

Jim Ross will discuss the various winter covering strategies, intervention strategies and how these strategies will prevent winter injury.

The effect of ice encasement and two protective covers on the winter survival of six turfgrasses on putting greens

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During the winter, plants are subjected to a multitude of stresses, which differ from region to region and from year to year. Grass plants may have to tolerate a number of various stress factors, alone or in combination throughout the winter months: i) lack of light; ii) prolonged exposure to freezing temperatures; iii) flooding or ice encasement (IE); iv) fungal diseases; v) soil heaving; vi) solar radiation and vii) wind. Winter stress management options with the aim to minimize winter stress injuries are required. Protective covers against low temperatures and IE have been utilized in Canada with promising results. Ice encasement issues are one of the most important winter stress factors in Scandinavia, however little is known about the IE tolerance of the different putting green species/sub species. A number of Scandinavian golf courses have started using protective covers and it was therefore of interest to study the response of protective covers under Scandinavian conditions.The objective of this study was to assess the impact of IE and two protective covers on the winter survival of the most common turfgrass species in Scandinavia.

The experiment was conducted on a USGA-green seeded with colonial bentgrass (*Agrostis capillaris*) ‘Jorvik’, velvet bentgrass (*A.canina*) ‘Villa’, creeping bentgrass (*A. stolonifera*) Independence’, Chewings fescue (*Festuca rubra ssp. communtata*) ‘Musica’, slender creeping red fescue (*F. rubra ssp. litoralis*) Cezanne’ and annual bluegrass (*Poa annua*) (unspec.) at the Bioforsk Research Station, Apelsvoll, Norway, 61˚41’ N (inland climate), during the winters of 2011-12 and 2012-13. The green was seeded in mid-June of 2011 and 2012 due to destructive sampling throughout the experiment. Nitrogen was applied from May to September at two-week intervals which amounted to 2 kg m-2 year-1 for *Festuca* spp., 2.8 kg m-2 year-1 for *A. canina* and *A. capillaris*, and 3.2 kg m-2 year-1 for *A. stolonifera* and *P. annua*. One fungicide application of Delaro® (protioconazole and trifloxystrobin) was applied during late September at a rate of 1L ha-1. The two protective covers (plastic and plastic covering a 10 mm woven mat to create an air space underneath) were installed in November once the ground was frozen. IE was established on 22.11.11 and 4.12.12 after the soil surface was frozen by adding small amounts of water over a period of three days. The control treatment consisted of natural winter conditions. Core samples (8 cm diameter) were removed from the plots at the time of cover installation, and then 6 times with two-week intervals from the start of January until snow melt. Core samples were thawed for two days at 4˚C, clipped to 4 mm, potted and set to grow in a growth chamber under optimal conditions (18˚C day/night temperature, 18-h photoperiod) for 21 d. At this point percentage turf coverage and dry weight was determined. The percentage of turf coverage was also determined on field plots on 22.03.12, 25.04.12 and 29.05 and 06.05.13 and 27.05.13. These are reported as average coverage for each of the experimental years. The experiment was a split-split-plot design, with covers as the whole plot treatment, and turfgrass species and date of sampling as the sub-plot treatments.

The first winter was short, with warmer temperatures and an earlier snow melt than normal. Mild temperatures beginning in January caused a layer of ice to accumulate under the snow over all treatments. The second winter of the experiment was a more normal winter, with 141 days of snow cover and no ice development observed under the snow on control plots. The plastic cover and plastic with a mat improved the coverage of *P. annua* in the spring of 2012, but no benefits of the covers were measured in the spring of 2013 compared with control. The response in 2012 was most likely due to the avoidance of complete IE under the covers. The springtime coverage of *A. canina, A. stolonifera, F. rubra ssp communtata* and *F. rubra ssp. trichophylla* had no response to the covers, compared with natural winter conditions in both years. In the spring of 2012, *A.capillaris* which had been covered with plastic with a mat had poorer springtime coverage, compared to natural winter conditions and the plastic cover. When the covers where removed in the spring of 2013 *Microdocium nivale* was observed particularly on *A. capillaris*, however this did not significantly influence overall impression and turf coverage taken in May.

IE conditions lasted for 98 d in 2011/12, and the coverage of *P. annua* was reduced to below 50% already on the first sampling date, 42 days of IE. Measurements following 21 d of recovery showed that *P.annua* samples had significantly lower dry weights following IE than all other species tested in 2011/12. The duration of ice encasement in 2011/12 was not sufficient to reduce coverage of the other species to below 50%, however dry weight measurements of *A.canina* following 21 d of recovery were significantly larger than for *A.capillaris*, *F. rubra ssp communtata* and *F. rubra ssp. trichophylla* and *P.annua*. 119 d of IE in 2012/13 gave sufficient duration of anoxic conditions to separate the species based on tolerance to IE. The tolerance of *A. capillaris was* poor, with coverage dropping to 50% after approximately 50 d in 2012/13. *A. canina* on the other hand showed superior tolerance to IE, and even after 119 d of IE the coverage had not dropped to below 75%. Spring coverage of *A. canina* was not significantly reduced by the IE conditions after 98 or 119 d in 2011/12 and 2012/13, respectively. In the spring of 2012 the coverage of *A. stolonifera* was also not reduced by IE. This was however not the case in 2013, indicating that *A. canina* has better tolerance to longer IE conditions, compared to *A. stolonifera*. Coverage measurements following 21 d regrowth show that *A. canina* had superior coverage following IE, compared to *A.capillaris*, *P. annua* and *F. rubra ssp. Trichophylla,* and that *A. stolonifera* and *F. rubra ssp communtata* had higher coverage following 21 d regrowth compared than *P. annua*.

Results indicated that velvet bentgrass had superior tolerance to IE lasting for 98 and 119 d in 2011-12 and 2012-13, compared to the five other species/subspecies. IE conditions did not significantly impact the coverage of *A. canina* in the spring, compared to natural winter conditions. A. *capillaris* responded negatively to the protective covers. *P. annua* was shown to have the lowest tolerance to IE and it was the only species which benefited from the protective covers.

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