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Winter hardiness and management of velvet bentgrass (*Agrostis canina*) on putting greens in northern environments

Report from the first experimental year 2007

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Summary:

This is a report from the first experimental year of the project 'VELVET GREEN - Winter hardiness and management of velvet bentgrass (*Agrostis canina*) on putting greens in northern environments'. The report is divided into three parts, the first giving results from evaluation of winter hardiness of velvet bentgrass under controlled conditions, the second describing experimental layout and preliminary results from two field trials with fertilizer levels, thatch control methods and topdressing levels; and the third describing experimental layout and preliminary results from a lysimeter study on irrigation stategies for velvet bentgrass on greens varying in rootzone composition.

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Arne Sæbø	Trygve S. Aamlid
Leader of Bioforsk's section 'Urban Greening'	Project leader

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1. Abstract

During 2003-06, velvet bentgrass (*Agrostis canina* L.) had better winter survival and turf quality than any other species in green trials at Bioforsk Apelsvoll and Landvik, Norway. Major concerns for the introduction of this species on Nordic golf courses are whether current cultivars have sufficient winter hardiness, and if it is possible to control the rapid formation of thatch in this species. To meet these challenges our project is divided into three subprojects: 1) screening of velvet bentgrass cultivars for winter hardiness; 2) fertilization, mechanical / biological thatch control and topdressing on velvet bentgrass greens; and 3) irrigation regimes on velvet bentgrass greens with different rootzone compositions.

Screening of the velvet bentgrass cultivars Avalon, Greenwich, Legendary and Villa compared with the creeping bentgrass cultivar Penn A-4 (control) for winter hardiness was carried out at UMB during 2006/2007. None of the tested cultivars, whether hardened or not, tolerated freezing to – 9 ºC or lower. On average for hardened and unhardened plants, the velvet bentgrass cultivars tolerated freezing to -6ºC better than Penn A-4. Velvet bentgrass Greenwich was the most tolerant to freezing.

In a second experiment exposing the same cultivars to various combinations of simulated snow cover, ice cover and/or pink snow mould (*Microdochium nivale*), creeping bentgrass Penn A-4 survived better than the velvet bentgrass cultivars. Among the velvet bentgrasses, Avalon (SR 7200) was less winter tolerant to the simulated winter conditions than Villa, Legendary and Greenwich. The hardening requirement was lower and the tolerance to *M. nivale* better in Penn A-4 than in the velvet bentgrasses, but Penn A-4 and the velvet bentgrasses did not differ significantly in tolerance to simulated ice or snow cover. During the winter 2007/2008 these preliminary data will be supplemented by new results which also include the velvet bentgrass cultivars Vesper and Venus and the pathogens *Typhula ishikariensis* and *T. incarnata*.

Field trials were initiated at the coastal location Landvik (58 °N, 12 m a.s.l.), and the inland location Apelsvoll (61 °N, 250 m a.s.l.) in SE Norway in August 2007 to examine velvet bentgrass requirements for fertilizer inputs, mechanical/ biological thatch control, and topdressing levels. The experimental treatments started when grow-in was completed about two months after sowing. The higher fertilizer level 1.5 kg N/100 m^2/yr resulted in better turfgrass overall impression and apparently less disease (mostly caused by *Microdochium nivale* and *Pythium sp*.) than the lower fertilizer level 0.75 kg N/100 m^2/yr. Application of 1.0 mm sand every two weeks was too much at the lower fertilizer level, but at 1.50 kg N/100 m^2/yr there was no difference in turfgrass overall impression between the 0.5 and 1.0 mm topdressing levels. Grooming and grooming plus verticutting led to better turfgrass overall impression than grooming plus coring/spiking, but the effects of these mechanical thatch methods on turfgrass ground cover, tiller density, colour or disease levels were not significant. Five applications of the biological product "Thatch-less™" had no effect on total bacteria or fungi numbers in soil samples taken in November 2007.

A lysimeter field trial at Landvik was started in August 2007 to compare wilt-based and field-capacity-based irrigation on rootzones with and without 2.5 % (w/w) organic matter from garden compost. Turfgrass overall impression was better and disease levels lower with inclusion of organic matter in the rootzone. Different irrigation regimes had no significant effect on plots overall impression, density or colour, but field-capacity-based irrigation (light and frequent) led to significantly higher soil humidity, better turfgrass ground coverage and less diseases than wilt-based irrigation (deep and infrequent).

The field trials will continue in 2008 and 2009.

Key words: *Agrostis canina*, freezing tolerance, golf, green, hardening, ice cover, irrigation, *Microdochium nivale*, nitrogen, snow mould, thatch control, topdressing, velvet bentgrass

2. Introduction

The present project was triggered by the results of the previous project "Evaluation of *Festuca* and *Agrostis* cultivars for Scandinavian putting greens", which was carried out at Bioforsk Landvik and Apelsvoll from 2003 to 2006 (Aamlid et al., 2005, 2006). In that project, 43 cultivars of creeping bentgrass (*Agrostis stolonifera*), velvet bentgrass (*Agrostis canina*), colonial bentgrass (*Agrostis capillaris*), red fescue (*Festuca rubra*), and annual bluegrass (*Poa annua*) were compared. The most conspicuous result was the outstanding performance of velvet bentgrass at both locations. Velvet bentgrass not only produced the densest, finest and most even turf, but two out of three cultivars of velvet bentgrass also had better winter hardiness than any other species (Photo 1).

Photo 1. Only velvet bentgrass (green plots to the left) came out of the winter 2004/05 with hardly any winter damage at Apelsvoll. To the right: Creeping bentgrass. (Photo in May 2005 by Bjørn Molteberg)

Velvet bentgrass is a native species to north and central Europe (Clayton & Renvoize, 1986). It grows from lowlands to alpine levels, particularly on acid and wet soils (Brilman, 2003). It was introduced to North America in the late 1800s as 'South German' bent which supposedly consisted of several *Agrostis* species. Velvet bentgrass soon established itself as an important species on golf courses in New England, which has a climate fairly similar to coastal regions in Scandinavia. Golfers were often impressed by its high density which resembles a carpet of velvet fabric. In 1927, R.A. Jones, on behalf of the United States Golf Association (USGA) Advisory Committee, stated that 'velvet bent produces the finest and most beautiful turf of any of the northern grasses' (Brilman & Meyer, 2000). After World War II, velvet bent fell out of favour as commercial fertilizers and pesticides were introduced and golf course management programs became adapted to Penncross and other creeping bentgrass cultivars. These programs with high inputs of nitrogen, irrigation and fungicides, most likely 'managed the velvet bentgrass to death' (Torello & Lynch, undated). However, most of the germplasm collected on golf courses in New England was preserved and improved, and this resulted in Avalon (= SR 7200 in North America), the first velvet bentgrass cultivar to be released for over 30 years (Brilman & Meyer, 2000).

During the last decade, there has been a strong resurgence in the interest for velvet bentgrass in North America. In New England and New York, velvet bentgrass is now perceived as the ideal species for integrated pest management (IPM) of putting greens (Grant & Rossi, 2004). Research programs are now running at Rutgers University, New Jersey, Cornell University, New York, and University of Guelph, Canada. A breeding program is underway at Rutgers, and this has so far resulted in cultivars such as Greenwich, Venus, Legendary, and Villa.

According to earlier research, the main advantages of velvet bentgrass on putting greens are:

1. Low nitrogen requirement, high nitrogen use efficiency and thus reduced potential for nitrogen leaching. The optimal N input to velvet bentgrass in Ontario, Canada, was 1.5 kg N / 100 m^2 / yr as opposed to 3.0 kg N / 100 m^2 / yr for creeping bentgrass (Paré, 2004). However, this has to be adjusted both to the growth medium used for green construction and to the annual precipitation. In the Nordic countries, greens are either constructed of straight sand or with an amendment of 10-25% (v/v) *sphagnum* peat or compost to the rootzone, while the annual rainfall varies from more than 2000 mm on the west coast to less than 400 mm in the inland. Skogley (1976) found N requirements to decrease with increasing age of velvet bentgrass greens.
2. No redundant stomata (Shearman & Beard, 1972), deep root system, and thus improved water use efficiency compared with other species (McCann & Huang, 2005). DaCosta & Huang (2006) found that velvet bentgrass maintained at fairway mowing heights (15-20 mm) had acceptable turf quality with only 60 % replacement of evapotranspiration water. These results will have to be verified at green mowing heights (3-5 mm), and they must also be evaluated in relation to rootzone composition and nitrogen input.
3. Better shade tolerance than colonial and creeping bentgrass (Reid, 1933; Brilman & Meyer, 2000). This is especially important at high latitudes where the low inclination of the sun results in long shades from trees, buildings etc. (Kvalbein 2004).
4. Very high tiller density and thus resistance to invasion of annual bluegrass (Pioppi 2003).
5. Better resistance to take all (*Gauemannomyces graminis*) and brown patch (*Rhizoctonia* spp.) than most cultivars of creeping and colonial bentgrass (Brilman & Meyer 2000). Both diseases are common on Scandinavian golf courses.

All taken together, these advantages make velvet bentgrass a very interesting alternative for Nordic golf courses that have adopted an IPM strategy, thus striving to reduce inputs of fertilizers, pesticides and labour.

The main challenge associated with velvet bentgrass on putting greens is thatch control. Thatch is the undecomposed or partly decomposed layer of organic matter that is formed between the soil surface and the aerial tillers (Turgeon, 2002). A thick thatch layer is incompatible with good putting quality, as it creates a soft, spongy surface with low wear resistance, deep ball marks and an ideal environment for turfgrass diseases. It may also often become hydrophobic, thus reducing infiltration rates and resulting in localized dry spots (Taylor & Blake, 1982). Thatch accumulation occurs when production exceeds decomposition of organic matter and is most accentuated in northern environments with low soil temperatures and high rainfall (Beard, 1973). In the cultivar trials at Landvik and Apelsvoll, velvet bentgrass accumulated more thatch than the other turfgrass species (Photo 2). To some extent this may be due to the fertilizer and irrigation program, which was adapted to creeping bentgrass rather than to velvet bentgrass. Moreover, a soil pH close to 7.0 was probably not ideal for velvet bentgrass (Brilman & Meyer, 2000). Other means of controlling thatch is vertical cutting or hollow tine coring (removal of dead material) and topdressing with sand (dilution of organic matter) at regular intervals. According to Cashel et al. (2005), the wear and compaction tolerance and recuperative capacity of velvet bentgrass is on the same level as for creeping bentgrass. It is, however, a common observation that stolon development is less vigorous in velvet than in creeping bentgrass (Jones, 1927), and Boesh (2005) observed that velvet bentgrass needed longer time than creeping bentgrass to recover from deep vertical cutting or coring. Thus, before introducing velvet bentgrass on Nordic golf courses, we need to find a combination of rootzone compositions, fertilizer inputs, irrigation and mechanical thatch control treatments that will produce an optimal putting quality without excessive thatch accumulation and without significant loss of wear resistance.

A most important question regarding velvet bentgrass on Nordic golf courses is whether the present cultivars are winter-hardy enough? Avalon and Villa emerged from three months of ice cover in excellent condition, but Greenwich suffered moderate winter damage from snow mould (Aamlid et al. 2006). Jones (1927) stated that velvet bentgrass was less winter hardy than creeping bentgrass, and North American cultivar trials showed variable results with velvet bentgrasses in continental areas such as Iowa, Minnesota and Wisconsin (NTEP, 2006). The winter hardiness of newly released cultivars of velvet bentgrass therefore has to be evaluated before they can be recommended for golf courses in the Nordic countries.

Photo 2. Thatch accumulation 15 months after sowing of red fescue Calliope, colonial bentgrass Bardot, creeping bentgrass Penn G6 and velvet bentgrass Greenwich (Photo: Trygve S. Aamlid)

The objectives of the project 'VELVET GREEN' are:

1. To compare the tolerance of available cultivars of velvet bentgrass to freezing temperatures, ice cover, snow cover, and snow mould with that of a control cultivar of creeping bentgrass under controlled conditions.
2. To determine the effect of fertilizer levels, mechanical / biological thatch control methods and topdressing levels on thatch accumulation and turfgrass quality of velvet bentgrass on putting greens in a coastal and an inland area of Norway.
3. To determine the effect of rootzone organic matter and irrigation regimes on thatch accumulation, turfgrass quality and nutrient leaching from velvet bentgrass greens.

The project is scheduled for the period 2007-2010. This is the first annual report giving a status of the project as of 1 January 2008. The report is divided into three parts according to subprojects corresponding to the objectives outlined above.

3. Winter survival of velvet bentgrass cultivars under controlled conditions

3.1. Materials and methods

In September 2006, four velvet bentgrass (*Agrostis canina)* cultivars, Avalon, Greenwich, Villa, and Legendary, and the creeping bentgrass (*Agrostris stolonifera*) cultivar Penn A-4 were sown at rate 6.7 g/m^2 in 7.5 x 10 x 10 cm pots which had been filled with a USGA-spec. growth medium containing 0.5% (w/w) organic matter. After germination the plants were grown in a greenhouse at 18/12 $^{\circ}$C day/night temperature and 16 h daylength (150 µmol/s/ m^2) for nine weeks, or at the same temperature and light conditions for eight weeks followed by two weeks of hardening at 2 $^{\circ}$C, also with 16 h daylength (250 µmol/s/m^2). The pots were watered regularly and fertilized every 7 days with 25 ml of a complete nutrient solution containing micronutrients and 0.31 g nitrogen (N), 0.05 g phosphorus (P) and 0.36 g potassium (K) per litre. At the last two fertilizer applications before hardening or winter treatments, the concentration of nitrogen was reduced to 0.20 g/L and the concentration of potassium increased to 1.0 g / litre. The turf was mowed at 5 mm three times a week using a hand-held electric grass cutter "Gardena".

Unhardened and hardened plants of the four cultivars were included in tests for freezing tolerance and tolerance to ice cover, snow cover and pink snow mould (*Microdocium nivale*) under different simulated winter conditions. The experiments had three replicates.

<u>To test freezing tolerance,</u> pots were transferred to a controlled climate chamber for one week. The temperature was lowered at a rate of 2°C h^{-1} to -6, -9, -12 or –15 $^{\circ}$C, respectively, and maintained at those temperatures for 24 h. After 24 h the temperature was increased at increments of 2 $^{\circ}$C h^{-1} to –2 $^{\circ}$C, at which it was maintained for 12 h before further increase to 2 $^{\circ}$C. The pots were then transferred back to the greenhouse and grown under the same conditions as before treatments. Freezing tolerance was assessed visually as turf coverage, i.e. the percent of a pot covered with healthy grass, after two weeks of recovery in the greenhouse.

<u>To test tolerance to ice cover, snow cover and/or *Microdochium nivale*,</u> unhardened or hardened plants were sprayed with approximately 2 ml per pot of a mycelial suspension of *M. nivale*. A Norwegian isolate of *M. nivale* was grown on Potato Dextrose Broth (PDB) for 14 days at 9 ^{o}C, then ground intermittently in a Waring Blender for 5 – 10 minutes. The concentration of the suspension was adjusted to an optical density (OD$_{430}$ of 0.48, which is roughly equivalent to 10^5 cfu/ml. Control pots were sprayed with water. The pots were incubated for 6 or 12 weeks in darkness at 0.5 - 1.0 ^{o}C, either uncovered (simulating winter conditions with no snow or ice cover), enclosed in air-tight vacuum bags (simulating anaerobic conditions under ice cover), or covered with a sheet of wet cotton and wrapped in plastic (simulating snow cover). In all cases, plant responses were evaluated as turf coverage after two weeks of recovery in the greenhouse.

The results from both experiments were analyzed using the SAS procedure PROC ANOVA according to factorial designs with three factors (cultivar, hardening and freezing temperature) in the first experiment, and five main factors (cultivar, hardening, duration of winter treatment, inoculation with *M.nivale*, and no cover vs. ice cover vs. snow cover) in the second experiment.

3.2. Results and discussion

<u>3.2.1.Tolerance to freezing</u>

All experimental factors, cultivar, hardening, and freezing temperature, had significant effects on percent turf coverage. Main effects are given in Table 1. The velvet bentgrass cultivar Greenwich had higher tolerance to freezing than the other velvet bentgrass cultivars. The lowest freezing tolerance was found in creeping bentgrass Penn A-4. Hardened plants had almost five times higher percent turf coverage than unhardened plants. Most plants survived freezing to -6 ^oC (Photo 3), but hardly to -9 ^oC (Photo 4), and not to -12 ^oC and -15 ^oC.

Table. 1. Main effects of experimental factors on turf coverage.

Cultivars	Turf coverage, % (mean)	**Hardening**	Turf coverage, % (mean)	**Freezing temperature**	Turf coverage, % (mean)
Greenwich	17	Hardened	25	-6 ^oC	57
Villa	16	Unhardened	5	-9 ^oC	3
Legendary	16			-12 ^oC	0
Avalon	15			-15 ^oC	0
Penn A-4	13				
Sign. level	***	*Sign. level*	***	*Sign. level*	***
$LSD_{5\%}$	2			$LSD_{5\%}$	2

The following significance levels are used in this and the following tables: *** : P < 0.1 %, ** : 0.01 % < P < 1 %,* : 1% < P< 5%, ns: not significant.

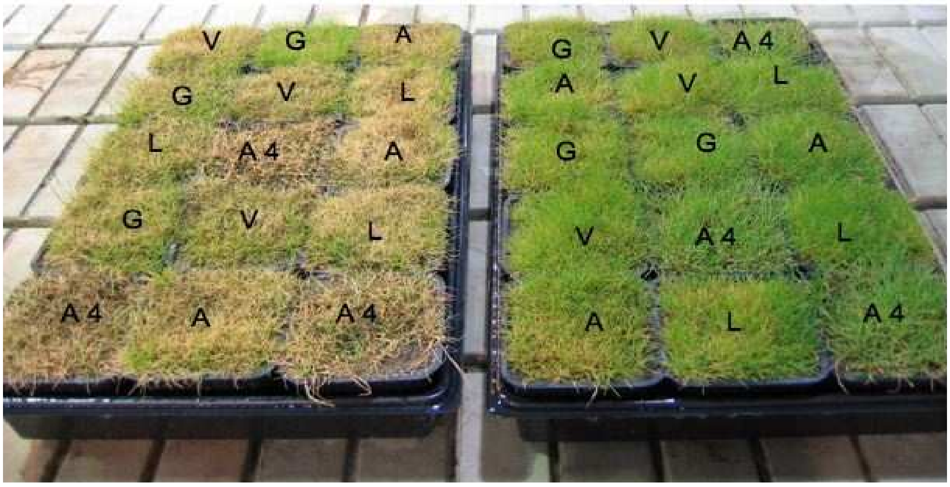


Photo 3. Unhardened (left) and hardened (right) plants two weeks after exposure to -6°C
A = Avalon V = Villa G = Greenwich L = Legendary A4 = Penn A-4 (Photo: Katarina Gundsø Jensen)

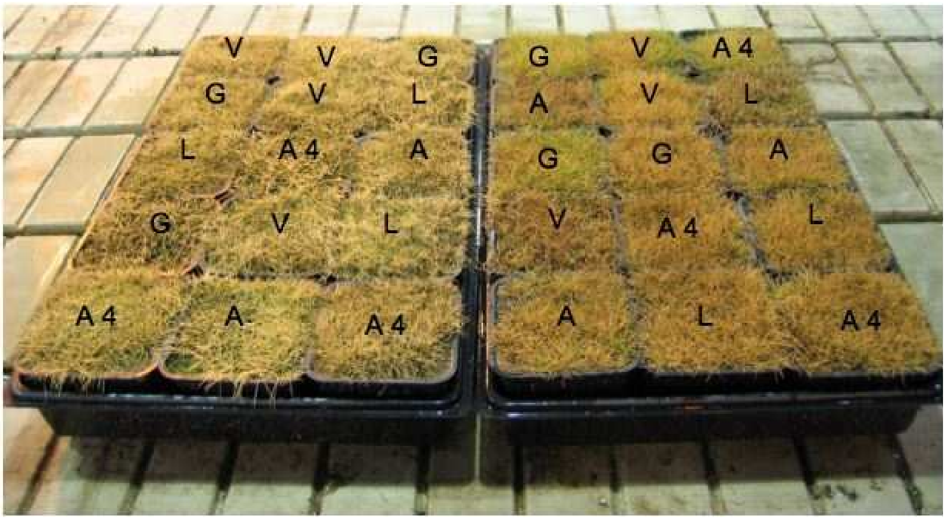


Photo 4. Unhardened (left) and hardened (right) plants two weeks after exposure to -9°C
Legend as in Photo 3. (Photo: Katarina Gundsø Jensen).

A significant cultivar x hardening interaction indicated that Greenwich had higher freezing tolerance only in the unhardened state (Fig. 1). The difference between hardened and unhardened plants was more pronounced in Penn A-4 than in the velvet bentgrass cultivars.

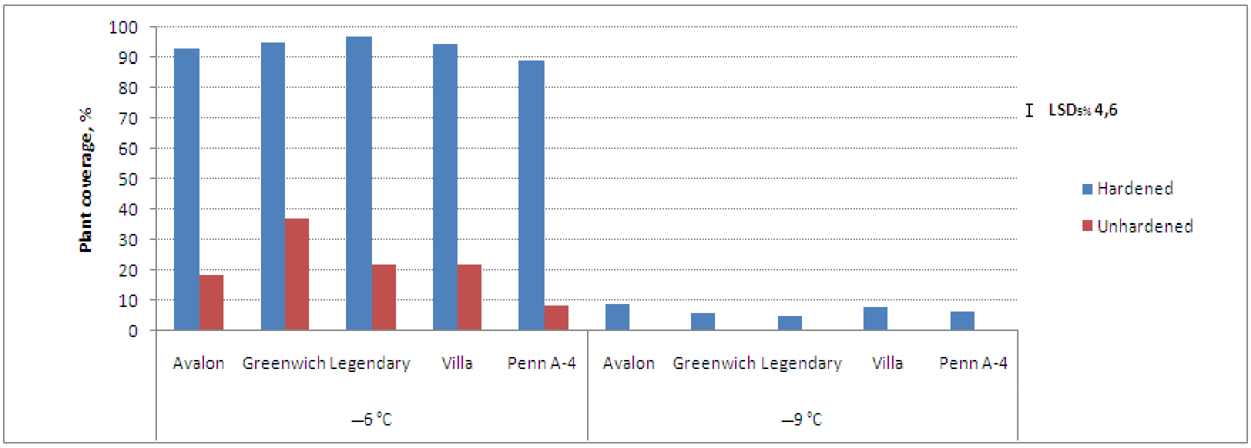


Fig. 1. Effect of hardening and freezing to -6 °C and -9 °C on plant coverage of various cultivars.

Freezing tolerance of turfgrass species varies. Little is known about winter hardiness of velvet bentgrass. Creeping bentgrass is reported to have a high freezing tolerance (DiPaola & Beard, 1992; Stier & Fei, 2008). However, freezing tolerance depends on several factors (e.g. Dionne et al., 2001; Anderson et al., 2002). The degree of hardening is one of them. Hardening, or cold acclimation, in perennial turfgrass species occur in two distinct phases – first at relatively high temperature (2-5 °C) and then at lower, subfreezing temperature (-2 °C) (Levitt, 1980; Stier & Fei, 2008). In our experiment hardening may not have been complete as it consisted only of the first phase occurring at 2 °C for 2 weeks. The lack of a second hardening phase at subzero temperature may have affected freezing tolerance more negatively in Penn A-4 than the velvet bentgrass cultivars in our study.

3.2.2. Tolerance to ice cover, snow cover and/or infection by *Microdochium nivale*

Main effects

On average for all simulated winter conditions imposed in this experiment, Penn A-4 survived better than the velvet bentgrass cultivars. Among the velvet bentgrass cultivars, Avalon survived better than Greenwich, Legendary and Villa (Table 2). As a main effect, hardening resulted in significantly better tolerance to winter conditions and inoculation with *M. nivale*. The average percent ground coverage of hardened plant was 72 %, of unhardened plants only 43 %. Prolongation of winter conditions from 6 to 12 weeks led to a decrease in turf survival. The ground cover after being 12 weeks under winter conditions was 40 % as opposed to 76 % after 6 weeks. Noninoculated plants survived better as compared with inoculated plants; the ground cover was 69 % and 48 %, respectively. Finally, as the last main effect, winter conditions without cover showed 2 times better turf survival in comparison with artificial ice or snow cover.

Interactions between species / cultivars and the other factors

Table 3 indicates significance levels of two and three factor interactions. While there were many significant interactions among the various treatments, only some of the interactions including cultivar as one of the factors were significant.

A significant cultivar x hardening interaction indicated that the effect of hardening on survival after snow or ice cover and / or inoculation with *M.nivale*, was greater in velvet bentgrass, especially Avalon, than in creeping bentgrass Penn A-4 (Fig. 2a). All inoculated velvet bentgrass cultivars had significantly lower plant coverage than noninoculated, but in the case of Penn A-4, inoculation with *M. nivale* hardly affected winter survival (Fig.2b). The figure also suggests that Greenwich was more susceptible to *M.nivale* than the other velvet bentgrass cultivars; this is in agreement with former cultivar trials (Aamlid et al. 2006).

As there were no differences between the cultivar responses or to ice or snow cover (Table 3), the experiment gave no indication which of the species / cultivars are most tolerant to these conditions.

Table 2. Main effects of cultivar, hardening, duration of winter conditions, inoculation with M. nivale *and snow / ice cover on turfgrass winter survival.*

Factors	Turf coverage, % (mean)
Cultivars	
Penn A-4	66
Legendary	60
Greenwich	58
Villa	57
Avalon	48
Significance level	***
$LSD_{5\%}$	*6*
Hardening	
Hardened	72
Unhardened	43
Significance level	***
Duration of winter conditions	
6 weeks	76
12 weeks	40
Significance level	***
Inoculation with *M. nivale*	
Noninoculated	69
Inoculated	48
Significance level	***
Cover	
No cover	85
Simulated ice cover	44
Simulated snow cover	44
Significance level	***

Table 3. Significance levels of two and three factors' interactions.

	Duration of winter conditions [1]	Harden-ing	Inoculation with *M. nivale*	Cover
Cultivar	ns	*	**	ns
Duration of winter conditions[1]		ns	**	***
Hardening			***	***
Inoculation with *M. nivale*				***
Cultivar x Duration of winter conditions		*	***	ns
Cultivar x Hardening			ns	ns
Cultivar x Inoculation with *M. nivale*				ns
Duration x Hardening			*	
Duration x Hardening				***
Duration x Inoculation with *M. nivale*				***
Hardening x Inoculation with *M. nivale*				***

[1] – 6 and 12 weeks under winter conditions

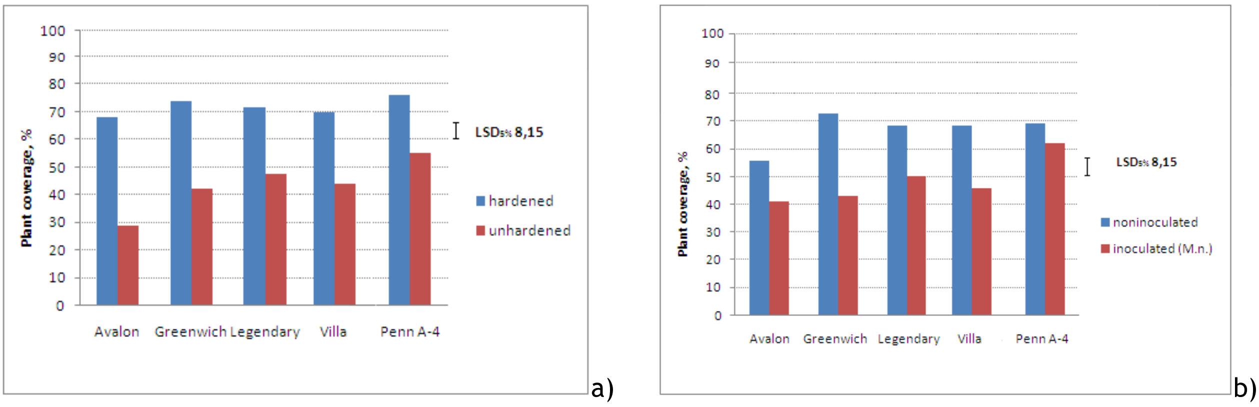


Fig.2. Effect of hardening (a) and inoculation with M. nivale *(b) on cultivars' survival under simulated winter conditions.*

Interactions between various winter conditions (common to all cultivars)

Although some three-factor interactions were also significant (Table 3), this paragraph will be limited to some of the two factor interactions showing interesting relationships between various winter conditions. Ice cover led to significantly more winter injury than no cover and to significantly less injury than snow cover with a 6 week exposure period (Fig. 3). However, when the duration of "winter" was prolonged to 12 weeks, ice cover caused the largest damage with a turf survial of only 9 %. This can be explained by anaerobic conditions and accumulation of toxic gases (Levitt, 1980), which probably reached a critical level somewhere between 6 and 12 weeks of exposure. Aamlid et al. (in press), using a similar simulation technique as in our experiment, found critical ice encasement periods of 25-30 days in annual bluegrass (*Poa annua*) and 42-47 in creeping bentgrass.

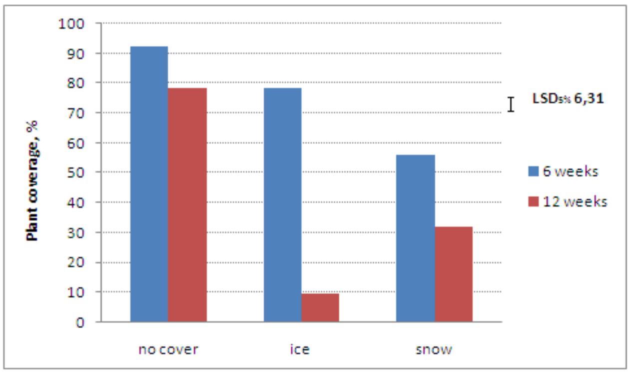


Fig. 3. Effect of duration of ice and snow cover on turfgrass survival.

Significant two factor interactions indicated that the positive effect of hardening on turfgrass winter survival was stronger for inoculated than noninoculated turf (Fig. 4a, Photos 5 and 6) and stronger with snow cover than with ice cover or no cover (Fig. 4b).

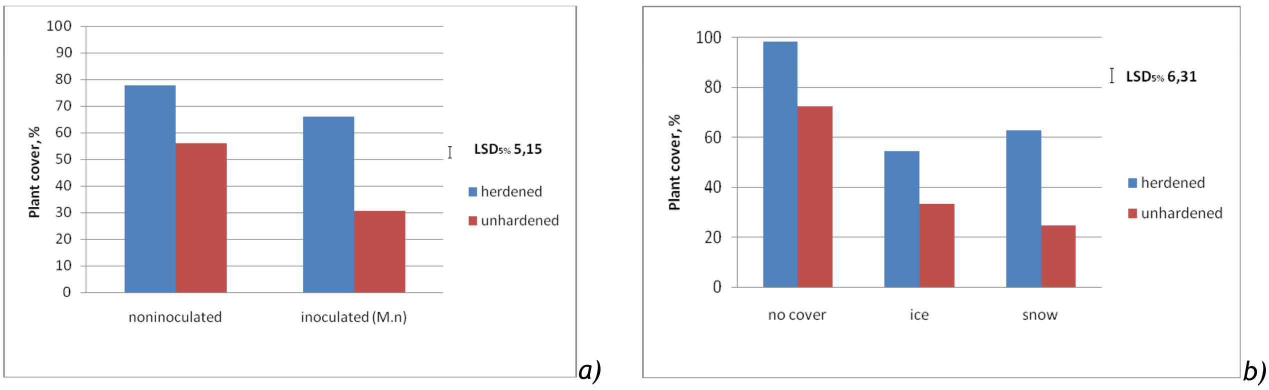


Fig. 4. Two factor interactions between hardening and inoculation with M. nivale *(a) and hardening and ice or snow cover (b) on turfgrass survival.*

Photo 5. Symptoms of M. nivale *on unhardened (left) and hardened (right) turf after 12 weeks without ice or snow cover. Photo taken after two weeks recovery in the greenhouse. Legend as in Photo 3.(Photo: Katarina Gundsø Jensen).*

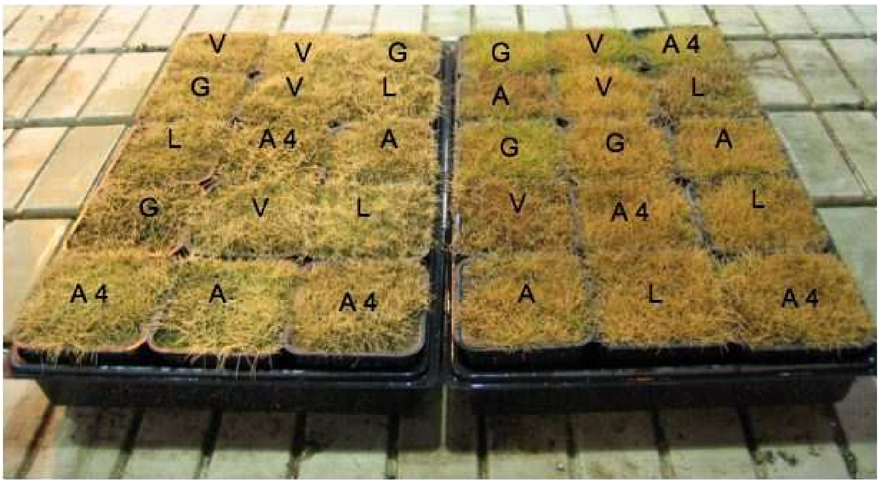


Photo 6. Damage by M. nivale *on unhardened (left) and hardened (right) turf after 12 weeks under artificial snow cover. Photo taken after two weeks recovery in the greenhouse. Legend as in Photo 3 (Photo: Katarina Gundsø Jensen).*

The interaction between inoculation with *M. nivale* and cover was significant (Table 3), suggesting that *M. nivale* was more detrimental on turf covered with snow than on turf without coverage. Inoculation with *M.nivale* had no effect on turf covered with ice, possibly because both the turf and the fungus were injured by the anaerobic conditions prevailing under the ice cover (Fig. 5).

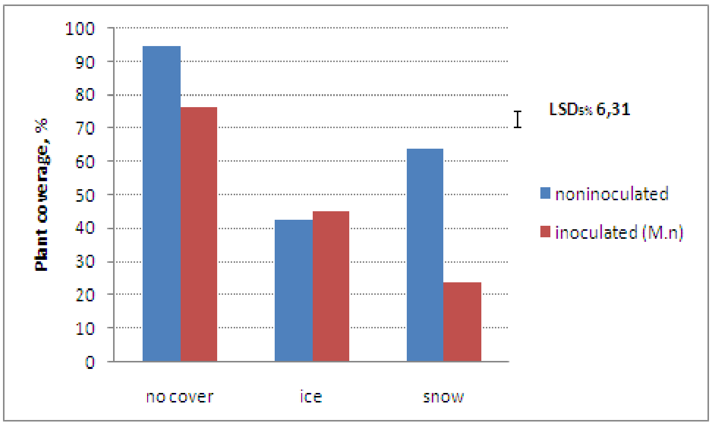


Fig. 5. Effect of the interaction between ice or snow cover and inoculation with M. nivale *on turf survival.*

3.3. Conclusions

As the subproject continues with a second experiment trial under controlled conditions during the winter 2007/08, the following conclusions must be regarded as provisional:

Tolerance to freezing

None of the tested cultivars, whether hardened or not, tolerated freezing to – 9 ºC or lower. This was probably due to incomplete hardening. On average for hardened and unhardened plants, the velvet bentgrass cultivars tolerated freezing to -6ºC better than creeping bentgrass Penn A-4. The velvet bentgrass cultivar Greenwich was the most tolerant.

Tolerance to ice cover, snow cover and/or *Microdochium nivale*

As a main effect, the creeping bentgrass cultivar Penn A-4 survived the simulated winter conditions in this experiment better than the velvet bentgrass cultivars. Among the velvet bentgrasses, Avalon was less winter tolerant than Villa, Legendary and Greenwich. The hardening requirement seemed to be lower and the tolerance to *M. nivale* better in Penn A-4 than in the velvet bentgrasses. However, Penn A-4 and the velvet bentgrass cultivars did not differ significantly in tolerance to simulated ice or snow cover.

On average for cultivars, prolongation of the winter conditions from six to twelve weeks caused a more dramatic decline in the turfgrass survival under simulated ice cover than under simulated snow cover or with no cover.

Hardening had a positive effect on turfgrass survival under all kinds of simulated winter conditions, but was especially important in the presence of *M. nivale* and under simulated snow cover.

Inoculation with *M. nivale* was more detrimental on turf covered with snow than on turf without coverage, and had no effect on turf covered with ice.

4. Fertilization, mechanical / biological thatch control, and topdressing on velvet bentgrass putting greens

4.1. Materials and methods

4.1.1. Experimental sites and weather data

Field trials were carried out at Bioforsk Landvik and Apelsvoll Research Stations (Fig. 6). Landvik, located on the Norwegian south coast (58 °N, 12 m a.s.l.), has an intermediate climate with a high annual rainfall (1230 mm) and an average temperature from May to October of 12.7 °C. Apelsvoll, located in the inland north of Oslo (61 °N, 250 m a.s.l.), has a continental climate with less rainfall (600 mm) and lower temperature (10.8 °C) during the growing season.

During the period from May to October 2007 the average temperatures were 13.0 °C and 11.6 °C at Landvik and Apelsvoll, respectively; the rainfall totalled 655 mm at Landvik and 405 mm at Apelsvoll for the same period. Meteorological conditions at the research stations during the growing season 2007 are shown in Fig. 7.

4.1.2. Green establishment and maintenance until start of experimentation

The field trials were laid out on USGA greens which had been constructed at Apelsvoll in June 2003 and at Landvik in November 2004. On the completion of previous projects in spring 2008, the sod was removed to a depth of 3-4 cm, and new growth media added at both sites. The rootzone was a USGA sand amended with 15 % (v/v) of *sphagnum* peat at Landvik and a USGA sand amended with 20 % (v/v) garden compost ('Green Mix', Norsk Jordforbedring, Grimstad, Norway) at Apelsvoll. Results of chemical soil analyses are given in Table 4.

Table 4. Analysis of soil samples taken in October 2006 at Apelsvoll and July 2007 at Landvik.

Research stations	pH (H_2O)	mg per 100 g dry soil	
		P-AL	K-AL
Apelsvoll	7.2	5,5	5.9
Landvik	5.9	0.6	2.3

The greens were seeded to velvet bentgrass 'Legendary' on 30 May and 26 June at Landvik and Apelsvoll, respectively. The seeding rate at both sites was 0.6 kg per 100 m^2. After seeding, the greens were irrigated every third hour and covered with a permeable tarp for approximately 10 days. The greens were mowed for the first time with walk-behind mowers to 12 mm about three weeks after seeding. After this, mowing height was gradually decreased to 4 mm at the start of experimentation. Fertilizer applications before seeding and during the grow-in phase at Landvik and Apelsvoll are given in Tables 5 and 6, respectively.

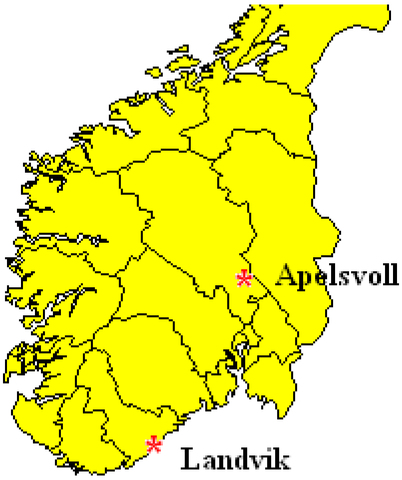
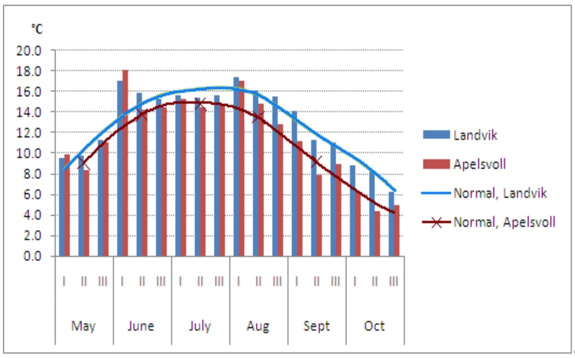
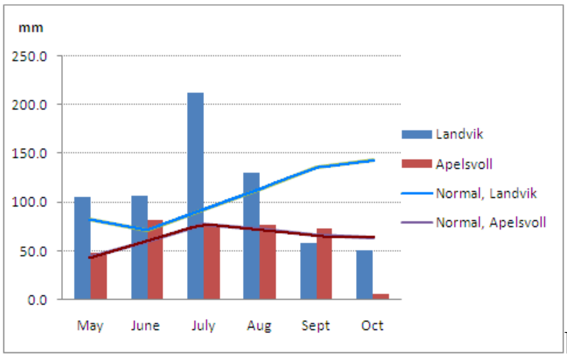


Fig. 6. Map of South Norway showing location of experiments



a)



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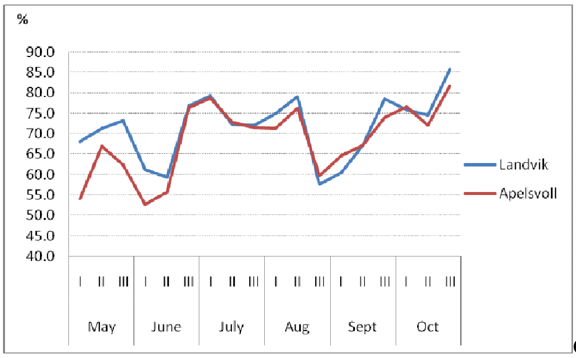

c)

Fig. 7. Average temperature (a), rainfall (b) and relative air humidity (c) during the growing season 2007 at Landvik and Apelsvoll Research Stations, according to data from Bioforsk AgroMetBase. Normal temperature and precipitation values are based on the period 1961-90.

Table 5. Fertilizer application before seeding and during grow-in at Landvik.

	Date	Fertilizer type	kg per 100 m^2							
			Fertilizer	N	P	K	Mg	S	Ca	Fe
Before sowing	29 Mai	Turf Food 14-3-5*	5.00	0.700	0.060	0.210	0.025	0.200	0.050	0.200
Establishment phase	12 Jun.	Arena** Green Plus 12-1-14	1.00	0.120	0.010	0.145	0.018	0.060	0.021	0.000
	18 Jun.	Arena Green Plus 12-1-14	1.00	0.120	0.010	0.145	0.018	0.060	0.021	0.000
	27 Jun.	Arena Høst Extra 3-3-15	2.00	0.064	0.066	0.292	0.020	0.210	0.000	0.108
	2 Jul.	Arena Start 22-3-10	0.70	0.154	0.021	0.070	0.000	0.028	0.000	0.000
	17 Jul.	Arena Green Plus 12-1-14	1.50	0.180	0.015	0.218	0.027	0.090	0.032	0.000
TOTAL				1.338	0.182	1.080	0.108	0.648	0.124	0.308

*** Turf Food 14-3-15: Feathermeal + humic substances + sea weed + methylen-urea + mineral N**
**** Arena: Granular mineral fertilizer**

Table 6. Fertilizer application before sowing and during grow-in at Apelsvoll.

	Date	Fertilizer type	kg per 100 m^2							
			Fertilizer	N	P	K	Mg	S	Ca	Fe
Before sowing	25 Jun.	Turf Food 14-3-5*	5.00	0.700	0.060	0.210	0.025	0.200	0.050	0.200
Establishment phase	20 Jul.	Arena Høst Extra 3-3-15	3.00	0.096	0.099	0.438	0.030	0.315	0.000	0.162
	2 Aug.	Ammoniumsulfate	0.50	0.106	0.000	0.000	0.000	0.121	0.000	0.000
	17 Aug.	Arena Høst Extra 3-3-15	3.00	0.096	0.099	0.438	0.030	0.315	0.000	0.162
TOTAL				0.998	0.198	0.876	0.060	0.751	0.000	0.324

Before the start of experimentation soil samples from both sites were studied for organic matter content at different depths. At Landvik data were also recorded on soil moisture content and root development (Table 7).

Table 7. Data on soil organic matter, soil water content (w/w) and root development at the start of experimentation in July / August 2007.

Depth, cm	Loss on ignition, %		Root dry weight g/m^2 Landvik	Moisture content, % (w/w), Landvik
	Landvik	Apelsvoll		
0-1	4.0*	2.0 (0-2 cm)	87.9 (0-4 cm)	14.2
1-4	2.7			9.3
4-6	2.1	2.0 (2-5 cm)	32.6	10.0
6-10	1.8	2.2 (5-10 cm)	30.9	10.6
10-15	1.6	2.5	17.1	11.4
15-20	1.6	2.2	16.6	14.4
20-30	2.0	2.1	3.6	18.8

*** Means of three samples at each location.**

4.1.3. Experimental plan and implementation

Treatments were initiated on 31 July at Landvik and on 28 August at Apelsvoll, i.e. about two months after seeding at both sites. The experimental plan was a split-plot with three blocks (replicates). At Landvik (Photo 7) each block consisted of 8 main plots, each containing 2 subplots. Due to size limitations, the corresponding numbers at Apelsvoll were 6 main plots and 12 subplots. The size of subplots was 2 x 1.5 = 3 m^2 and of main plots 2 x 3 m^2 = 6 m^2 at both sites.

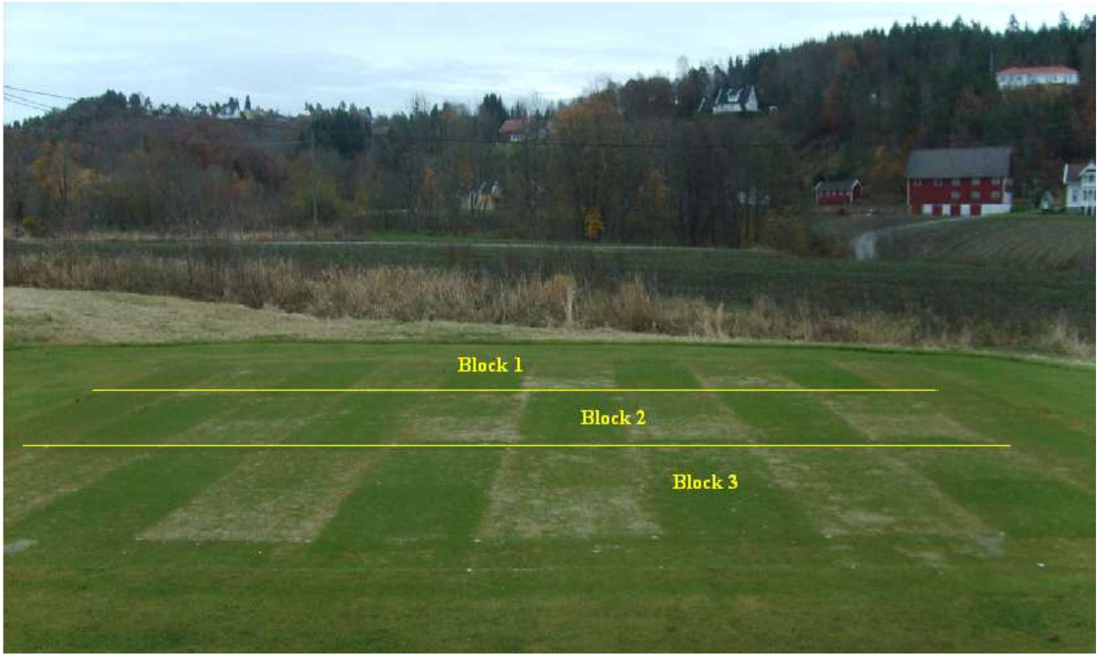

Photo 7. The experimental green at Landvik on 2 November 2007. The effects of nitrogen and topdressing levels are very conspicuous (Photo Trygve S. Aamlid)

The experimental plan included the following treatments in factorial combination:

Factor 1: Fertilizer level (main plots)

A. 0.75 kg N/100 m^2/yr
B. 1.50 kg N/100 m^2/yr

Factor 2: Mechanical / biological methods for thatch control (main plots)

1. Grooming to +/- 0.1 mm depth once a week (groomer mounted on mower)
2. As 1 + verticutting to 2 mm depth every two weeks
3. As 1 + spiking with 8 mm solid tines (Apelsvoll) or coring with 6 mm hollow tines (Landvik) once a month
4. As 3 + the addition of the biological product "Thatch less™[1]" (100 ml product diluted in 7.5 litre water per 100 m^2) after each spiking (only at Landvik)

Factor 3: Topdressing with straight sand without organic matter (subplots)

i) 0.5 mm every two weeks
ii) 1.0 mm every two weeks

[1] Thatch-less™ contains *Bacillus licheniformis*, *Bacillus subtilis* and cellulase enzymes derived from *Trichoderma reesei* (Novozymes Biological Inc., Salem, VA, USA).

Fertilizers were always applied in solid formulations. Actual dates for fertilizer applications (Factor 1) are given in Tables 8 and 9 for Landvik and Apelsvoll, respectively, and for implementation of the various thatch control (Factor 2) and topdressing (Factor 3) treatments in Table 10. As the first thatch control treatments with 6 mm hollow tines at Landvik (Photo 8) and 8 mm solid tines at Apelsvoll (Photo 9) were rather disruptive to the turf, these treatments were performed only once at each site. When used on this more or less immature turf, the treatments were too tough to be repeated again. For the same reason, thatch control treatments 3 and 4 were also not groomed after the initial coring (Landvik) and spiking (Apelsvoll) treatments. Due to lack of mechanical equipment, grooming at Landvik was suspended from 2 August to 4 September also in treatments 1 and 2. The biological product “Thatch less™” was applied using a back-pack plot sprayer. The first application was performed on 1 Aug., i.e. the day after hollow tine coring. Both this and subsequent applications were followed by topdressing and/or irrigation treatments.

Table 8. Fertilizer inputs during the experimental period 31 Jul. – 1 Nov. 2007 at Landvik

Factor 1	Date	Fertilizer type	kg per 100 m^2							
			Fertilizer	N	P	K	Mg	S	Ca	Fe
Treatment A	3 Aug.	Arena Score 12-1-14	0.25	0.031	0.003	0.036	0.004	0.034	0.000	0.001
	9 Aug.	Arena Green Plus 12-1-14	0.30	0.036	0.003	0.044	0.005	0.018	0.006	0.000
	17 Aug.	Arena Start 22-3-10	0.30	0.066	0.009	0.030	0.000	0.012	0.000	0.000
	6 Sep.	Arena Green Plus 12-1-14	0.50	0.060	0.005	0.073	0.009	0.030	0.011	0.000
	18 Sep.	Arena Start 22-3-10	0.40	0.088	0.012	0.040	0.000	0.016	0.000	0.000
	3 Oct.	Arena Green Plus 12-1-14	0.35	0.042	0.004	0.051	0.006	0.021	0.007	0.000
	16 Oct.	Arena Høst Extra 4-4-18	0.50	0.021	0.021	0.092	0.006	0.062	0.000	0.034
TOTAL				0.344	0.056	0.365	0.031	0.193	0.024	0.035
Treatment B	3 Aug.	Arena Score 12-1-14	0.50	0.061	0.007	0.073	0.009	0.068	0.000	0.002
	9 Aug.	Arena Green Plus 12-1-14	0.60	0.072	0.006	0.087	0.011	0.036	0.013	0.000
	17 Aug.	Arena Start 22-3-10	0.60	0.132	0.018	0.060	0.000	0.024	0.000	0.000
	6 Sep.	Arena Green Plus 12-1-14	1.00	0.120	0.010	0.145	0.018	0.060	0.021	0.000
	18 Sep.	Arena Start 22-3-10	0.80	0.176	0.024	0.080	0.000	0.032	0.000	0.000
	3 Oct.	Arena Green Plus 12-1-14	0.70	0.084	0.007	0.102	0.013	0.042	0.015	0.000
	16 Oct.	Arena Høst Extra 4-4-18	1.00	0.042	0.041	0.183	0.012	0.123	0.000	0.068
TOTAL				0.687	0.113	0.729	0.062	0.385	0.048	0.070

Table 9. Fertilizer inputs during the experimental period 28 Aug. – 1 Nov. 2007 at Apelsvoll.

Factor 1	Date	Fertilizer type	kg per 100 m^2							
			Fertilizer	N	P	K	Mg	S	Ca	Fe
Treat-ment A	29 Aug.	Ammoniumsulfate	0.25	0.053	0.000	0.000	0.000	0.061	0.000	0.000
	13 Sept.	Ammoniumsulfate	0.25	0.053	0.000	0.000	0.000	0.061	0.000	0.000
	27 Sept.	Arena Høst Extra 3-3-15	1.00	0.032	0.033	0.146	0.010	0.000	0.105	0.054
	16 Oct.	Arena Høst Extra 3-3-15	1.00	0.032	0.033	0.146	0.010	0.000	0.105	0.054
TOTAL				0.170	0.066	0.292	0.020	0.121	0.210	0.108
Treat-ment B	29 Aug.	Ammoniumsulfate	0.50	0.106	0.000	0.000	0.000	0.121	0.000	0.000
	13 Sept.	Ammoniumsulfate	0.50	0.106	0.000	0.000	0.000	0.121	0.000	0.000
	27 Sept.	Arena Høst Extra 3-3-15	2.00	0.064	0.066	0.292	0.020	0.000	0.210	0.108
	16 Oct.	Arena Høst Extra 3-3-15	2.00	0.064	0.066	0.292	0.020	0.000	0.210	0.108
TOTAL				0.340	0.132	0.584	0.040	0.242	0.420	0.216

Table 10. Dates for implementation of mechanical / biological methods for thatch control (Factor 2) and topdressing (Factor 3) at Landvik and Apelsvoll.

Factor 2. Thatch control methods	Landvik	Apelsvoll
1. Grooming	2 Aug., 4 Sep., 10 Sep., 17 Sep.	28 Aug., 2 Oct.
2. Verticutting	2 Aug., 16 Aug., 4 Sep., 17 Sep.	28 Aug.,13 Sept.
3. Coring or spiking	only 31 Jul.	only 28 Aug.
4. "Thatch less™" (Landvik only)	1 Aug., 16 Aug., 5 Sep., 20 Sep., 5 Oct.	–
Factor 3: Topdressing	7 Aug., 16 Aug., 15 Sep., 18 Sep., 18 Oct.	28 Aug., 13 Sep.

Photo 8. Coring with 6 mm hollow tines on approximately two months old velvet bentgrass green at Landvik, 31 July 2007 (Photo: Trygve S. Aamlid).

Photo 9. Spiking with 8 mm solid tines at Apelsvoll 27 Aug. 2007 (Photo: Tatsiana Espevig).

The total amounts of sand for topdressing in treatments i) and ii) were 3.5 and 5.5 mm at Landvik, and 1 and 2 mm at Apelsvoll. The sand (grain size 0.2-0.7 mm) was spread by hand and brushed into the turf at both sites (Photo 10).

Photo 10. Hand-topdressing at Apelsvoll, 27 Aug. 2007 (Photo: Trygve S. Aamlid).

4.1.4. Mowing, irrigation and fungicide application

Irrigation and mowing were common treatments to all plots in both experiments. The greens were mowed with walk-behind mowers to 3 mm three times a week (Monday, Wednesday and Friday) until the last week of September when mowing height was raised to 4 mm. The last mowing was performed in early October at both locations.

Subject to weather conditions, both experiments were irrigated 5-12 mm after each application of fertilizer, “Thatch less™”, and/or topdressing.

Due to severe infestation of *Pythium* sp. and *Microdochium nivale* in the late autumn, the trial at Landvik was sprayed with Amistar Duo, 1.0 L ha^{-1} (azoxystobin, 200 g a.i. ha^{-1} + propconazole, 125 g a.i. ha^{-1}) on 17 Oct. 2007.

4.1.5. Registrations and statistical data manipulation

Assessments of turfgrass visual quality before the first experimental treatment ensured that the turf cover was uniform at both sites. After the start of experimentation, the following parameters were observed at monthly intervals: overall impression (visual merit), ground cover, shoot density, colour and diseases. At Landvik there was also one observation of volume percent water using a portable TDR probe in the 7 cm topsoil layer on 15 October, i.e. shortly before winter.

A short description of the characters is given below:

- Ground cover (plant coverage) is the percentage of a plot covered with healthy (undiseased) turf of the sown cultivar.
- Density is the number of shoots per area unit. The character was evaluated using a scale from 1 (very thin) to 9 (very dense turf).
- Colour was evaluated using a scale from 1 (very light) to 9 (very dark green).
- Diseases were assessed as percentage of a plot affected by turfgrass pests.
- Overall impression (visual merit / turf quality) is an overall score summarizing all characteristics mentioned above and emphasizing plot uniformity. Evaluation was carried out using a scale from 1 (very bad turf) to 9 (very good turf).

In order to study the effect of the biological product “Thatch less™” at Landvik, soil samples were taken and analyzed for the number of fungi, bacteria and fluorescent *Pseudomonas*. Samples were collected from the four combinations of the two nitrogen levels and thatch control treatments 3 and 4 at the lower topdressing level (12 samples altogether). Microbial densities were estimated using a dilution-plate technique.

All experimental data were analyzed using the SAS procedure PROC ANOVA. Significant differences were identified by LSD at the 5% probability level.

4.2. Results and discussion

Main effects of the various experimental treatments at Landvik are given in Table 11. The higher fertilizer level (1.5 as opposed to 0.75 kg N /100 m^2 /yr) led to higher overall impression, more complete ground cover, higher tiller density, darker green colour, and higher soil humidity. Nitrogen input and fertility requirements for velvet bentgrass are poorly presented in literature. Velvet bentgrass requires small amount of nitrogen (0.5-1.5 kg N /100 m^2/ yr) (Beard, 2002; Torello & Lynch, undated), but the amount of the fertilizer depends on green age. Skogley (1976) reported that velvet bentgrass response to fertilization changed during five years of experiments: During the first three years visual quality increased with nitrogen rate, but during the last two years the quality was completely reversed. Watson et al. (2007) tested velvet and creeping bentgrasses at several nitrogen rates (from 0.12 to 0.28 kg N/100 m^2/week) under controlled conditions. They concluded that both species showed positive response to increased nitrogen rate during grow-in, however, velvet bentgrass declined over time at the higher rates.

Table 11. Main effects of fertilizer level, mechanical / biological methods for thatch control and topdressing levels at Landvik. Data are means of 7 observations for overall impression, and 4 observations for ground cover, density, colour and diseases. Soil humidity was determined using a 7 cm long TDR probe on 15 Oct.

Factor	Treatment	Overall impression, (1-9)	Ground cover %	Density, (1-9)	Colour, (1-9)	Diseases,% of plot area	Soil humidity, vol %
Nitrogen level	0.75 kg/ 100 m^2/yr	2.9	72	4.1	5.1	22	20.0
	1.50 kg/ 100 m^2/yr	3.6	87	5.0	5.6	9	20.7
	Significance level	*	*	*	**	*	*
Mechanical/ biological methods for thatch control	Grooming	3.4	80	4.6	5.4	15	20.4
	Grooming + Verticutting	3.5	78	4.7	5.4	17	20.4
	Grooming + Coring	3.1	82	4.6	5.4	13	20.6
	Grooming + Coring + "Thatch less™"	3.0	78	4.4	5.4	16	20.0
	Significance level	**	*ns*	*ns*	*ns*	*ns*	*ns*
	LSD $_{5\%}$	*0.25*	-	-	-	-	-
Topdressing level	0.5 mm/2 weeks	3.4	82	4.8	5.4	13	20.6
	1.0 mm/2 weeks	3.2	77	4.4	5.4	17	20.1
	Significance level	**	*	***	*ns*	*	*ns (P%=8)*

Microbial analysis of diseased turf at Landvik showed the presence of at least two pathogenic fungi, namely *Microdochium nivale* and *Pythium* spp. (*P.torulosum* and/or *P.vanterpoolii*). Murphy et al. (2006) and Torello & Lynch (undated) considered establishment of velvet bentgrass to be difficult due to a seedling disease tentatively identified as a *Pythium* species. Murphy et al. (2006) found that the disease could be managed by limiting the seeding rate to 2.4-4.9 g/m^2. In our study the seeding rate was 6 g/m^2, which might have contributed to the relatively high percentage of plot area being affected by diseases during the establishment stage.

Nitrogen may also influence turfgrass diseases (Carrow et al., 2001; Fry & Huang, 2004). In the present experiment the higher nitrogen input of 1.50 kg/100 m^2/yr reduced diseases 2.5 times as compared with 0.75 kg N/100 m^2/yr (Table 11). Furthermore, it should be noticed that rainfall during establishment in June and especially in July, exceed the 30 yr normal values at Landvik (Fig. 7b), and this may also have promoted the development of diseases. The temperature during the same period was low (Fig. 6a), but *Microdochium nivale* and *Pythium* spp. occur in cold climates (Smiley et al., 2005).

Aeration methods in combination with topdressing help to improve soil physical properties (Carrow, 2004; Smith, 2004) and get thatch under control (Beard, 2002; Charbonneau, 2004). In a previous study at Landvik and Apelsvoll, velvet bentgrass accumulated more thatch than any other turfgrass species (Photo 2; Aamlid et al., 2006). In the present study, the mechanical thatch control methods affected the overall impression of velvet bentgrass. Because of the tough initial coring treatment on 31 July, the overall turfgrass impression remained lower on these plots than in plots that had only been groomed or groomed plus verticut for about six weeks (Fig. 8). This is an agreement with McCarty et al. (2005) who found that turfgrass overall impression of creeping bentgrass was slightly reduced from June to October because of scalping associated with core cultivation. None of the other characters in our experiment were significantly affected by mechanical or biological thatch control treatments, and there was also no significant interaction between this factor and any of the other factors in the trial.

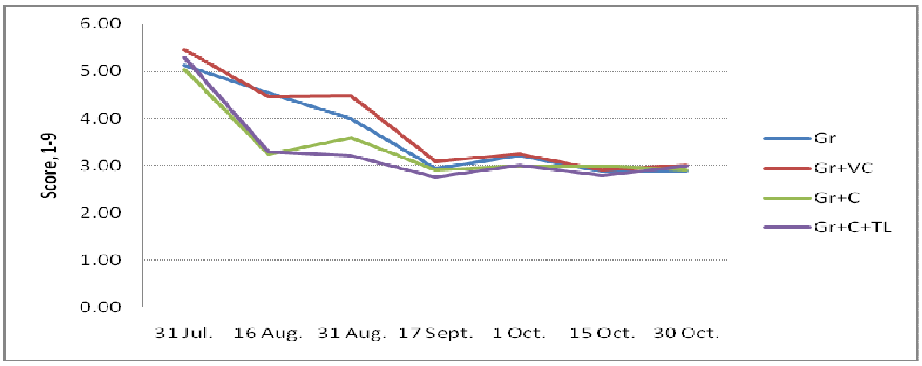

Fig. 8. Effect of thatch controll methods on overall impression of velvet bentgrass at Landvik (GR - grooming, VC – verticutting, C – coring, TL – "Thatch less^{TM}"

Although frequent and light topdressing has been advised for velvet bentgrass (Skogley, 1976), there is little research into optimal topdressing programs for this species. Doubling the amount of topdressing sand significantly decreased turfgrass overall impression, coverage and density and increased visual disease occurrence at Landvik (Table 11). Most interactions between fertilization and topdressing were also significant as shown in Table 12. Application of 1.0 mm sand every 2 weeks was obviously too much at the low nitrogen level. By contrast, topdressing had no significant effect on any of the parameters on plots receiving 1.50 kg N/100 m^2/ yr. This can be explained by a lower recuperative capacity at the combination of a low nitrogen and a high topdressing level.

Contradictory results have been reported regarding use of biological thatch control products (Berndt et al., 1990; McCarty et al., 2005). In this project, five applications of the biological product "Thatch less™" at Landvik had no significant effect on total bacteria or fungi numbers in soil samples taken in November 2007 (Fig. 9). The influence of "Thatch less™" on thatch development will be studied over the next years of the project.

Table 12. Turfgrass overall impression, ground cover, density, colour, diseases and soil humidity as affected by various combinations of nitrogen and topdressing in the trial at Landvik. Data are means of four methods of mechanical / biological thatch control, and 7 observation dates for overall impression and 4 observation dates for ground cover, density, colour and diseases. Soil humidity was determined using a 7 cm long TDR probe on 15 Oct.

N, kg/ 100m^{-2} yr^{-1}	Top-dressing, mm(2 weeks)$^{-1}$	Overall impres-sion, 1-9	Ground cover, %	Den-sity, 1-9	Colour, 1-9	Diseases, %	Soil humidity, vol %
0.75	0.5	3.1	78	4.4	5.2	17	20.1
	1.0	2.8	66	3.8	5.1	27	19.9
1.5	0.5	3.7	87	5.1	5.6	9	21.2
	1.0	3.6	87	4.9	5.7	8	20.2
Significance level (interaction)		*ns (P%=7)*	*	*	*ns*	*	*ns*
$LSD_{5\%}$		-	*7.4*	*0.2*	-	*5.5*	-

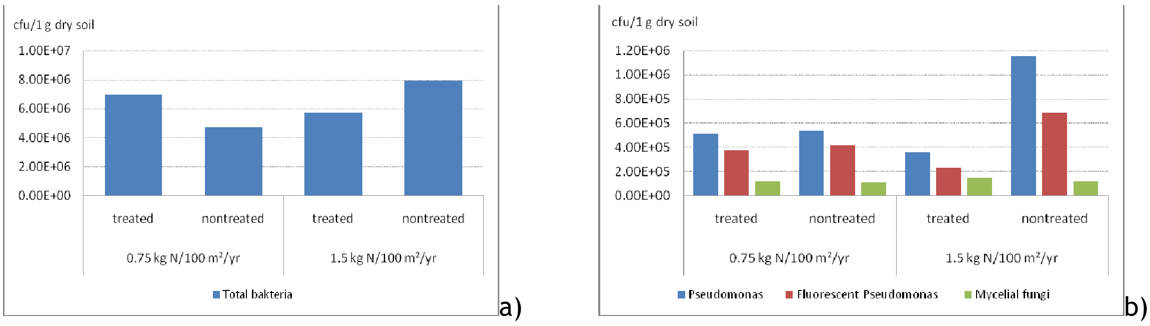

Fig. 9. Effect of "Thatch less™" on the number of cell forming units of bacteria (a) and other microorganisms (b) in soil samples.

Table 13. Main effects of fertilizer level, mechanical methods for thatch control and topdressing levels at Apelsvoll. Data are means of 2 observations for overall impression, ground cover, density, and colour and 3 observations for diseases.

Factor	Treatment	Overall impression	Ground cover, %	Density	Colour	Diseases, %
Nitrogen levels	0.75 kg/ 100 m^2/yr	3.5	87	6.0	4.3	32
	1.50 kg/ 100 m^2/yr	4.3	90	6.0	4.8	18
	Significance level	*ns (P%=6)*	*ns (P%=6)*	*ns*	*	*ns*
Mechanical methods for thatch control	Grooming	4.2	89	6.0	4.7	26
	Grooming + Verticutting	3.9	89	6.0	4.6	24
	Grooming + Spiking	3.7	89	6.0	4.5	23
	Significance level	*ns*	*ns*	*ns*	*ns*	*ns*
Topdressing	0.5 mm/2 weeks	4.0	89	6.0	4.7	22
	1.0 mm/2 weeks	3.8	88	6.0	4.5	27
	Significance level	*ns*	*ns*	*ns*	*	*ns*

Results from Apelsvoll are shown in Table 13. In this trial, the main effect of fertilizer level on turf overall impression and ground cover were almost significant (P%=6). Mechanical thatch control had no effect on any characters, but turf colour improved significantly with higher amount of nitrogen (1.50 kg vs. 0.75 kg N/ 100m^2/yr) and lower amount of topdressing (0.5 mm/2 weeks).

There was no significant effect of nitrogen and sand level separately on the percentage of plot affected by diseases at Apelsvoll (Table 13), but the interaction of these two factors had a significant effect on the development of diseases caused by *M. nivale* and *Pythium* spp. (Fig. 10). This is in good agreement with the results from Landvik (Table 12).

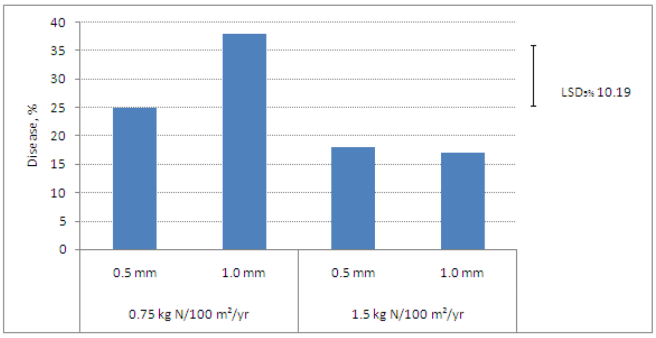

Fig. 10. Effect of fertilization and topdressing on percent of plot affected by Microdochium nivale *and/or* Pythium *sp. at Apelsvoll.*

4.3. Conclusions

At Landvik the higher nitrogen input of 1.5 kg/100 m^2/yr led to better turfgrass overall impression and less diseases than 0.75 kg/100 m^2/yr. As a main effect, light topdressing with of 0.5 mm sand every 2 weeks improved turf quality as compared with 1.0 mm every 2 weeks. As indicated by a significant nitrogen x topdressing interaction, 1.0 mm sand every 2 weeks was too much at the lower nitrogen level but had no effect on any of the of the recorded characteristics on plots receiving 1.50 kg N/100 m^2/ yr.

Grooming and its combination with verticutting led to better turfgrass overall impression than grooming plus coring or spiking, but differences between mechanical thatch control methods were not significant for any of the specific turfgrass characteristics in the trial at Landvik. Five applications of the biological product “Thatch-less™” in the grow-in year had no effect on total bacteria or fungi numbers in soil samples taken in November 2007.

Results from Apelsvoll showed significant improvements in turfgrass colour and almost significant (P%=6) improvements of overall turfgrass overall impression and ground coverage by doubling the nitrogen input from 0.75 to 1.5 kg N / 100m^2/ yr. Mechanical thatch control had no effect on any character, but turfgrass colour improved significantly with reduced amounts of topdressing (0.5 vs. 1.0 mm / 2 weeks). There was also a significant interaction as high amounts of topdressing sand had a negative impact on diseases occurrence (*M. nivale* and *Pythium* spp.) only at the lower nitrogen level.

5. Irrigation regimes on velvet bentgrass putting greens with different rootzone compositions

5.1. Materials and methods

5.1.1. Experimental site

This trial was conducted on an experimental green containing 16 lysimeters at Bioforsk Landvik (Fig. 6). The rootzones in all lysimeters had USGA profiles, but they were filled with two different growth media – either straight sand without organic matter or the same sand amended with 20% v/v garden compost ('Green Mix', Norsk Jordforbedring, Grimstad, Norway). The cation exchange capacities of the two media were 0.4 and 4.8 $cmol_c$/kg, respectively (Larsbo et al., 2008). In spring 2007, the sod in each lysimeter was removed and replaced with a new 4 cm top layer identical to the rest of the rootzones. On 8 June, the green was seeded to velvet bentgrass Legendary, at a rate of 0.6 kg per 100 m^2. Grow-in followed the same procedure as in section 4.1.2.

5.1.2. Experimental plan and implementation

Experimental treatments started on 21 Aug (10 weeks after sowing) and continued until 1 October. On 21 Aug., all rootzones were at field capacity after 42 mm rainfall on 20 Aug.

The experiment had four blocks (replicates). Each block consisted of four plots, two plots of each rootzone composition. The size of net experimental plots where all observations were collected, was 2.0 x 1.0 = 2 m^2, corresponding to the surface area of the lysimeters. Gross plots including borders measured 2.0 x 3.0 = 6 m^2.

Undisturbed cylinder samples for determination of capillary and air-filled porosities were taken in September 2007. As of 1 February 2008, the results of these analyses are not yet available, but samples taken in September 2006 at a depth of 2.0-5.7 cm on the same plots indicated water holding capacities (0.002 – 1.5 MPa tension) of 10.6 and 24.5 vol% on straight sand and 'Green Mix' rootzones, respectively (Larsbo et al., 2008). Assuming root development to 20 cm depth, this corresponds to field capacities of 21 and 49 mm, respectively.

The experimental plan was as follows:

Factor 1: Rootzone composition

1. Straight sand without organic matter
2. 'Green Mix' (20% v/v garden compost)

Factor 2: Irrigation regime

A. Field-capacity-based, or light and frequent irrigation. Water was applied at 5 mm water deficit on (24 % depletion of field capacity on sand plots and at 10 mm deficit (20% depletion of field capacity on 'Green Mix' plots.
B. Wilt-based, or deep and infrequent irrigation. Water was applied at 10 mm water deficit (48% depletion of field capacity) on sand plots and 20 mm deficit (40% depletion of field capacity) on 'Green Mix' plots.

For definitions of 'field capacity-based' and 'wilt-based' irrigation, see Fry & Huang (2004). The trial was irrigated by hand (Photo 11).

Evaporation was measured daily using a class A evaporation pan. Fig. 11 shows daily evaporation, precipitation and irrigation values as well as cumulative water deficit in the various treatments. The total evaporation and rainfall during the experimental period 21 Aug. – 1 Oct. were 65 and 80 mm, respectively. Nearly all of the rainfall came after mid September. Irrigation treatments were implemented by hand-watering each plot individually. The total amounts of irrigation were 35 mm, 45 mm and 25 mm in treatments 1A, 1B/2A and 2B, respectively.

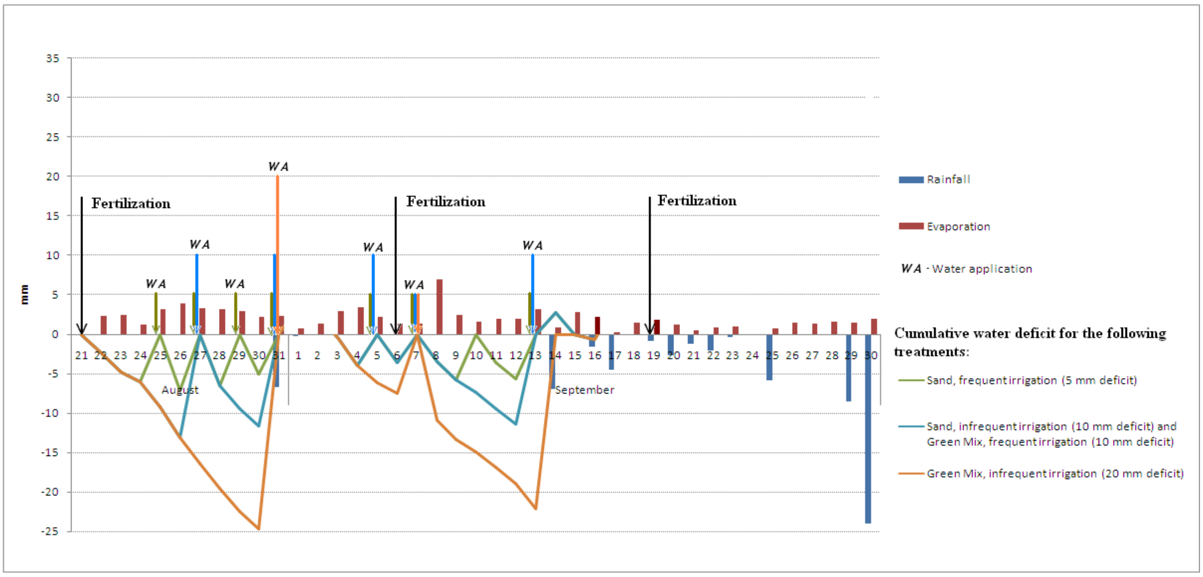

Fig. 11.Evaporation, natural rainfall, irrigation and estimated soil water deficit depending on irrigation regime on USGA-greens with and without organic amendment ('Green Mix') to the sand-based rootzone.

5.1.3. Mowing, fertilization and cultivation

After initiation of the trial on 21 Aug., the green was mowed at 3-4 mm three times a week (Monday, Wednesday and Friday). From mid September mowing heights were raised gradually until the last mowing to 4.5 mm on 2 October. During the experimental period 21 Aug – 1 Oct., fertilizer was applied three times at total rate 0.34 kg N per 100 m^2. There were also more two fertilizer applications in the late fall (Table 14).

Table 14. Fertilizer inputs in autumn 2007. Total inputs for N, P and K during the experimental period from 21 Aug. to 1 Oct. corresponded to 0.34, 0.04 and 0.25 kg/100 m^2, respectively.

Date	Fertilizer type	kg per 100 m^2							
		Fertilizer	N	P	K	Mg	S	Ca	Fe
21 Aug.	Arena Start 22-3-10	0.60	0.132	0.018	0.060	0.000	0.024	0.000	0.000
6 Sept.	Arena Green Plus 12-1-14	1.00	0.120	0.010	0.145	0.018	0.060	0.021	0.000
19 Sept.	Arena Start 22-3-10	0.40	0.088	0.012	0.040	0.000	0.016	0.000	0.000
3 Oct.	Arena Green Plus 12-1-14	0.70	0.084	0.007	0.102	0.013	0.042	0.015	0.000
16 Oct.	Arena Høst Extra 4-4-18	0.50	0.021	0.021	0.092	0.006	0.062	0.000	0.034
TOTAL			0.445	0.068	0.439	0.037	0.204	0.036	0.034

The green was groomed shortly before the start of experimentation in August. Sand without organic matter (grain size distribution 0.2-0.7 mm) was dressed on 7 Aug., 18 Sept. and 18 Oct., the total amount corresponding to 3.5 mm.

5.1.4. Registrations and statistical data manipulation

Registrations of turfgrass quality started on 26 Aug. and were carried out at two week intervals using the same characteristics as described in section 4.1.5.

Soil moisture was measured using a portable 7 cm long TDR probe “Moisture Meter” on 30 Aug., 6 Sep., 10 Sep. and 12 Sep. (Photo 12). As a somewhat delayed initial characterization of the two rootzones, soil samples from plots receiving ‘light and frequent irrigation’ were studied for moisture content and organic matter content at different depths on 12 September. Results from these analyses are shown in Fig.12.

Leaching water from the lysimeters was accumulated throughout the experimental period 21 Aug. – 1 Oct. Samples were analysed for nitrate and nitrite, total N, P and K concentrations at AnalyCen laboratory, and the total nutrient leakage calculated based on concentrations and the total amount of leakage water.

The experimental data were analyzed using the SAS procedure PROC ANOVA.

Photo 11. Irrigation by hand of the trial plots at Landvik (Photo: Tatsiana Espevig).

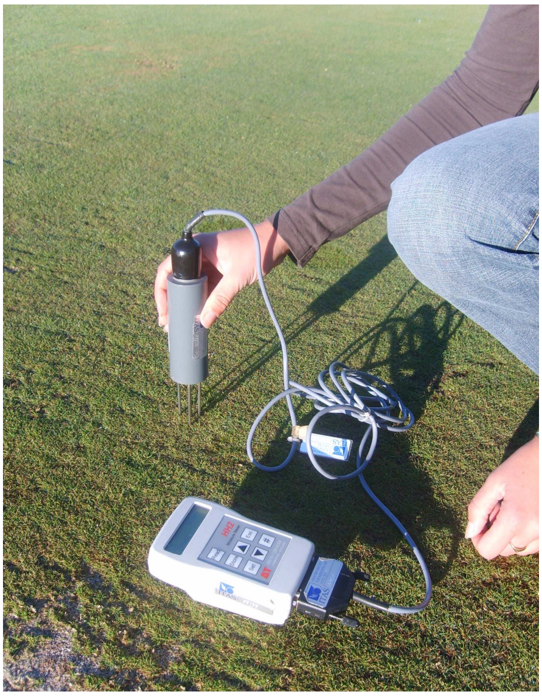

Photo 12. Measurement of soil moisture by a portable 7 cm long TDR probe “Moisture Meter” (Photo: Trygve S. Aamlid)

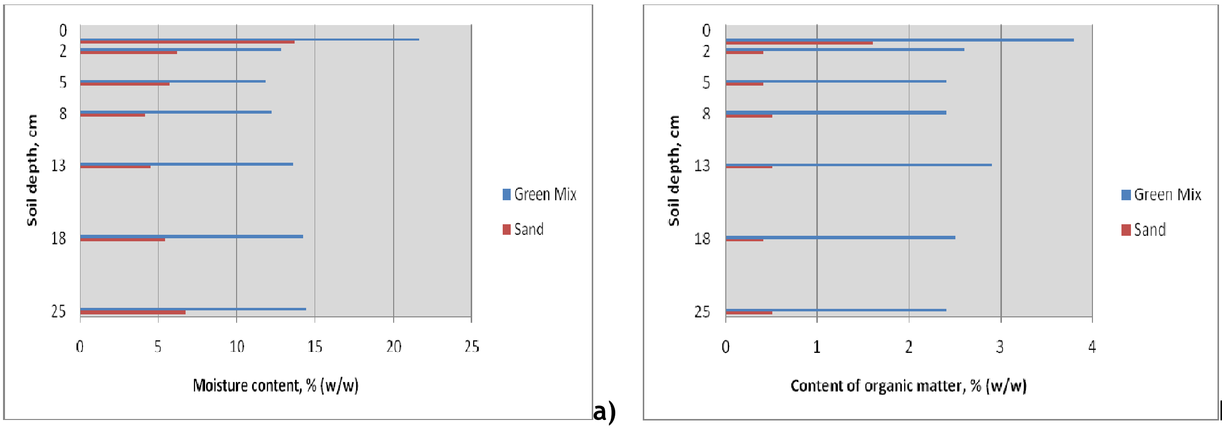

Fig. 12. Moisture content (a) and organic matter content (b) of the soil samples taken at different depths on 12 Sep. 2007.

5.2. Results and discussion

Irrigation requirements have been discussed for most bentgrasses (Jordan et al., 2003; Barton & Colmer, 2006; DaCosta & Huang, 2006), but there is not much information about optimal irrigation strategy on velvet bentgrass putting greens.

The main effect of the studied factors and their interactions on various turfgrass characteristics are given in Table 15. The velvet bentgrass had significantly better overall impression and less diseases when grown on 'Green Mix' than on straight sand rootzones. Only colour was independent of rootzone medium. This is in agreement with earlier studies showing that sand based rootzones may lead to leaching of major nutrient and therefore reduced turf quality (Carrow et al., 2001).

Table 15. Effect of rootzone composition and irrigation regime on turf quality. Data are means of 3 observations for density, 4 observations for ground cover and colour and 5 observations for overall impression and diseases. Soil humidity was determined using a 7 cm long TDR probe on 30 Aug., 6 Sept., 10 Sept. and 12 Sept.

Root zone composition	Irrigation regime	Overall impression	Ground cover, %	Density	Colour	Diseases, %	Soil humidity, %
Green Mix	-	3.9	92	4.9	5.2	7	16.9
Straight sand		2.9	84	4.4	5.2	10	11.3
Significance level		***	***	*	*ns*	*	***
-	Light, frequent	3.5	90	4.6	5.2	6	15.1
	Deep, infrequent	3.3	86	4.6	5.2	10	13.1
Significance level		*ns*	*	*ns*	*ns*	*	***
Green Mix	Light, frequent	3.9	93	4.9	5.3	6	18.0
	Deep, infrequent	3.9	91	4.9	5.2	8	15.7
Straight sand	Light, frequent	3.0	86	4.4	5.2	7	12.2
	Deep, infrequent	2.8	81	4.3	5.2	12	10.5
Sign. level (interaction)		*ns*	*ns*	*ns*	*ns*	*ns*	*ns*

Organic amendment of sand and-based media will also increase the media's water holding capacity, which in our case led to higher soil moisture contents on 'Green Mix' as compared with straight sand rootzones (Table 15, Fig. 12a). Reduced incidence of diseases on 'Green Mix' plots might be explained by suppressive propeties of compost (Grebus et. al, 1994; Boulter et al., 2002), but this point can be discussed.

In their experiments with deficit irrigation of creeping, colonial and velvet bentgrass fairways, DaCosta & Huang (2006) found that velvet bentgrass had lower water requirements than other bentgrass species. In our study, different watering regimes had no significant effect on turfgrass overall impression, density or colour, but field-capacity-based irrigation (light and frequent) led to significantly higher soil humidity, better turf coverage and less diseases than wilt-based irrigation (deep and infrequent) (Table 15).

Interactions between rootzone compostion and watering regime were not significant for any of the turfgrass characteristics.

Table 16 shows effects of the experimental factors on the leaching of major nutrients. As compared with 'Green Mix' plots, straight sand caused eight times more leaching of nitrate/nitrite and 70% more leaching of total nitrogen. For phosphorus and potassium, the situation was reversed, 'Green Mix' causing, in turn, seven times and two times more leaching than straight sand. For P and K, this suggests that the losses were not primarily due to fertilizer applicatons, but rather to leaching from the organic matter in the 'Green Mix' rootzone. Even for total nitrogen, losses only corresponded to 3 % and 6 % of the applied fertilizer on 'Green Mix' and straight sand rootzones, respectively (Tables 14 and 16). This is in agreement with Canadian greenhouse studies showing lower leaching losses from velvet bentgrass than from other turfgrass species (Paré et al., 2004). In their study, 6%, 11%, 11% and 37-57 % of a total fertilizer input of 1.0 kg N/100 m^2 over a six week growing period was leached from pots with velvet bentgrass, colonial bentgrass, creeping bentgrass, and annual bluegrass, respectively.

Table 16. Effect of rootzone compositions and irrigation regimes on nutrients' leaching

Root zone compo-sitions	Irrigation regimes	Concentration in leaching water				Lea-ching water, L/ m^2	Total content in leaching water		
		Nitrate and nitrite-N µg/L	Total nitrogen µg/L	Phosphor µg/L	Potassium mg/L		Nitrogen g/m^2	Phosphor g/m^2	Potassium g/m^2
Green Mix	-	302	1814	205	30.5	59.63	0.11	0.0124	1.83
Straight Sand		2413	3076	26	13.7	63.38	0.20	0.0017	0.87
Significance level		***	*	***	***	*ns*	*	***	***
-	Light, frequent	1356	2586	112	22.9	68.31	0.18	0.0072	1.51
	Deep, infrequent	1359	2304	119	21.3	54.69	0.12	0.0069	1.19
Significance level		*ns*	*ns*	*ns*	*ns*	*ns (P%=6)*	*ns*	*ns*	*
Green Mix	Light, frequent	370	1853	195	31.3	62.38	0.12	0.0122	1.95
	Deep, infrequent	235	1775	215	29.7	56.88	0.10	0.0126	1.71
Straight Sand	Light, frequent	2343	3320	28	14.5	74.25	0.25	0.0022	1.08
	Deep, infrequent	2483	2833	23	12.8	52.5	0.14	0.0012	0.67
Significance level (interaction)		*ns*	*ns*	*ns*	*ns*	*ns*	*ns*	*ns*	*ns*

Light and frequent irrigation can greatly reduce nutrient leaching losses, compared with heavy and less frequent irrigation (Kenna & Snow, 2000). While our results showed very small differences in nutrient concentrations, the total amount of leaching water was almost significantly (P%=6) higher from plots receiving light and frequent irrigation than from plots receiving infrequent and heavy irrigation. Although much of the leaching probably occurred after the heavy rainfall on 30 Septmeber (Fig. 11), this might reflect that the light and frequent irrigation treatment sometimes exceeding the soil's water holding capacity, at least on the straight sand rootzone. Despite this, differences in total nutrient losses were significant only for potassium, and the interactions between rootzone composition and irrigation regimes were not significant for any of the nutrients.

5.3. Conclusions

Turfgrass overall impression was better and disease levels lower with inclusion of organic matter (garden compost) in the rootzone. Different irrigation regimes had no significant effect on turfgrass overall impression, density or turf colour, but field-capacity-based irrigation (light and frequent) led to significantly higher soil humidity, better turf coverage and less diseases than wilt-based irrigation (deep and infrequent).

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