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

Report from the second experimental year 2008

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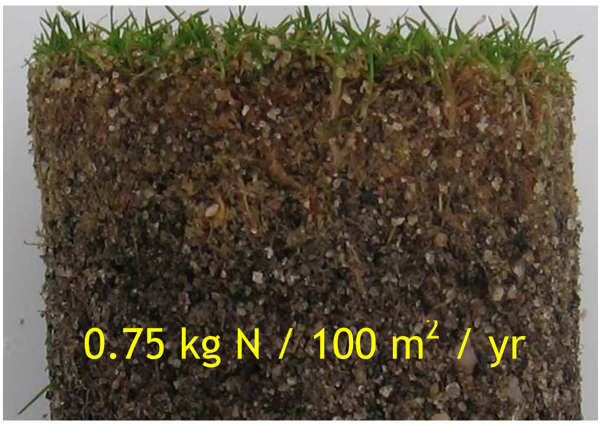

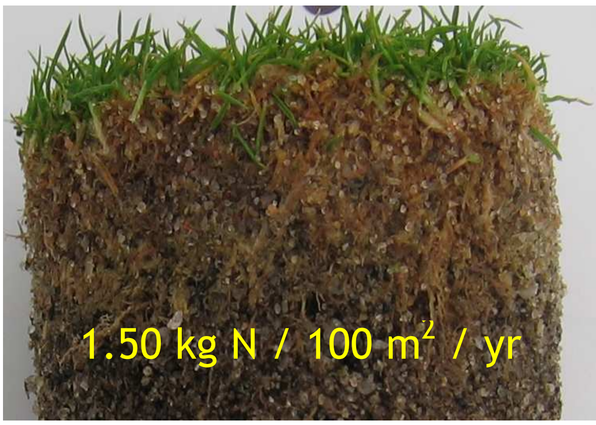

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Summary:

This is a progress report from the second 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 four main chapters, 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; the third describing experimental layout and preliminary results from a lysimeter study on irrigation stategies for velvet bentgrass on greens varying in rootzone composition; and the fourth describing a supplemental experiment evaluating the biological product 'Thatch-less' for thatch decomposition.

Bioforsk Øst Landvik 24 July 2009

Tatsiana Espevig | Trygve S. Aamlid

Contents

1. Abstract

Major concerns for the introduction of velvet bentgrass (*Agrostis canina* L.) 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, this second report from the project 'VELVET GREEN' gives an update from the following three subprojects: 1) Evaluation 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 root zone compositions. A supplemental experiment evaluating the biological product 'Thatch-less™' for thatch control is also described.

Three experiments comparing freezing tolerance of the velvet bentgrass cultivars 'Avalon', 'Greenwich', 'Legendary', 'Villa', 'Venus' and 'Vesper' with that of creeping bentgrass (*Agrostis stolonifera* L.) 'Penn A-4' (control) showed no significant difference between cultivars. For all cultivars, turf hardened at +2 °C for two weeks did not survive temperatures below -6 ºC, while turf that had been hardened for two additional weeks at -2 ºC mostly survived at –9 ºC and partly at -12 ºC. Only turf that had been hardened under natural outdoor conditions from August to January survived at -15 °C.

In two experiments exposing the same cultivars to various combinations of simulated snow cover, ice cover and winter diseases, creeping bentgrass 'Penn A-4' showed better winter survival than the velvet bentgrass cultivars, which were not significantly different. Hardening at subfreezing temperature was not included in these trials, but hardening at +2 °C improved the tolerance to these complex winter hazards as compared with unhardened plants.

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. Biweekly application of fertilizer corresponding to a seasonal rate of 0.75 kg N / 100 m^2 resulted in slower grow-in, more diseases and delayed repair after winter damage compared with to a seasonal rate of 1.50 kg N / 100 m^2. However, once the turf had developed complete coverage, 1.50 kg N / 100 m^2 resulted in slower ball roll and a softer surface due to excessive accumulation of thatch. Because of less winter damage and a longer growing season with higher temperature and more rainfall, thatch build-up was far worse at the coastal location Landvik than at the inland location Apelsvoll. Under coastal growing conditions, a seasonal input of at least 15 mm topdressing sand seems necessary to dilute and control the thatch layer on velvet bentgrass greens. Among the mechanical treatments investigated in these trials, verticutting produced a better playing surface with less thatch than spiking with solid tines, but spiking once or twice per season was necessary to maintain infiltration capacity. Application of the biological product 'Thatch-less' had no detectable effect on thatch thickness or organic matter content; this was also verified by a incubation experiment under controlled conditions.

A lysimeter field trial at Landvik was started in August 2007 to compare light and frequent (LF) and deep and infrequent (DI) irrigation on root zones with and without 20% (v/v) organic matter from garden compost. Until late May 2008, turfgrass overall impression was better and disease levels lower with inclusion of organic matter in the root zone. After this, irrigation regime was the overriding factor governing turf quality on both root zones. Compared with DI irrigation, LF irrigation improved turfgrass visual quality and reduced soil water repellency, but had no significant effect on ball roll distance or surface firmness. On straight sand root zones, LF irrigation (at 5 mm deficit) increased the total drainage volume, however, this was compensated by a lower concentration of nutrients in drainage water resulting in no significant difference in total nutrient losses. On compost-amended root zones, LF irrigation (at 10 mm deficit) caused a rapid increase in the ignition loss (organic matter content)of the thatch layer. This might suggest that other irrigation methods, i.g. deficit irrigation og longer irrigation intervals, may be advisable on such root zones.

The field trials continue in 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

There is a need for a turfgrass species that produce excellent playing surfaces without any high inputs of pesticides, fertilizers, or irrigation water. With appropriate management, velvet bentgrass (*Agrostis canina* L.), may become such a species. In our first report from the Scandinavian project 'VELVET GREEN' (Espevig et al., February 2008), we reviewed some experimental results this species, showing velvet bentgrass to be an environment-friendly alternative for golf course greens and fairways.

Since February 2008, at least three papers have been published that are relevant for velvet bentgrass cultivar selection and management and that show many of the positive characteristics of this species:

- On average for 24 locations across North America, the five velvet bentgrass cultivars included in the National turfgrass variety evaluation program were ranked in the order Villa > 'Legendary' = 'Venus' > 'Greenwich' > 'Vesper' > 'Avalon' (NTEP 2008).
- Velvet bentgrass performed better and was more resistant to invasion of annual bluegrass (Poa annua) than creeping bentgrass under traffic and wear stress in trials at Rutgers University, New Jersey. (Samaranayake et al. 2009).
- Velvet bentgrass 'Vesper' produced better turf quality, better resistance to dollar spot, quicker spring green-up and greater tiller density than creeping bentgrass 'Penncross' and 'L-93' in trials in Wisconsin (Koeritz & Stier 2009). In these trials, the quality of 'Vesper' was better at 2.5 than at 4.0 mm mowing height and at a seasonal N-rate of 146 kg N ha^{-1} compared to 48 kg N ha^{-1}. However, In another trial, the same authors found that velvet bentgrass produced high-quality turf even at 48 kg N ha^{-1} (Stier 2009).

The objectives of our 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 (*Agrostis stolonifera* L.), 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.
4. To implement the results from greenhouse and field trials on demonstration greens at golf courses in various parts of the Nordic countries.

This is the second annual progress report giving the status of the project by the start of the growing season 2009. The report consists of four main chapters. Chapters 3-5 correspond to subprojects 1-3 above. Chapter 4 reports results from a supplemental experiment evaluating the use of 'Thatch-less' to control organic matter accumulation on velvet bentgrass greens. Practical experiences with velvet bentgrass on Nordic golf courses are reported in Norwegian language in Appendix.

3. Winter survival of velvet bentgrass cultivars under controlled conditions

3.1. Summary of findings 2006-07

The first experiments evaluating tolerance of five velvet bentgrass cultivars and creeping bentgrass 'Penn A-4' to simulated winter hazards were conducted during the winter 2006-07 and reported by Espevig et al. (2008). In short, none of the tested cultivars, whether hardened or not, tolerated freezing to – 9 ºC or lower. This was probably due to incomplete hardening. The velvet bentgrass cultivars, especially 'Greenwich', tolerated freezing to -6ºC better than creeping bentgrass 'Penn A-4'. By contrast, 'Penn A-4' was less susceptible to *Microdochium nivale* than the velvet bentgrasses. Differences in tolerance to simulate ice or snow cover were not significant.

3.2. Experiments 2007-08 and 2008-09

3.2.1. Materials and methods

Establishment and hardening of plant material

In 2007-08, the six velvet bentgrass cultivars, 'Avalon', 'Greenwich', 'Legendary', 'Venus', 'Vesper', and 'Villa', and the creeping bentgrass cultivar 'Penn A-4', were sown at rate of 6.7 g/m^2 in 10 x 10 x 7.5 cm pots that 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 ten weeks (unhardened), or at the same temperature and light conditions for nine 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. The turf was mowed at 5-7 mm three times a week using a hand-held electric grass cutter 'Gardena'.

In 2008-09 the four velvet bentgrass cultivars, 'Avalon', 'Greenwich', 'Legendary', and 'Villa', and the creeping bentgrass cultivar 'Penn A-4' were raised in a growth chamber at the same temperature and light conditions as described above. In addition to unhardened plants, three treatments for hardening were included: 1) hardening for 2 weeks at 2 $^{\circ}$C (as in 2007-08); 2) hardening for 2 weeks at 2 $^{\circ}$C followed by 2 weeks in darkness at -2 $^{\circ}$C, and 3) natural hardening. For natural hardening, four velvet bentgrass cultivars, 'Avalon', 'Greenwich', 'Legendary', and 'Villa', and two creeping bentgrass cultivars, 'Penn A-4' and 'Nordlys', were sown at rate 6.7 g/m^2 on a green on 21 Aug. The plots were mowed with walk-behind mowers to 3 mm three times a week until the last week of September when mowing height was raised to 4 mm. The last mowing was performed in mid October. The plots were irrigated regularly and fertilized at biweekly intervals until late October. Plugs of cultivars, L x W x D = 10 x 10 x 7.5 cm were taken from the green and potted on 19 Jan., the day before freezing tests started. Until the start of freezing treatments, outdoor (naturally hardened) plants were exposed to temperatures and light intensities as shown in Fig. 1.

Evaluation of freezing tolerance, 2007-08 and 2008-09

Plants that had been exposed to various hardening conditions were transferred to a controlled climate chamber where they were incubated at 2°C for the first 12 h. Then temperature was lowered at a rate of 1°C h^{-1} to -2 where it was maintained for 24 h. After this, temperature was again then lowered at a rate of 1°C h^{-1} to -6, -9, -12 or –15 $^{\circ}$C, respectively, and maintained at these levels for 24 h. After 24 h exposure, temperature was increased at increments of 1 $^{\circ}$C h^{-1} to –2 $^{\circ}$C, at which it was maintained for 5 - 23 h before being increased to 2 $^{\circ}$C. The pots were then transferred back to the greenhouse and grown under the same conditions as before the freezing treatments.

Freezing tolerance was assessed visually as turf coverage, i.e. the percent of a pot covered with healthy grass, after 14 days in 2007-08 and 16 and 26 days of recovery in the greenhouse 2008-09.

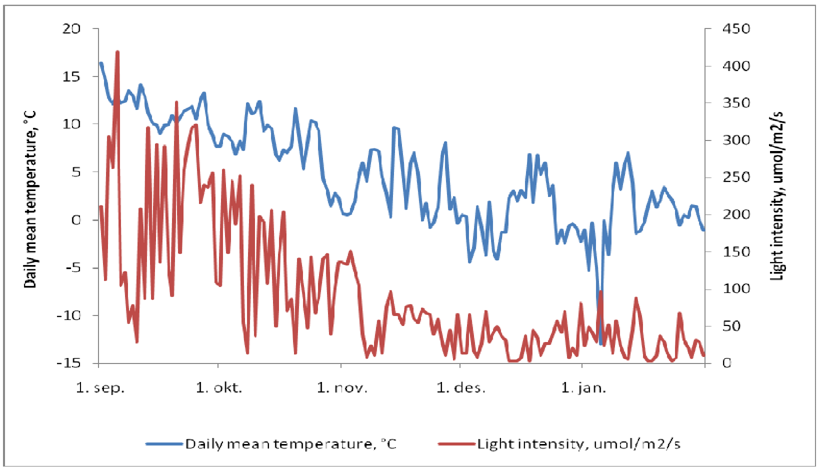

Fig. 1.

Mean diurnal temperature and mean diurnal light intensity (averaged over 24 h) at Landvik in autumn and early winter 2008-09.

(Bioforsk AgroMetBase)

Both experiments evaluating freezing tolerance had three replicate pots per combination of cultivar, hardening condition and freezing temperature. In 2008-09, an additional three pots per combination of cultivar and hardening conditions were included for analyses of water soluble carbohydrates. On the day of freezing treatments, plants in these pots were washed free of sand using cold water. The 1 cm crown region was isolated, dried at 60 °C for 48 h, weighted and analysed for glucose, fructose, sucrose and fructans in the Chemical laboratory at the Swedish University of Agricultural Sciences.

Evaluation of tolerance to ice cover, snow cover, and resistance to *Microdocium nivale, Typhula ishikariensis* and *T. incarnata* 2007-08

This experiment was carried out in 2007-08 as a follow-up and an extension of experiment one year earlier. Unhardened and hardened (+2 °C for 2 wk) plants were sprayed with approximately 2 ml per pot of a mycelial suspension of *M. nivale, T. ishikariensis* or *T. incarnata*. Norwegian isolates of the fungi were grown on Potato Dextrose Broth (PDB) for 14 days at 9 °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 °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 experiment had three replicates.

Statistical analyses

The results from all experiments were analyzed using the SAS procedure PROC ANOVA according to factorial designs with three factors (cultivar, hardening and freezing temperature) in the freezing tolerance experiment, and five factors (cultivar, hardening, duration of winter treatment, inoculation with winter diseases, and no cover vs. ice cover vs. snow cover) in the experiment with tolerance to ice cover, snow cover, and resistance to *Microdocium nivale, Typhula ishikariensis* and *T. incarnata*.

3.2.2. Results

Tolerance to freezing 2007-08 and 2008-09

Hardening and freezing temperature had significant effects on percent turfgrass coverage (survival), but differences between cultivars were insignificant in both experiments.

In 2007-08 there was virtually no survival after exposure to temperatures lower than -6 °, and there were no significant interactions among varieties and the other factors (Table 1).

Table 1. Main effects of experimental factors on turf coverage registered 14 d after freezing test, 2007-08.

Cultivars	Turf coverage, % (mean)	**Hardening**	Turf coverage, % (mean)	**Freezing temperature**	Turf coverage, % (mean)
Avalon	6	UH[1]	0	-6 °C	22 a
Greenwich	6	H (+2 °C)	11	-9 °C	0 b
Legendary	2			-12 °C	0 b
Venus	7			-15 °C	0 b
Vesper	8				
Villa	7				
Penn A-4	3				
Sign. level	*ns*		***[2]		***

1. UH: Unhardened. H +2: Hardened 2 wk at 2°C
2. The following significance levels are used in this table: *** : P < 0.1 %, ** : 0.01 % < P < 1 %,* : 1% < P< 5%, ns: not significant.

In 2008-09, plant coverage was significantly higher after 26 (Table 2) than after 16 (data not shown) days of recovery in the greenhouse. Unhardened plants had very low survival. Plants hardened at 2 °C for two weeks had an average of 89, 8, 0, and 0 % plant coverage after freezing to -6, -9, -12 and -15 °C, respectively (Fig. 2). This is in good agreement with the first experiment in this series (Espevig et al. 2008).

The survival of plants which had been hardened also at subfreezing temperature was not significantly different from those which had been hardened at 2 °C if frozen at – 6 °C (Fig. 2). However, and additional 2 weeks of hardening at - 2 °C significantly improved survival to 60, 57 and 30 % after freezing to -9 °C, -12 °C and -15 °C, respectively. Plants which had been hardened under field conditions, survived all freezing temperatures. This is also shown in Photo 1.

Table 2. Main effects of experimental factors on turf coverage registered 26 d after freezing test, 2008-09.

Cultivars	Turf coverage, % (mean)	**Hardening**	Turf coverage, % (mean)	**Freezing temperature**	Turf coverage, % (mean)
Avalon	44	UH[1]	0	-6 °C	69 a
Greenwich	47	H +2	24	-9 °C	42 b
Legendary	47	H +2/-2	58	-12 °C	39 b
Villa	44	NaturH	98	-15 °C	31 c
Penn A-4	44				
Sign. level	*ns*		***[2]		***

1. UH: Unhardened. H +2: Hardened 2 wk at 2°C. H+2/-2: Hardened 2 wk at 2°C followed by 2 wk at -2°C; NaturH: Hardened under natural field conditions.
2. The following significance levels are used in this table: *** : P < 0.1 %, ** : 0.01 % < P < 1 %,* : 1% < P< 5%, ns: not significant.

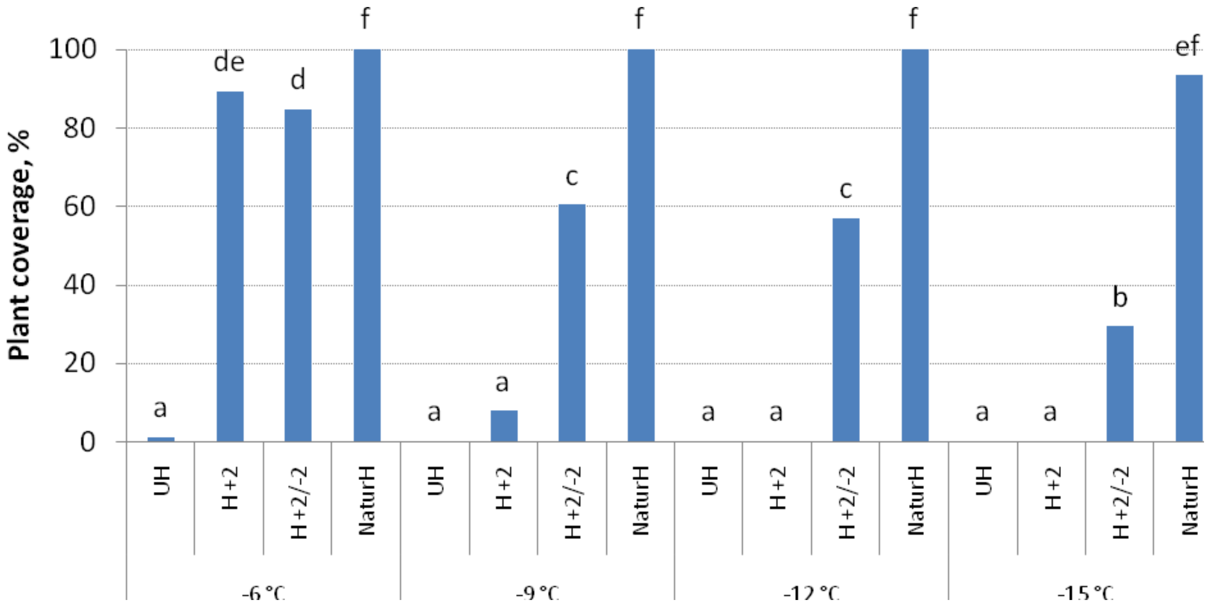

Fig. 2. Effect of hardening on plant coverage 26 days after exposure to freezing temperatures, 2008-08 experiment (means for plants hardened naturally under field conditions do not include Nordlys).

A separate ANOVA of plants hardened under field conditions showed significant differences in winter survival among cultivars after exposure to freezing at -15 °C. Creeping bentgrass 'Nordlys' and velvet bentgrass 'Villa' had the highest, and velvet bentgrass 'Avalon' the lowest survival (Fig. 3).

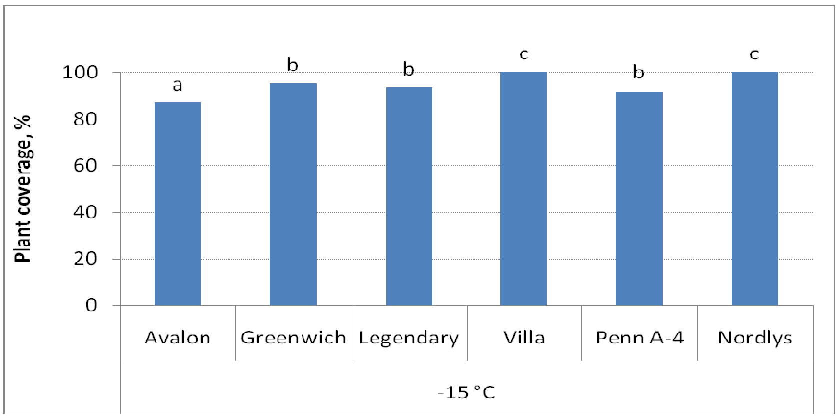

Fig. 3. Recovery of naturally hardened plants 26 days after exposure to -15 °C.

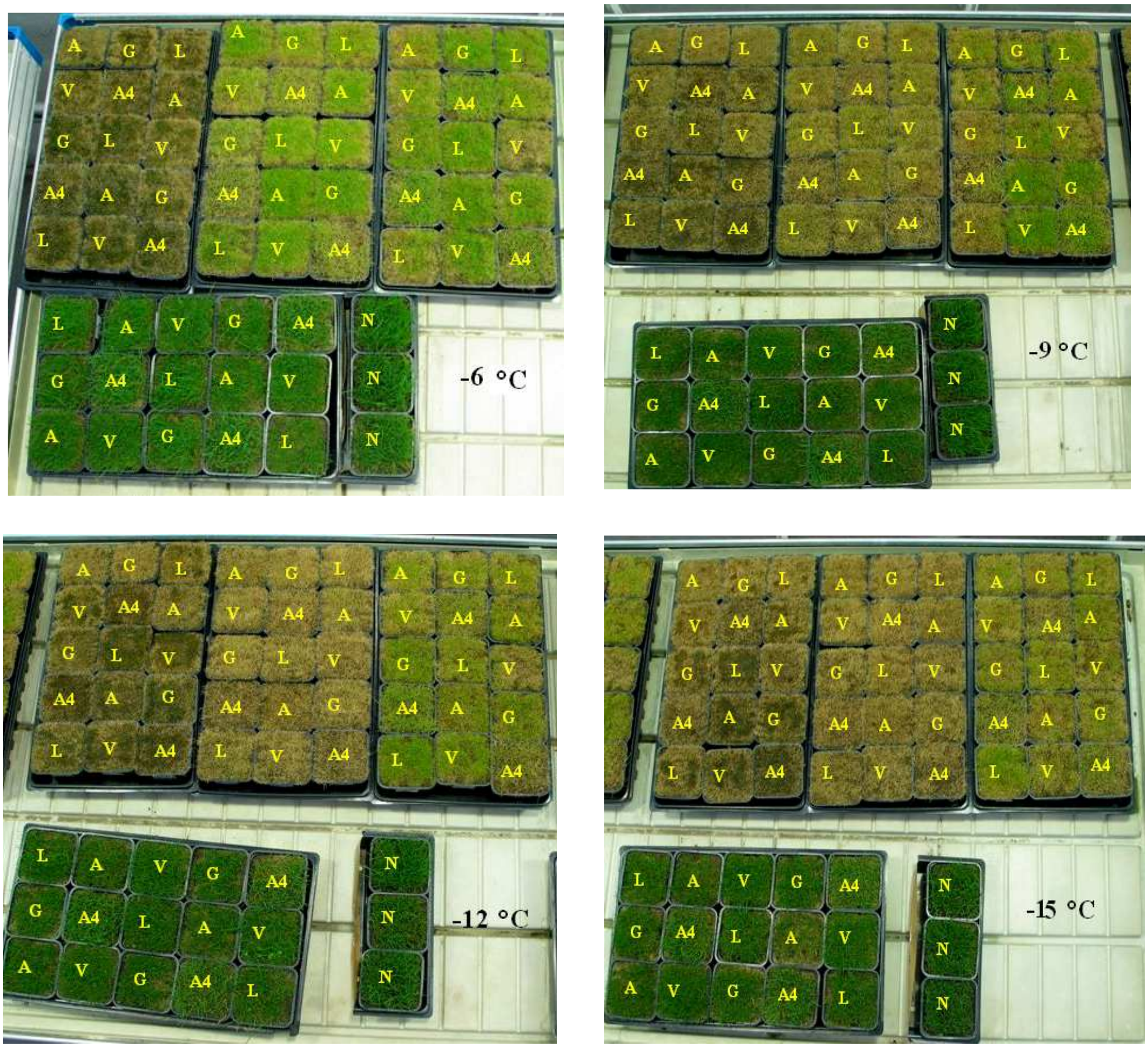

Photo 1. Recovery of plants 26 days after exposure to freezing temperatures, 2008-09. Trays in top row on each photo are from left to right: Unhardened plants; plants hardened for 2 wk at +2 °C; and plants hardened 2 wk at +2 °C followed by 2 wk at -2°C. Bottom rows are plants hardened under natural field conditions. A=Avalon, G=Greenwich, L=Legendary, V=Villa, A4=Penn A-4, N=Nordlys (Photo: Arne Tronsmo)

<u>Water soluble carbohydrates (WSC) in freezing experiment 2008-09</u>

The predominant WSC in turfgrass crowns were sucrose and fructans (Fig. 4). The monosaccarides glucose and fructose only contributed a minor part of the total WSC concentration. Compared with unhardened plants, both fructose, sucrose and fructan concentrations increased significantly during the two week hardening period at +2 °C. This may be due to the high light intensity during this period. Exposure to -2 °C in darkness had no further effect on these concentrations. Probably due to 60-70 % lower light intensity (Fig. 1), natural hardening resulted in total carbohydrate concentrations significantly lower than for plants exposed to artificial hardening (Fig. 4).

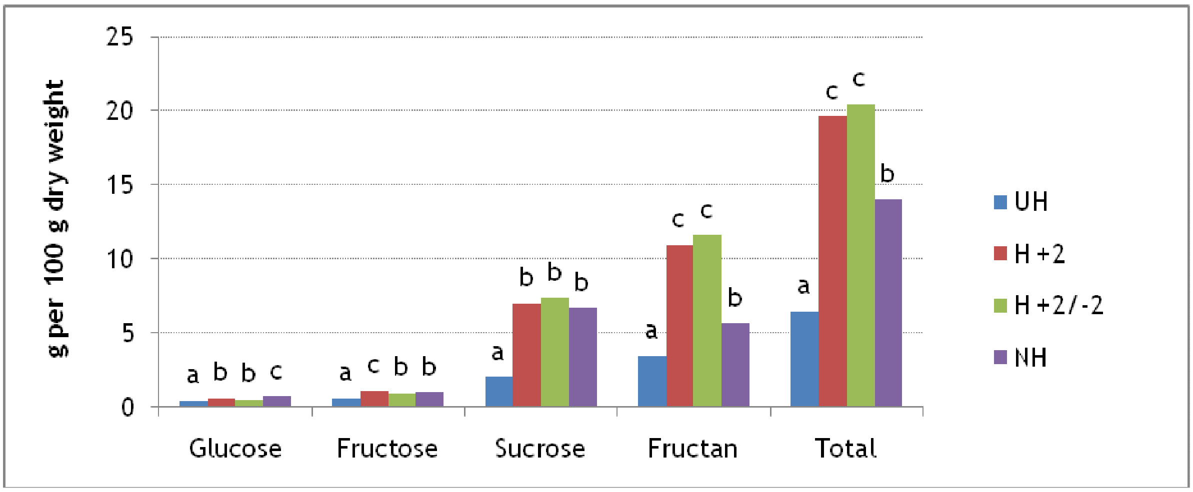

Fig. 4. Concentration of water soluble carbohydrates in crown dry matter as affected by hardening conditions. UH: Unhardened; H+2: Hardened at +2°C for two weeks; H+2/-2: Hardened at +2°C for 2 weeks followed by 2 weeks at -2°C; NH: Natural hardening, outdoor conditions.

On average for hardening conditions, 'Penn A-4' had significantly higher total WSC concentrations than the velvet bentgrass cultivars (Table 3). Among the velvet bentgrasses, more WSC accumulated in 'Avalon' than in 'Greenwich', 'Villa' and 'Legendary'. However, as the total weight of crowns was lower in 'Penn A-4', differences in total WSC per area unit was not significantly different among cultivars.

The cultivar x hardening interaction was not significant for WSC concentration in crowns.

Table 3. Main effect of cultivar on water soluble carbohydrate concentration in crown dry matter, crown dry weight and caluculated total WSC per area unit at the start of freezing treatments, 2008-09. Mean of four hardening treatments.

Cultivar	Total WSC, % of crown dry matter	Dry weight of crowns, g/m^2	Total WSC, g/ m^2
Avalon	15.7	190	30
Greenwich	14.3	193	28
Villa	14.2	191	27
Legendary	13.8	222	31
Penn A-4	17.7	166	29
Sign.	***	***	ns
LSD 5%	1.7	24	-

<u>Tolerance to ice cover, snow cover and/or infection by *M. nivale, T. ishikariensis and T. Incarnata*, 2007-08.</u>

Plant survival was generally lower than in the experiment conducted one year earlier (Espevig et al. 2008). We don't know the reason for this, but plants were generally weaker and possibly affected by other non-lethal diseases. Nonetheless, the results showed significant differences between cultivars. On average for all simulated winter conditions, 'Penn A-4' survived better than the velvet bentgrass cultivars. This is in agreement with Espevig et al. (2008). However, contrary to our previous data, 'Avalon' tended to survive the simulated winter conditions better than the other velvet bentgrass cultivars (Table 4).

As in the 2006-07 trial, the main effects of hardening and duration of simulated winter conditions were significant also in 2007-08 (Table 4). Prolongation of winter conditions from 6 to 12 weeks led to a decrease in survival. Hardening increased of cultivars' tolerance to ice cover, snow cover and/or infection by *M. nivale*, *T. ishikariensis* and *T. incarnata* (Fig. 5), but the exact effects of inoculation and ice or snow cover were less clearcut than those reported last year (Espevig et al. 2008).

Table 4. Main effects of cultivar, hardening, and duration of winter conditions on survival from Microdochium nivale, Typhula sp. and/or ice and snow cover, 2007-08.

Factors	Turf coverage, % (mean)
Cultivars	
Avalon	19 b
Greenwich	18 cb
Legendary	12 d
Venus	15 cbd
Vesper	16 cbd
Villa	14 cd
Penn A-4	35 a
Hardening	
Hardened	28 a
Unhardened	9 b
Duration of winter conditions	
6 weeks	28 a
12 weeks	9 b

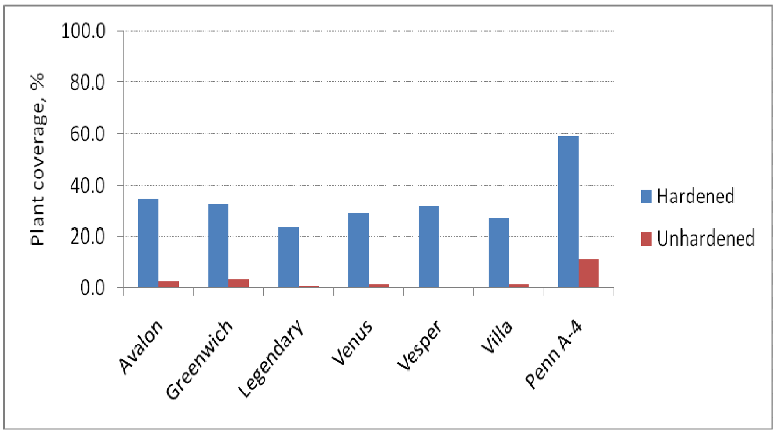

Fig. 5. Effect of hardening on cultivars' survival, $LSD_{5\%}$ =6.

3.3. Discussion, preliminary conclusions and further suggestions

3.3.1. Freezing tolerance

Little is known about winter hardiness of velvet bentgrass. Creeping bentgrass is reported to have a high freezing tolerance. However, freezing tolerance depends on several factors. The degree of hardening is one of them. Hardening, or cold acclimation, in perennial turfgrass species probably occurs in two phases – the first at relatively high temperature (2-5 ^{o}C) and the second at lower, subfreezing temperature (-2 ^{o}C). While the first phase is characterized by a rapid accumulation of carbohydrates, other physiological mechanisms, such as protein configuration, membrane plasticity and cell water content are probably more important during the second phase (Sakai and Larcher, 1987). The results from the 2008-09 experiment showed that hardening for two weeks at 2°C followed by two weeks at -2°C led to significantly better plant survival after exposure to freezing temperatures as compared with plants hardened at 2 °C only. Better freezing tolerance of plants hardened under natural outdoor conditions can be explained by the longer hardening period and perhaps by the exposure to subfreezing temperatures in early January (Fig. 1). Given the suggested role of sucrose as a cryoprotectant in plant tissue (Bhowmik et al., 2008) it is noteworthy that the ratio of sucrose to fructan (Gaudet et al., 1999) was higher after hardening under natural outdoor conditions than after hardening in growth chambers.

As in 2006-07 (Espevig et al. 2008), the main effect of cultivar on freezing tolerance was not significant in either of the two experiments reported here. At least for the varieties used in this project, it therefore seems that velvet bentgrass and creeping bentgrass has the same tolerance to freezing stress. This is also confirmed by recent data from our studies into physiological mechanisms for freezing tolerance in creeping bentgrass 'Penncross' and velvet bentgrass 'Greenwich' at Rutgers University (Espevig et al. unpublished). In the 2007-08 and 2008-09 trials, the interactions among hardening conditions, freezing temperature and cultivar were also mostly insignificant. As discussed above, a higher WSC-level in hardened plants of 'Penn A-4' did not confer a higher freezing tolerance, as other mechanisms related to the second phase of hardening were probably more important.

3.3.2. Tolerance to snow cover, ice cover and winter diseases

We have now two year results showing 'Penn A-4' to be more tolerant to a combination of *M. nivale* infection and snow or ice cover, than the velvet bentgrass cultivars. In our previous report (Espevig et al., 2008), we suggested that this was due to a differential tolerance in susceptibility to *Microdochium nivale* rather than a differential tolerance to prolonged ice and snow cover. Unfortunately, the results from 2007-08 are not of sufficient quality to either confirm or reject this hypothesis. We would therefore like to repeat this experiment one more time, and when doing so, it is probably useful to split it into two subtrials, one investigating the effect of increasing duration of exposure to simulated ice cover, and the other investigating the combination of winter pathogens and simulated snow cover.

What seems clear from the studies conducted so far, is that a hardening period at 2 ^{o}C improves turfgrass tolerance to ice, snow and winter pathogens. This is in agreement with other studies showing hardening to enhance both freezing tolerance and snow mould resistance. Whether there is an additional effect of subfreezing temperature on turfgrass tolerance to these types of winter damage, as there for freezing tolerance, warrants further investigation.

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

4.1. Materials and methods

Locations and experimental plan

Velvet bentgrass 'Legendary' was seeded on experimental greens at Bioforsk Landvik (Norwegian south coast, 58 °N, 12 m a.s.l.) and Bioforsk Apelsvoll (inland location north of Oslo, 61 °N, 250 m a.s.l.) on 30 May and 26 June 2007, respectively (See map, Fig.6). The rootzones were USGA-spec. sand amended with 15 % (v/v) of *Sphagnum* peat at Landvik and 20 % (v/v) garden compost ('Green Mix', Norsk Jordforbedring, Grimstad, Norway) at Apelsvoll.

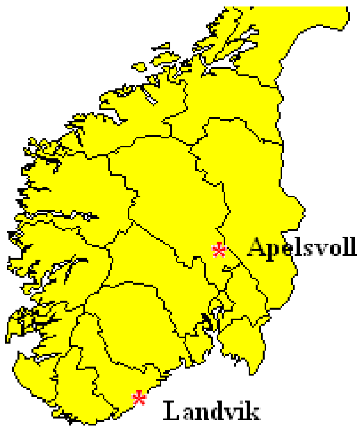

Fig. 6. Map of South Norway showing location of experiments

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 once a month
3. As 1 + spiking with 8 mm solid tines once a month
4. As 3 + the addition of the biological product 'Thatch-less' (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

The experimental design at both sites was split-plot with three blocks (replicates), two factor on main plots (combinations completely randomized) and one factor on subplots. At Landvik each block consisted of 8 main plots, each with 2 subplots. Due to size limitations, the corresponding numbers at Apelsvoll were 6 main plots with a total of 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.

Treatments were initiated on 31 July 2007 at Landvik and on 28 August 2007 at Apelsvoll. Experimental details and results from the first year 2007 were presented by Espevig et al. (2008). The major conclusions from the first experimental year were 1) that a nitrogen input of at least 1.50 kg N 100 m^2 was needed in the grow-in year; (2) that spiking with solid tines, and especially hollow-tine coring as early as two months after seeding was too early as the turf was still immature.

Weather conditions and irrigation, 2008

At Landvik, the winter 2007-08 implied occasional snow falls and frequent fluctuations between frost and thaw periods. There were periods with ice, but never for more than a couple of weeks. Green-up started in the second week of March, but in late March the green was covered with snow for about two weeks. This caused a severe outbreak of pink snow mould (*Microdochium nivale*),

At Apelsvoll, the first snow covered the green in mid November. After intermittent rainfall, the green was again covered with snow by the end of December; at this time also with a 1-2 cm layer of ice under the snow. The ice layer gradually became thicker, and on 27 March the green had 30 cm of snow and a 5 cm layer of ice. The snow had melted by mid April, but the growing season did not start before the end of April due to cold weather. All in all, the green had a continuous layer of snow and ice for at least 3.5 months, and these winter conditions caused a lot of damage. The experiment therefore had to be reseeded on 13 May 2008.

Temperature and rainfall data for the growing season 2008 are presented in Figures 7 and 8, respectively. At Apelsvoll, the mean temperature for the growing season was 1.0°C higher than the 30 year normal value, but it was still 1.5°C lower than the seasonal mean temperature at Landvik.

There was no rainfall from 2 May till 13 June at Landvik The rest of the season was rather wet, with almost 250 mm in August only. Although August had more rain than normal even at Apelsvoll, the total rainfall for the growing season was only 475 mm as opposed to 825 mm at Landvik.

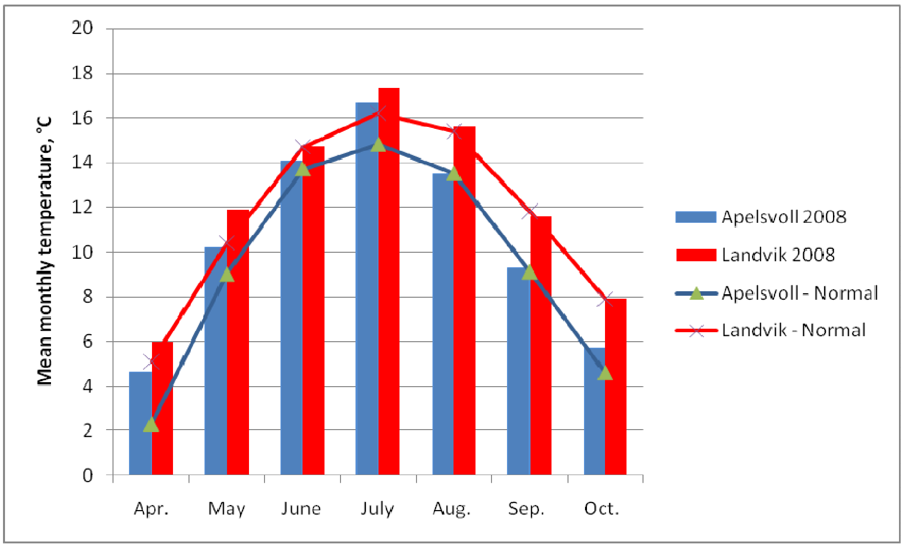

Fig. 7. Mean monthly temperature during the growing season 2008 and 30 year normal values at Apelsvoll and Landvik.

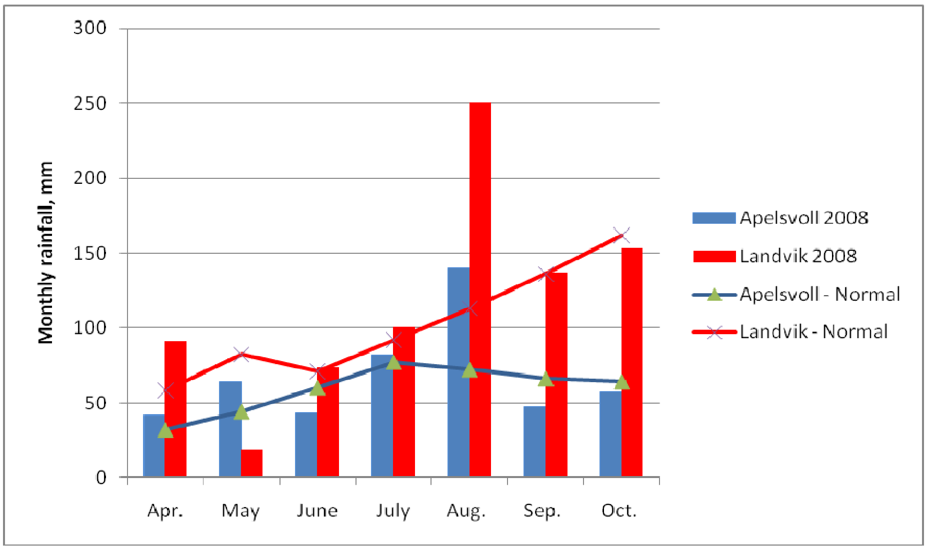

Fig. 8. Monthly rainfall during the growing season 2008 and 30 year normal values at Apelsvoll and Landvik.

The trials at both sites were irrigated whenever necessary. After reseeding on 13 May, the green at Apelsvoll was irrigated several times per day. During the dry period 2 May – 13 June, the experiment at Landvik was irrigated four times a week. The total amount of irrigation water was 130 mm, roughly corresponding to pan evaporation during the same period.

Soil analyses 2008

Soil samples taken in April 2008 showed lower pH and lower contents of phosphorus, potassium and magnesium in the experiment at Landvik than at Apelsvoll (Table 5). This reflects the use of *Sphagnum* peat as organic amendment to the root zone at Landvik vs. garden compost at Apelsvoll.

Table 5. Analysis of soil samples taken in spring 2008 at Landvik and Apelsvoll.

Research stations	pH (H_2O)	mg per 100 g dry soil			
		P-AL	K-AL	Mg-AL	Ca-AL
Apelsvoll	7.1	5. 5	4.0	4.1	60
Landvik	6.3	1.0	2.0	1.7	15

Implementation of experimental plan

Fertilizer was applied every second week according to the experimental plan. At Apelsvoll, fertilizer applications alternated between Arena products and ammoniumsulfate (due to the high pH), always granular products. At Landvik, granular products were used until late August, after which we also applied liquid fertilizer Arena Crystal in order to avoid uneven coverage and spots resulting from too big granules. Fertilizer treatments were usually followed by application of 3-5 mm irrigation water.

Because of the winter damage at Apelsvoll and the immature condition of the green also at Landvik, the first treatments for thatch control were suspended until 9 July at Apelsvoll and 25 June at Landvik. Summarized over the season, vertical cutting (treatment 2) and spiking (treatment 3) were carried out three times at Apelsvoll and six times at Landvik. In the additional treatment with biological thatch control at Landvik, 'Thatch-less' was applied seven times, usually after spiking but before dressing and irrigation.

Topdressing was carried out according to the experimental plan, in total nine times at Apelsvoll and fourteen times at Landvik. At Apelsvoll the sand was spread by hand in both treatments. At Landvik, 0.5 mm sand was spread over the whole experiment using a centrifugal dresser, and the additional 0.5 mm applied by hand according to the experimental plan. We always used washed sand with no organic matter and grain size 0.2-0.8 mm (Baskarp, Sweden). Dressing treatments were usually followed by irrigation.

Mowing

The trials were mowed with walk-behind green's mowers on Mondays, Wednesdays and Fridays. In early spring, mowing heights were adjusted to 4.5 mm at Landvik and 5 mm at Apelsvoll. These heights were gradually reduced to 3 mm in mid June. From early September at Apelsvoll and late September at Landvik, mowing heights were again raised to 4.5 mm.

Registrations and statistical data analyses

Visual evaluations of turfgrass quality started in mid-March at Landvik and early May at Apelsvoll. Assessments were carried out at biweekly intervals for turfgrass overall impression (visual merit) and monthly intervals for tiller density, colour, turf coverage and diseases. At Landvik, monthly recordings also included surface hardness using the Clegg Hammer (two drops per plot) and ball roll distance using a stimpmeter modified for research plots. The stimpmeter had its ball release notch 38 cm rather than 76 cm from the beveled end, and measurements were always taken in two directions. These registrations for playing quality were also carried out at Apelsvoll, but only in late September and October.

The thickness and organic matter content of the thatch/mat layer and deeper layers were analyzed in September at both sites. Four soil cores, 2 cm in diameter, were taken per plot, separated into the layers thatch/mat, bottom of thatch/mat to 4 cm, 4-6 cm and 6-10 cm and used to determine soil loss on ignition after drying at 550°C for 3 h.

Infiltration rates were measured in September/October, using a double ring infiltrometer with an outer ring diameter of 128.5 mm and an inner ring diameter of 45 mm. Both rings were filled with 8 cm water and the water level in the inner ring measured after three minutes. Two consecutive measurements were taken at two sites per plot and the four values averaged before statistical analyses.

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

4.2.1. Landvik

Visual assessments

The wet snowfall in late March caused an outbreak of *Microdochium nivale*, notably on plots that were weak after low fertilizer input in 2007 (Table 6). A significant fertilizer x topdressing interaction revealed that the infection was especially bad on plots that had also received the higher amount of sand. However, as the infection was superficial, most patches disappeared by the first week of May.

On average for all observations taken during the growing season, Table 6 shows that fertilizer rate and topdressing level were the overriding factors governing turfgrass coverage, overall impression, seasonal diseases and tiller density. The interactions between these factors were often significant. Turfgrass overall impression generally improved from April to late July, but then there was a decline in the very wet month of August (Fig. 9). Except for slightly more disease on plots with spiking and a reduction in tiller density on plots with verticutting, spiking and spiking plus 'Thatchless', mechanical and biological treatments had little effect on turfgrass visual quality.

Table 6. Main effects of fertilizer rate, mechanical and biological thatch control and topdressing on visual assessments and playing quality characteristics in experiment at Landvik, 2008.

	Turfgrass winter disease, % of plot area	Turfgrass overall impres-sion, 1-9	Turf-grass coverage %	Seasonal diseases, % of plot area	Tiller den-sity, 1-9	Ball roll dist-ance, cm	Surface hardness (gravi-ties)
Number of observations	2 (April)	12	8	7	7	5	6
Factor 1: Seasonal N input							
0.75 kg N/100m^2	24	3.7	88	9	4.6	124	79
1.50 kg N/100m^2	4	5.2	97	2	6.7	117	74
P%	*	**	***	**	**	**	*
Factor 2: Mechanical / biological treatment							
Weekly grooming only	12	4.4	94	5	5.8	121	78
Monthly verticutting	14	4.5	93	5	5.6	120	77
Monthly spiking	16	4.5	92	6	5.7	119	75
Monthly spiking + Thatch-less	16	4.5	92	6	5.6	121	76
P%	ns	ns	ns	8	*	ns	9
LSD 5%	-	-	-	-	0.1	-	-
Factor 3: Topdressing level							
0.5 mm every 2 weeks	10	4.7	94	4	6.0	121	76
1.0 mm every 2 weeks	18	4.3	91	7	5.4	120	77
P%	**	***	***	***	***	ns	7

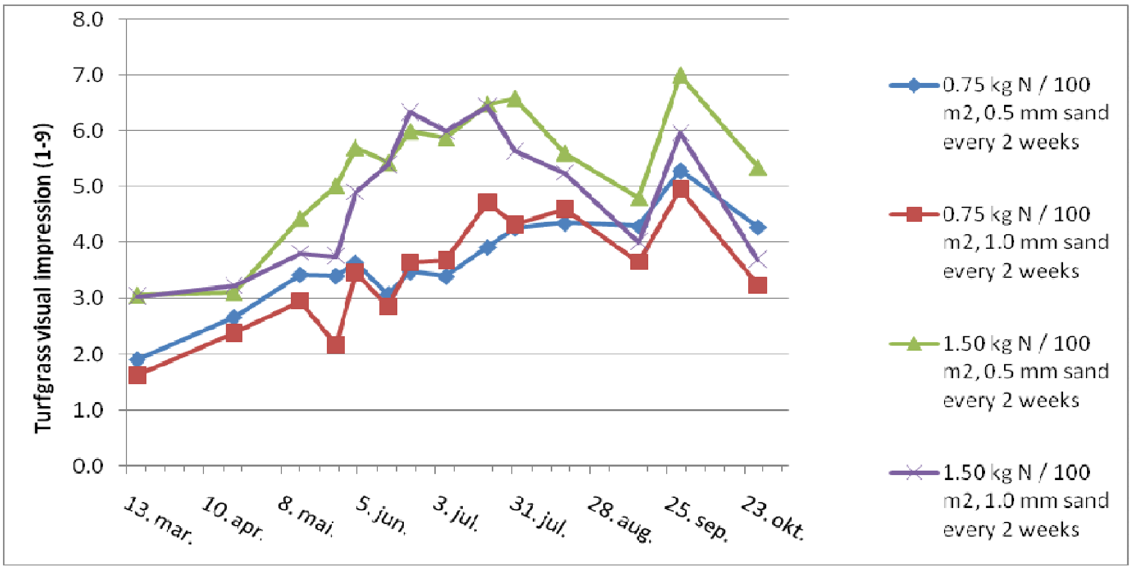

Fig. 9. Turfgrass visual quality over the season 2008 as affected by fertilizer rate and topdressing level in experiment at Landvik.

Playing characteristics

On average for five readings throughout the season, ball roll distance was significantly longer and the surface area significantly firmer on plots with the lowest N input (Table 6). Turfgrass ball roll distance was not affected by mechanical or biological treatments or topdressing, but spiking and the lower topdressing level tended give a softer surface on the green.

Thatch/mat thickness and per cent organic matter in various layers

When measured on 9 September the thatch/mat layer was significantly thicker on plots that had received the higher fertilizer and topdressing rates than on plots that had received the lower rates (Table 7, see also photos on the front cover of this report). Per cent organic matter in the thatch/mat layer varied from 5.5 to almost 10 %, with the highest content on plots with most fertilizer and least sand (Fig. 10).

Topdressing had no effect on per cent organic matter under the thatch/mat layer, but verticutting tended to reduce the accumulation of organic matter at 2-4 cm depth, and fertilizer rates tend to have an effect even at 2-4 cm depth.

Table 7. Main effects of fertilizer rate, mechanical and biological thatch control and topdressing on thatch/mat thickness, per cent organic matter in various layers and infiltration. All characters sere recorded in September at Landvik.

		% organic matter (ignition loss)				
	Thatch / mat thickness, mm, 9 Sep.	In thatch / mat layer	Thatch/ mat – 4 cm	4-6 cm	6-10 cm	Infiltration rate, mm/h
Factor 1: Seasonal N input						
0.75 kg N/100m^2	12	6.6	2.2	1.9	1.7	78
1.50 kg N/100m^2	16	7.6	2.5	2.0	1.6	77
P%	*	19	7	17	ns	ns
Factor 2: Mechanical / biological treatment						
Weekly grooming only	14	7.1	2.4	2.0	1.7	47
Monthly verticutting	14	6.9	2.1	1.9	1.7	52
Monthly spiking	14	7.0	2.4	1.9	1.7	107
Monthly spiking + Thatch-less	14	7.4	2.3	1.9	1.6	104
P%	ns	ns	10	ns	ns	7
LSD 5%	-	-	-	-	-	-
Factor 3: Topdressing level						
0.5 mm every 2 weeks	12	8.6	2.3	1.9	1.7	75
1.0 mm every 2 weeks	15	5.5	2.4	1.9	1.7	80
P%	***	***	ns	ns	ns	ns

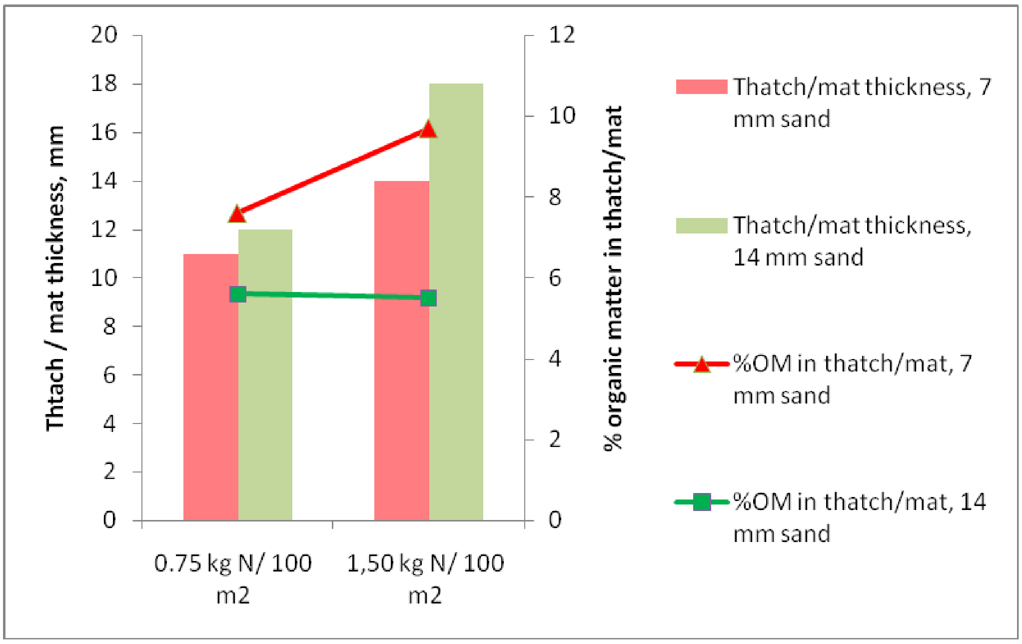

Fig. 10. Thickness and per cent organic matter in the thatch/mat layer in September 2008 as affected by fertilizer and topdressing rates over the season.

Infiltration

As compared with grooming only and grooming plus verticutting, spiking doubled infiltration rates in autumn (Table 7). Neither fertilizer rate nor topdressing level had any impact on this character.

4.2.2. Apelsvoll

Winter damage and visual assessments

After almost complete grow-in with a turf coverage of around 90% in autumn 2007 (Espevig et al. 2008), the experiment at Apelsvoll suffered severe damage during the winter 2007-08. As main effects, the damage tended to be worse on plots receiving the lower rate of nitrogen and the higher amount of topdressing sand in 2008 (Table 8). Part of the reason for the poor winter performance was winter diseases, both *Microdochium nivale* and *Typhula* sp.

After reseeding and dressing all plots on 13 May, the experiment gradually recovered. As shown in Fig. 11, recovery was stimulated by the higher amount of nitrogen and by verticutting as opposed to the other mechanical treatments. As the first experimental verticutting and spiking was not conducted until 9 July, some of the advantage of verticutting can possibly be traced back to better winter survival on these plots (Table 8). When averaged over the whole season, turfgrass coverage, and overall impression were higher and per cent of plot area infected by diseases lower on plots being verticut and fertilized with the highest amount of nitrogen. Topdressing levels had little influence on the visual assessments in this trial.

Table 8. Main effects of fertilizer rate, mechanical treatment and topdressing on visual assessments, and playing quality characteristics in experiment at Apelsvoll.

	% winter damage, 2 May, 2008	Overall impression (1-9)	Turfgrass coverage, %	Diseases , % of plot area	Tiller density (1-9)	Ball roll distance, cm	Surface hardness (gravities)
No of observations	1	11	5	7	5	3	1
Factor 1: Seasonal N input							
0.75 kg N/100m^2	54	3.8	85	16	4.9	106	75
1.50 kg N/100m^2	46	5.3	91	12	6.4	103	72
P%	8	<0.1	<5	<5	<1	<5	7
Factor 2: Mechanical treatment							
Weekly grooming only	55	4.3	87	15	5.6	102	78
Monthly verticutting	43	4.9	90	12	5.7	106	79
Monthly spiking	51	4.4	87	15	5.6	106	64
P%	>20	<1	<5	<1	>20	<5	<1
LSD	-	0.3	2	2	-	3	4
Factor 3: Topdressing level							
0.5 mm every 2 weeks	53	4.5	88	14	5.7	105	72
1.0 mm every 2 weeks	47	4.6	88	13	5.6	104	75
P%	13	>20	>20	>20	>20	>20	<1

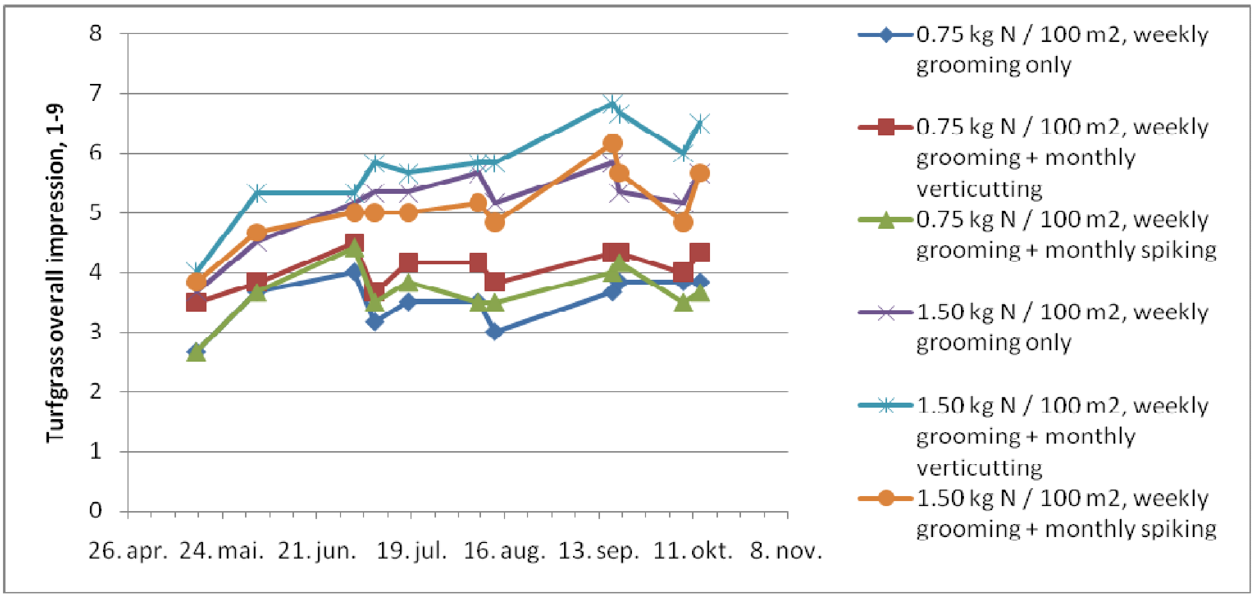

Fig 11. Assessments of turfgrass visual quality over the season as affected by fertilizer rate and mechanical treatments in experiment at Apelsvoll.

Playing quality

On average for measurements on 19 September, 23 September and 13 October, ball roll distance was significantly longer on plots receiving the lowest rate of nitrogen and either verticutting or spiking treatments compared with grooming only. The higher nitrogen rate, lower topdressing rate, and particularly spiking treatments (the last one conducted on 18 Aug, i.e. one month before measurement), resulted in a softer green surface (Table 8).

Thatch/mat thickness and organic matter content

Doubling the biweekly amount of topdressing sand from 0.5 to 1.0 mm resulted in a significant increase in thatch thickness when measured on 19 September (Table 9). Although soil samples taken on 10 October showed the ignition loss of the thatch/mat to be surprisingly low, there was a significant dilution effect of more sand as evidenced by the lower organic matter content in the thatch/mat layer.

Table 9. Main effects of fertilizer rate, mechanical treatment and topdressing level thatch/mat thickness, per cent organic matter in various layers and infiltration rate in experiment at Apelsvoll.

	Thatch/ mat thickness, mm	% organic matter (ignition loss), autumn 2008				Infilt- ration, mm/h
		In thatch/ mat	Thatch/mat – 4 cm	4-6 cm	6-10 cm	
Factor 1: Seasonal N input						
0.75 kg N/100m^2	11	1.2	1.3	1.1	1.5	547
1.50 kg N/100m^2	11	1.2	1.4	1.2	1.4	468
P%	>20	>20	>20	>20	>20	12
Factor 2: Mechanical treatment						
Weekly grooming only	11	1.3	1.4	1.2	1.4	268
Monthly verticutting	11	1.3	1.4	1.2	1.5	344
Monthly spiking	11	1.2	1.4	1.1	1.4	910
P%	>20	>20	>20	>20	>20	<1
LSD 5%						223
Factor 3: Topdressing level						
0.5 mm every 2 weeks	10	1.3	1.4	1.2	1.4	516
1.0 mm every 2 weeks	11	1.2	1.4	1.2	1.4	499
P%	<0.1	<5	>20	>20	>20	>20

Infiltration

Use of the double-ring infiltrometer on 16 October showed very high infiltration rates on all plots. While there was a tendency to better infiltration on plots receiving the lowest input of fertilizer (Table 9), spiking treatments, the last on 23 September, more than doubled infiltration rates. Topdressing levels had no significant effect on this character.

4.3. Discussion

As shown in Figs. 7 and 8, the experiments at Landvik and Apelsvoll are carried out under very different climatic conditions. A longer growing season and more rainfall causes more problems with thatch build-up and organic matter accumulation at Landvik, and this difference becomes even more conspicuous as the green at Apelsvoll will often have to be reseeded (restarted) in spring due to winter injury. The results suggest that ignition loss of the uppermost 1-2 cm layer is a better indicator of organic matter accumulation than the actual thickness of the thatch/mat layer.

In principle, there are at least three ways to avoid organic matter build-up or a green, namely (1) avoid excessive growth; (2) mechanical removal; and (3) dilution. Each of the three experimental factors (a) fertilizer rate, (b) mechanical treatments, and (c) amount of sand used for topdressing, correspond to one of these. A fourth way to avoid organic matter build-up is to stimulate microbial decomposition. This was attempted by using 'Thatch-less' at Landvik, but our results so far show that this microbial product had no effect. This is futher discussed in chapter 6 of this report.

The lowest seasonal fertilizer rate, 0.75 kg N/100 m^2, did not produce greens of acceptable quality in the grow-in year 2007 at Landvik and Apelsvoll, and certainly not in spring 2008 after winter damage at Apelsvoll. However, in light of the firmer greens with better speed and less organic matter in the upper layer, it might be argued that the lower fertilizer rate of 0.75 kg N/100 m^2 was sufficient on the established green at Landvik, at least during the latter part of the growing season. In Photo 2, taken at Landvik on 22 July, there is no doubt that the higher fertilizer inputs resulted in darker greens, but the playing quality may not have been better, and the management perhaps less sustainable in the long run.

Photo 2. Experiment at Landvik, 22 July 2008.

Among the mechanical treatments imposed in this experiment, vertical cutting was better than the grooming and spiking both with regard to visual quality, playing quality, and organic matter accumulation. On well-established greens, the frequency of verticutting may perhaps be increased from once per month to once every two weeks. The only advantage of spiking (soild tines) in these trials was that it improved infiltration rates. Although it was not documented in these trails, spiking most likely also improved the oxygen content of the topsoil layer. This may be important once or twice per season, but it is not sufficient as a general measure to control thatch on velvet bentgrass greens. Other mechanical thatch control treatments and combinations warrant further investigation.

Given a seasonal nitrogen input of 1.5 kg N 100 m^2, the higher topdressing level, 14 mm over the season, was clearly necessary to provide reasonable thatch control in the trial at Landvik. Given an average green size of 400 m2, this corresponds to 100 m3 or 160 tonnes of sand for dressing of the greens on an 18 hole golf course. A reduction in N input, at least during the latter part of the season, will of course reduce this requirement.

4.4. Preliminary conclusions

1) The problem with thatch accumulation on velvet bentgrass greens is far worse in coastal areas with a long and wet growing season than in inland areas with a shorter and dryer season (and growth reductions due to winter injuries).
2) Velvet bentgrass greens need to receive at least 1.5 kg N/100 m^2 in the grow-in year and corresponding amounts during repair of winter damages, but it is important to back off, perhaps to a rate corresponding to 0.75 kg N/100 m^2, as soon as turf coverage is complete.
3) Vertical mowing every two to three weeks seems to be a good way of reducing thatch on velvet bentgrass greens. Other mechanical methods / combinations may be explored. Spiking with hollow or solid tines should be accomplished once or twice per year to improve infiltration and the soil oxygen content.
4) The biological product ‘Thatch-less’ seems to have no effect under Scandinavian conditions.
5) The amounts of topdressing sand needs to be adjusted depending on length of growing season, irrigation and fertilizer rate. In coastal areas, golf courses with velvet bentgrass greens should have a budget for at least 15 kg fine sand per m^2 per season.

Photo 3. Spiking in experiment at Landvik.

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

5.1. Materials and methods

5.1.1. Experimental site and soil water holding capacity

The trial was conducted on an experimental green containing 16 lysimeters at Bioforsk Landvik (See Figs. 6-8 for geographical location and weather data). The root zones in all lysimeters had USGA profiles, but they were filled with two different growing media – either straight sand without organic matter (SS) or the same sand amended with 20% v/v garden compost (GM: 'Green Mix', Norsk Jordforbedring, Grimstad, Norway). In spring 2007, the sod in all lysimeters was removed and replaced with a new 4 cm top layer with a similar composition as the rest of the root zone. The experiment was seeded on 8 June 2007. Initial irrigation treatments were carried out from 21 Aug. to 1 Oct. 2007 as reported by Espevig et al. (2008).

Data from undisturbed soil cores taken at 13-50 and 150-187 mm depth in October 2007 are given in Table 10. On average for two depths, total porosity was significantly higher in the GM than in the SS root zones. As air-filled porosity tended to be higher in the SS root zone, the difference was wholly due to a higher content of capillary pores (water-filled micropores) after amendement with compost. The soil's capacity to store easily available water (pF 1.5-3.0) was only marginally higher in the GM than in the SS root zone, but the storage of tightly bound water (pF 3.0-4.2) was much higher, as was the content of unavailable water. Because of higher ignition loss, soil density was also lower in the GM rootzone (Table 10).

Table 10. Main effects of rootzone composition and soil depth on physical characteristics analysed in soil cores taken on 15 October 2007. (SS: Straight sand root zone; GM: Compost-amended (Green Mix) root zone.)

	Porosity, %		Plant-available water, %			Unavailable soil water, (pF>4.2) %	Soil density kg dm^{-3}	Ignition loss, %	Hydraulic conductivity, mm h^{-1}
	Total	Air-filled[1)]	pF 1.5 - 3.0	pF 3.0 - 4.2	Total				
Rootzone									
GM	43.3	19.4	15.1	6.0	21.0	2.9	1.416	2.14	210
SS	36.9	21.6	13.4	1.4	14.8	0.5	1.571	0.54	232
P%	<0.1	10	18	<0.1	<0.1	<0.1	<0.1	<0.1	7
Depth, mm									
13-50	40	18	16.2	3.9	20.1	1.9	1.509	1.52	213
150-187	40.2	23	12.2	3.5	15.8	1.4	1.478	1.16	229
P%	>20	<1	<1	>20	<1	>20	>20	>20	17

[1)]At 30 cm suction (pF 1.5).

On average for root zone material, air-filled (macro)porosity was higher and the water holding capacity lower at 150-187 mm depth than in an just below the thatch layer. For plant-available water capacaity, there was, however, a significant (P%<1) interaction as there was virtually no effect of depth in the GM root zone, but much less plant-available water in the lower than in the surface layer in the SS root zone (Fig. 12). Possible explanations for this interaction might be (1) that the sand used to replace the top layer after removal of sod from earlier experiments on SS plots in spring 2007 was finer than the sand used during construction in 2003, and (2) that the top layer of the SS rootzone was more liable to a reduction in average pore size due to compaction than the top layer of the GM root zone.

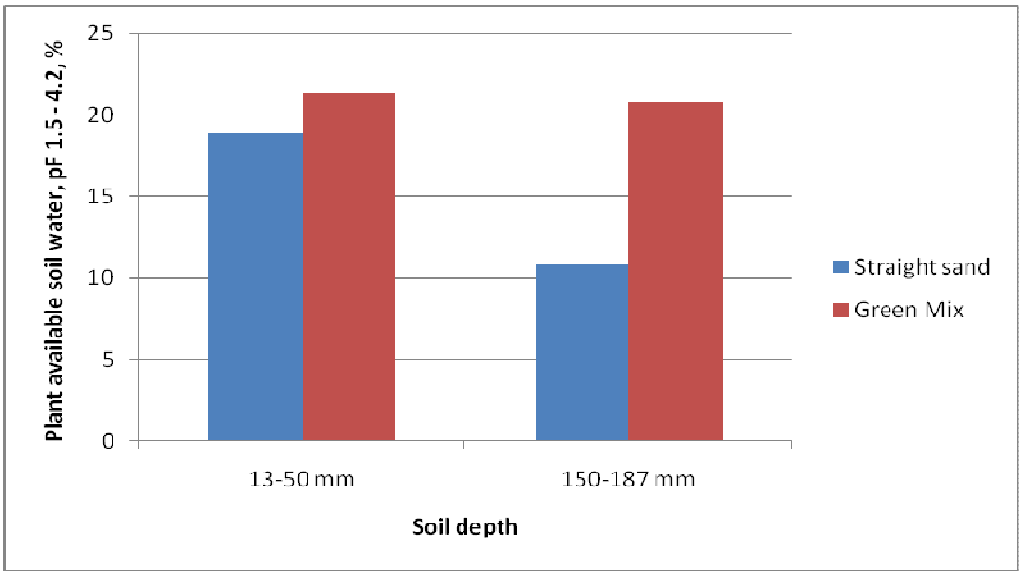

Fig. 12. Plant available water capacity (pF 1.5 – 4.2) as affected by root zone and soil depth.

On the assumptions of (1) 20 cm root depth in both root zones, and (2) that the data from 13-50 mm and 150-187 mm soil depths are representative for the 0-5 and 5-20 cm layers, respectively, the total water holding capacity for GM and SS root zones can be calculated as 42 and 25 mm, respectively.

5.1.2. Experimental plan and implementation

The experimental plan was as follows:

Factor 1: Root zone composition (growth media)

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

Factor 2: Irrigation regime

A. LF: Light and frequent irrigation ('field-capacity-based'). Water was applied at 5 mm water deficit (20% depletion of the total water-holding capacity) on SS plots and 10 mm deficit (24% depletion of the total water-holding capacity) on GM plots.
B. DI: Deep and infrequent irrigation ('wilt-based'). Water was applied at 10 mm water deficit (40% depletion of the total water-holding capacity) on SS plots and 20 mm deficit (48% depletion of the total water-holding capacity) on GM plots.

The experiment had four blocks (replicates). Each block consisted of four plots, two plots of each root zone composition. The size of net 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. The trial was irrigated very precisely using a wagon with drip nozzles at 20 cm x 20 cm distance and natural pressure from overlying barrels filled with the exact amount of water needed for 2.0 x 3.0 = 6 m^2 (Photo 4).

Photo 4. Plot irrigation wagon used in experiment.

Results from the first experimental year 2007 were presented by Espevig et al. (2008). Preliminary conclusions were (1) that turfgrass quality was better on GM than on SS root zones, and (2) that light and frequent irrigation resulted in more complete coverage and less diseases than deep and infrequent irrigation.

In 2008, experimental treatments started on 2 May and continued until 1 October. On 2 May all root zones were at field capacity after 24 mm rainfall on 1 May. Daily rainfall and evaporation from an open pan evaporimeter dug into the soil was measured every day at 1100h. Daily rainfall, pan evaporation, irrigation and soil deficit values are illustrated in Fig. 13 and monthly values summarized in Table 11.

Table 11. Monthly values for rainfall, pan evaporation and irrigation on straight sand (SS) and Green Mix (GM) rootzones with light and frequent (LF) or deep and infrequent (DI) irrigation regimes.

	Natural Rainfall, mm	Pan eva-poration, mm	Number of irrigations			Total irrigation water, mm		
			SS, LF	SS, DI and GM, LF	GM, DI	SS, LF	SS, DI and GM, LF	GM, DI
May	25	67	13	7	4	64	59	69
June	75	87	13	7	6	65	55	75
July	129	75	12	6	4	64	44	34
Aug.	241	68	5	2	1	28	18	8
Sep.	129	31	3	1	1	18	8	8
Total	599	328	46	23	16	239	184	194

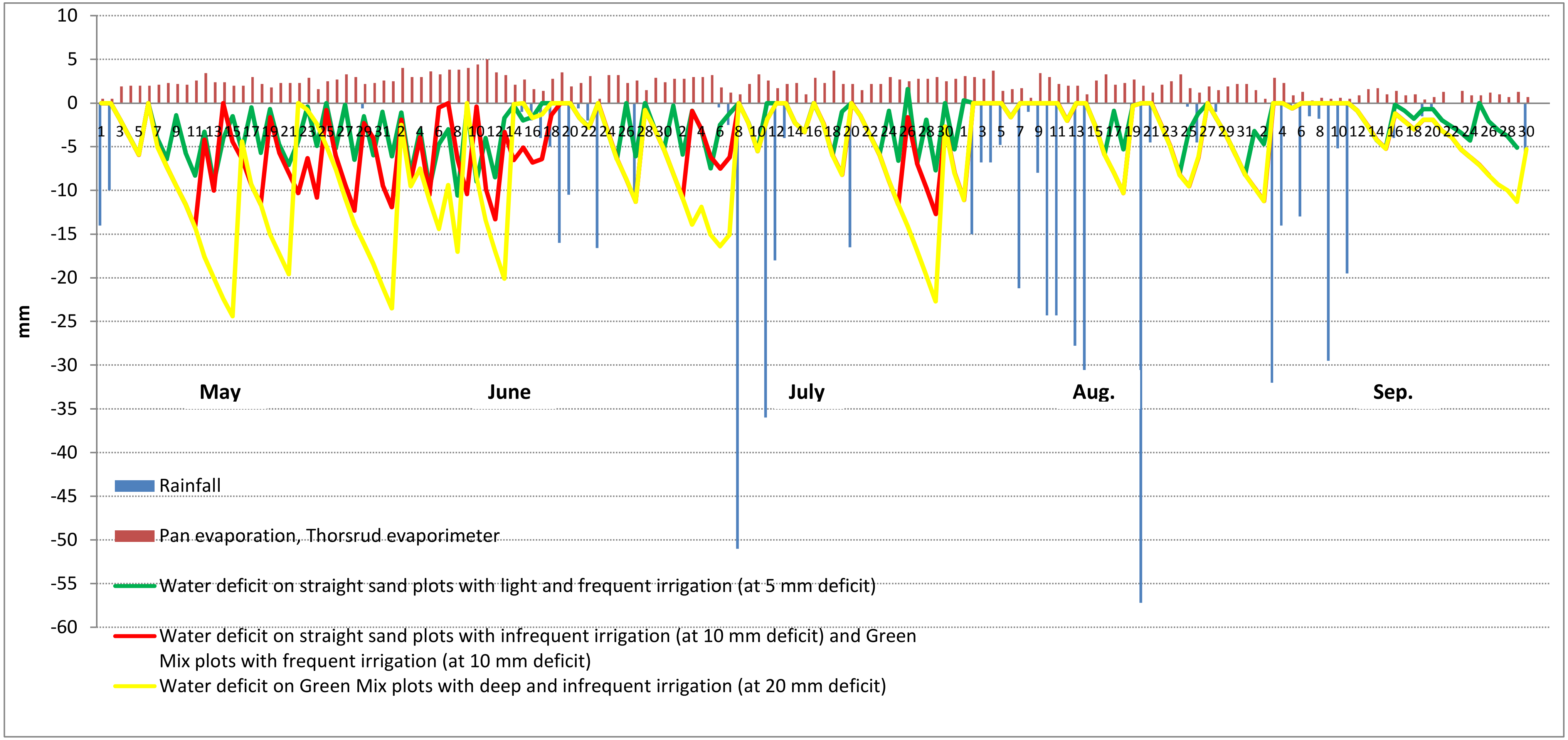

Fig.13. Rainfall, evaporation, irrigation and estimated soil water deficit depending on irrigation regime on USGA greens with straight sand or Green Mix root zones.

Mowing

The trial was mowed with a walk-behind green's mower three times a week (Monday, Wednesday and Friday). In 2008, after the first mowing to 5.0 mm on 16 April, mowing height was gradually reduced to 4.5 mm on 7 May, 4.0 mm on 19 May, 3.5 mm on 23 May and 3.0 mm on 16 June. In autumn, mowing height was raised to 3.5 mm on 22 Sep., 4.0 mm on 10 Oct. and 4.5 mm at the two last mowings on 17 Oct. and 27 Oct. No groomer og brush was used on the mower from April till June, but during July, August and early September, the mower was usually equipped with groomer on Mondays and brush on Wednesdays and Fridays.

Fertilization

On average for four soil samples taken from each root zone on 17 March 2008, pH (H_20) was 6.5 on SS plots and 7.2 on GM plots. Because of this, and because we expected more nitrogen to be mineralized on GM plots, fertilizer rates and -types differed between the two root zones. Ammoniumsulfate (either pure ammoniumsulfate or Anderson 13-2-13) was used on GM plots only (Table 12). As by mid-August the greens were considered to be very dense and building excessive thatch, the fertilizer rates of the original plan were cut by 50% from 26 Aug. (wk 35) onwards. From the same date, we started to use the liquid product Arena Crystal to get a more uniform distribution of fertilizer. Irrespective or irrigation treatment, all plots were usually irrigated 3-5 mm after application of fertlizer, and this was taken into account when calculating water deficits. The seasonal distribution of nitrogen inputs is shown in Fig. 13.

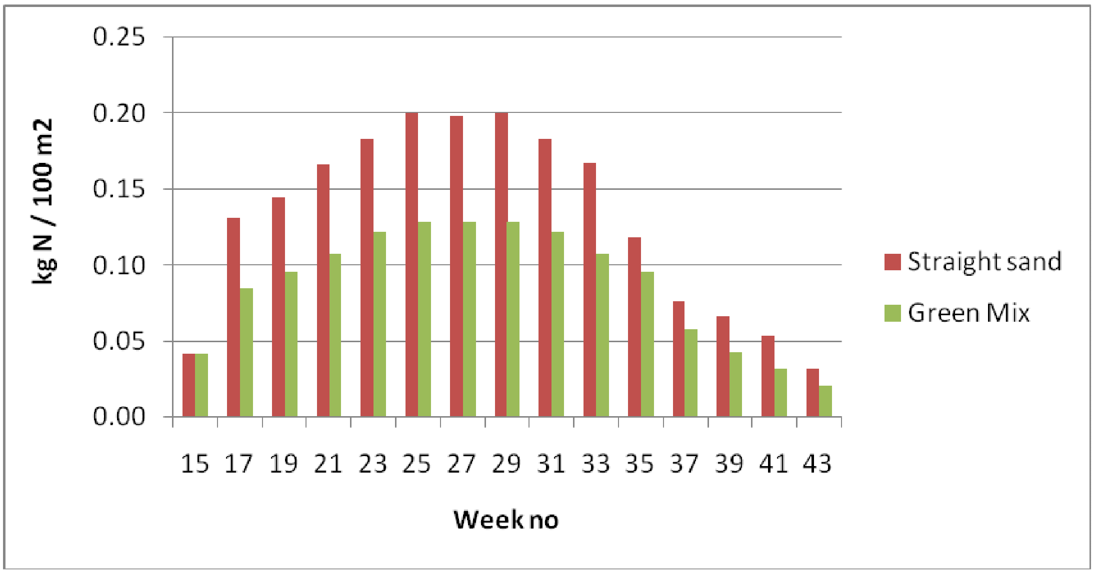

Fig. 14. Seasonal distribution of nitrogen inputs to straight sand and Green Mix plots, 2008.

Table 12. Fertilizer application to straight sand and Green Mix plots in irrigation trial at Landvik.

		Kg pr 100m^2								
Date	**Fertilizer type**	**Product**	**N**	**P**	**K**	**Mg**	**S**	**Ca**	**Fe**	**Mn**
Straight sand plots (SS)										
11 Apr.	Arena Høst Extra 4-4-18	1.00	0.042	0.041	0.183	0.012	0.123	0.000	0.068	0.004
23 Apr.	Arena Start 22-3-10	0.59	0.131	0.018	0.059	0.000	0.024	0.000	0.000	0.000
5 May	Arena Green Plus 12-1-14	1.20	0.144	0.012	0.174	0.022	0.072	0.025	0.000	0.005
22 May	Arena Start 22-3-10	0.76	0.167	0.023	0.076	0.000	0.030	0.000	0.000	0.000
3 June	Arena Score 12-1-14	1.50	0.183	0.020	0.218	0.026	0.204	0.000	0.006	0.006
16 June	Arena Start 22-3-10	0.91	0.200	0.027	0.091	0.000	0.036	0.000	0.000	0.000
3 July	Arena Green Plus 10-1-10	1.98	0.198	0.020	0.198	0.040	0.152	0.000	0.020	0.008
15 July	Arena Start 22-3-10	0.91	0.200	0.027	0.091	0.000	0.036	0.000	0.000	0.000
30 July	Arena Score Extra 13-1-16	1.42	0.183	0.020	0.227	0.026	0.140	0.000	0.028	0.006
12 Aug.	Arena Green Plus 10-1-10	1.67	0.167	0.017	0.167	0.000	0.033	0.012	0.017	0.007
26 Aug.	Arena Crystal 19-2-15	0.62	0.118	0.012	0.093	0.014	0.023	0.000	0.001	0.000
11 Sep.	Arena Crystal 19-2-15	0.40	0.076	0.008	0.060	0.009	0.015	0.000	0.001	0.000
23 Sep.	Arena Crystal 19-2-15	0.35	0.066	0.007	0.052	0.008	0.013	0.000	0.000	0.000
14 Oct.	Arena Crystal 19-2-15	0.28	0.054	0.005	0.043	0.007	0.011	0.000	0.000	0.000
28 Oct.	Arena Høst 3-3-15	1.00	0.032	0.033	0.150	0.010	0.105	0.000	0.054	0.003
			1.959	0.288	1.881	0.172	1.018	0.037	0.195	0.039
Green Mix plots										
11 Apr.	Arena Høst Extra 4-4-18	1.00	0.042	0.041	0.183	0.012	0.123	0.000	0.068	0.004
23 Apr.	Ammoniumsulfat	0.40	0.085	0.000	0.000	0.000	0.097	0.000	0.000	0.000
5 May	Ammoniumsulfat	0.45	0.096	0.000	0.000	0.000	0.110	0.000	0.000	0.000
22 May	Ammoniumsulfat	0.50	0.107	0.000	0.000	0.000	0.122	0.000	0.000	0.000
3 June	Arena Score 12-1-14	1.00	0.122	0.013	0.145	0.017	0.136	0.000	0.004	0.004
16 June	Anderson 13-2-13	0.98	0.128	0.009	0.106	0.000	0.177	0.000	0.020	0.001
3 July	Anderson 13-2-13	0.98	0.128	0.009	0.106	0.000	0.177	0.000	0.020	0.001
15 July	Anderson 13-2-13	0.98	0.128	0.009	0.106	0.000	0.177	0.000	0.020	0.001
30 July	Arena Score Extra 13-1-16	0.95	0.122	0.013	0.151	0.017	0.094	0.000	0.019	0.004
12 Aug.	Anderson 13-2-13	0.82	0.107	0.007	0.089	0.000	0.148	0.000	0.016	0.001
26 Aug.	Anderson 13-2-13	0.41	0.054	0.004	0.044	0.000	0.074	0.000	0.008	0.000
27 Aug.	Arena Crystal 19-2-15	0.22	0.042	0.004	0.033	0.005	0.008	0.000	0.000	0.000
11 Sep.	Arena Crystal 19-2-15	0.31	0.058	0.006	0.046	0.007	0.011	0.000	0.000	0.000
23 Sep.	Anderson 13-2-13	0.33	0.043	0.003	0.035	0.000	0.059	0.000	0.007	0.000
14 Oct.	Anderson 13-2-13	0.24	0.032	0.002	0.026	0.000	0.044	0.000	0.005	0.000
28 Oct	Arena Høst 3-3-15	0.66	0.021	0.022	0.098	0.007	0.069	0.000	0.035	0.002
			1.314	0.140	1.170	0.065	1.626	0.000	0.222	0.019

Reseeding and topdressing

In order to smooth out the surface and repair patches (old patches from take-all in 2007 and new patches from pink snow mould after the late snow fall in March 2008), the green was reseeded with a drop seeder on 23 April 2008. We used seed of velvet bentgrass ‘Legendary’ at an average rate of 0.2 kg 100 m^2. After seeding, the green was topdressed with 1 mm sand and irrigated with 4 mm (all plots). A new selective reseeding was accomplished after verticutting on 9 May.

After the initial topdressing with 1 mm sand, the green was top-dressed at one to two week intervals, in total 14 times, for the rest of the growing season. As each dressing was only a light ‘dusting’, the total amount of sand used over the season was only about 4 mm, or 6.5 kg per m^2. We used washed sand with grain size 0.2-0.8 mm and no organic matter (Baskarp, Sweden). Dressing was usually accomplished after mowing on Fridays as the green was left unmown during the weekend.

Verticutting and aeration

The green was aerated with Aerocore with 8 mm solid spikes (8 cm depth) on 12 June and verticut on 9 May, 23 June, 21 August, 5 Sep and 11 Sep. At the very end of the season, the whole experimental area was core-aerated to 8 cm depth on 20 Nov. and plugs removed using a blower. The holes were left open during winter.

Wear

From 5 May until 3 Oct. the green was exposed to artificial wear from a friction drum with golf spikes at least two times per week.

Registrations and statistical data analyses

Visual evaluations of turfgrass quality started on 17 March and were carried out at biweekly intervals for turfgrass overall impression (visual merit) and monthly intervals for tiller density, colour, turf coverage and diseases. At monthly intervals, we also measured surface hardness using a Clegg Hammer (two drops per plot) and ball roll distance using a stimpmeter modified for research plots. The stimpmeter had its ball release notch 38 cm rather than 76 cm from the beveled end, and measurements were always taken in two directions.

Turfgrass root depth was estimated on 1 July, 12 Aug. and 8 Sep. using a root auger, 30 cm long and 5 cm in diameter. One core was extracted per plot. The core was pushed out of the auger, lifted from the top, and the length of the core that did not break apart (i.e. that was held together by the roots) taken as an indication of root depth.

The thickness of the thatch/mat layer and root dry weights was further analyzed on 13 June and 8 Sept. using the same auger, but followed by separation, washing and drying of roots from the layers thatch/mat, thatch/mat – 2 cm, 2-6 cm, 6-10 cm and deeper than 10 cm.

Soil moisture was usually measured before irrigation of individual plots using a portable TDR “Moisture Meter” with 20 cm long probes. These measurements showed per cent water (v/v) in the upper 20 cm of the green profile. Three measurement per plot were averaged before analyses of variance. On 22-23 Sep, four soil cores, 2 cm in diameter, were taken per plot, separated into the layers 0-1 cm (=thatch/mat), 1-2 cm, 2-4 cm, 4-6 cm and 6-10 cm and used to determine soil gravimetric water content after drying for 48 h at 105°C and soil loss on ignition after drying at 550°C for 3 h.

Potential soil water repellency was measured on samples taken 13 June (after the six week drought period) and 15-16 September using the water drop penetration time (WDPT) test (e.g. Dekker and Jungerius, 1990). One soil sample per plot was taken with a spade sampler which removed a slice of soil, 11 cm wide, to a depth of 10 cm. After 48 h of air drying in the laboratory, three drops of water were placed at 0.5 (in thatch/mat), 1 (just under thatch/mat), 3, 5 and 10 cm depth on the surface of the samples and the time until drops had infiltrated measured. Since the WDPT test was done on dry samples the results reflect potential soil water repellency rather than actual repellency

(Dekker & Ritsema 1994). According to the classification scheme proposed by Dekker and Jungerius (1990) a soil is considered wettable if drop infiltration is immediate, non-repellent if WDPT<5 s, slightly water repellent if 5s<WTPT<60 s, and strongly water repellent if 60 s<WTPT<600 s.

Infiltration rates were measured on 12 June (after the six week dry period) and 17 September, using a double ring infiltrometer with an outer ring diameter of 128.5 mm and inner ring diameter of 45 mm (Photo 5). Both rings were filled with 8 cm water and the water level in the inner ring was measured after three minutes. Two consecutive measurements were taken at two sites per plot and the four values averaged before statistical analyses.

Photo 5. Double ring infiltrometer

Leaching water from each lysimeter was accumulated on a monthly basis except for May and June which were pooled due to little rainfall. The total amount of leachate was measured and representative samples taken and analysed for nitrate, total N, P and K concentrations at AnalyCen laboratory. Total nutrient leakage was calculated based on concentrations and the total amount of leakage water.

All experimental data were analyzed using the analysis of variance (ANOVA) procedure of the SAS software version 9.1 (SAS Institute 2002). Probability levels have been indicated in the text and figures. The term 'significant' always refers to P<0.05, and 'tendencies' to 0.05<P<0.10.

5.2. Results

<u>Turfgrass visual quality</u>

One week coverage of wet snow from 21 to 28 March 2008 led to a severe outbreak of *Microdochium nivale* on SS plots. Mostly for this reason, turfgrass overall impression was betteron GM plots than on SS plots until late May (Photo 6, left). Irrigation regime in 2007 had no effect on the severity of the snow mould infection (data not shown).

From late May onwards, the effect of irrigation regime was more apparent than the effect of root zone (Fig. 15, Photo 6, right). In late June and July, there was a certain infection of take all (*Gauemannomyces graminis*) which lowered the overall impression especially on GM plots with DI irrigation. On average for the growing season, turfgrass overall impression was significantly better on plots with LF irrigation than on plots with DI irrigation. Turfgrass coverage also tended to be better with LF irrigation, while tiller density was not affected by irrigation but significantly better on GM than on SS plots (Table 13). There were no signifcant rootzone x irrigation interactions for any of these characters.

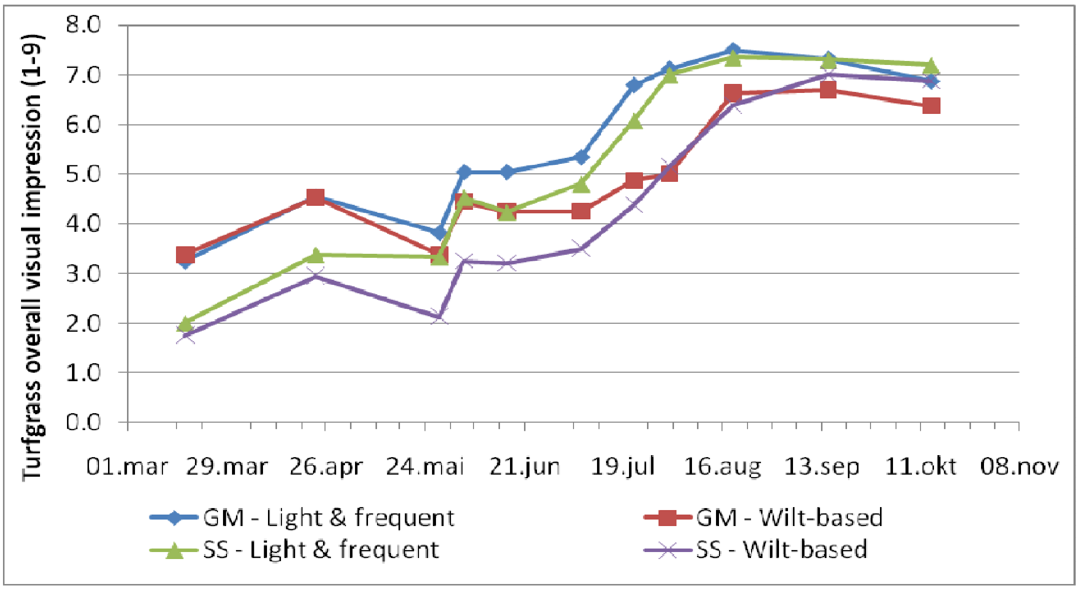

Fig. 15. Turfgrass overall visual impression during the growing season 2008 as affected by root zone and irrigation regime.

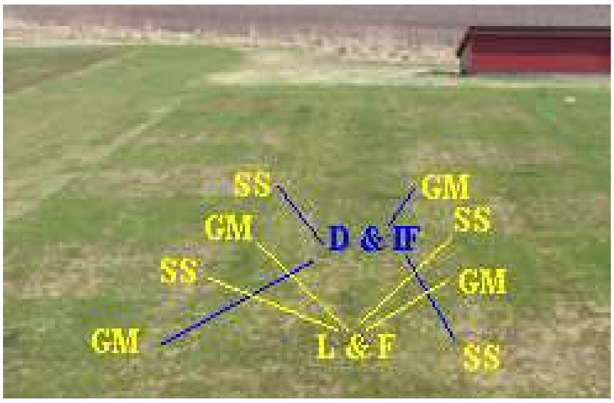

Photo 6. Differenses in overall impression between GM and SS plots became less apparent towards the end of growing season 2008. Photos taken on 3 April (left) and 17 September (right).

Table 13. Average values for turfgrass overall impression, tiller density, coverage of undiseased turf, surface hardness and ball roll distance during the season 2008.

	Overall impression (1-9)	Tiller density (1-9)	Turfgrass coverage (%)	Surface hardness (gravities)	Ball roll distance, cm
Straight Sand (SS)	5.3	6.6	98	88	115
Green Mix (GM)	5.8	7.2	98	75	117
P%	>20	<5	>20	<0.1	>20
Light & frequent (LF)	6.0	7.0	99	81	116
Deep and infrequent (DI)	5.0	6.9	97	82	116
P%	<5	>20	15	>20	>20

Turfgrass playing quality

On average for ten measurements with the Clegg hammer, the green surface was significantly softer on GM than on SS root zones (Table 13). Irrigation regime had no impact on this character. Turfgrass ball roll distance was not affected by any of the experimental factors.

Thatch/mat

On average for treatments, thatch/mat thickness increased from 6 mm in June to 10 mm in September (Table 14). At both recordings, there was a tendency (P% = 18) for thatch to be thicker on GM than on SS plots (Photo 7). Thatch thickness was not significantly affected by irrigation regime (Table 14).

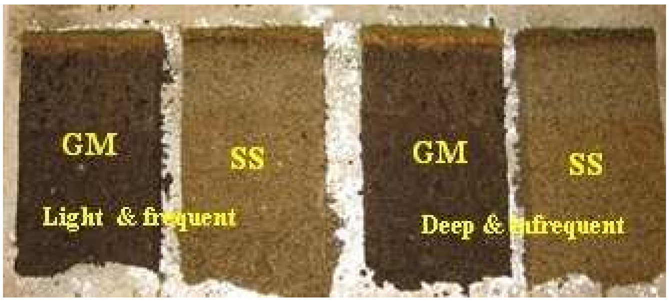

Photo 7. Thatch accumulation 15 months after establishment of the green as affected by root zone composition. Photo taken 9 Sept. 2008.

Root depth and root weight in various layers

The average length of intact root cylinders taken from the green in June and September was 14 and 18 cm, respectively. After the dry period in May and June, roots tended to be deeper on plots with DI than with LF irrigation, and this was also confirmed by the weight of roots deeper than 10 cm (Table 14). After natural rainfall had levelled out these differences, there was no significant effect of irrigation regime on core length or root weight under 10 cm in September. However, there tended to be more roots in the upper layers with LF irrigation.

Although differences were not always significant, roots were generally more developed on SS than on GM plots (Photo 8).

Table 14. Thatch / mat thickness, length of intact root cylinders and dry wegiht of root in different layers as determined by washing roots in mid June and mid September.

	Thatch / mat thickness, mm		Length of intact root cylinder, cm		Root dry weight, g m^{-2}, mid-June				Root dry weight, g m^{-2}, mid-September			
	June	Sept.	June	Sept.	In thatch	Thatch – 6 cm	6-10 cm	Under 10 cm	In thatch	Thatch – 6 cm	6-10 cm	Under 10 cm
Straight sand	5	9	14	21	450	207	81	84	466	169	55	65
Green Mix	6	10	14	15	523	146	49	32	474	181	27	24
P%	18	18	>20	<1	>20	<5	<1	<1	>20	>20	<0.1	<0.1
Light & frequent	6	10	12	18	553	192	63	51	486	207	70	44
Deep & infrequent	5	10	15	18	420	161	67	64	454	143	50	44
P%	>20	>20	17	>20	11	>20	>20	17	>20	10	<0.1	>20

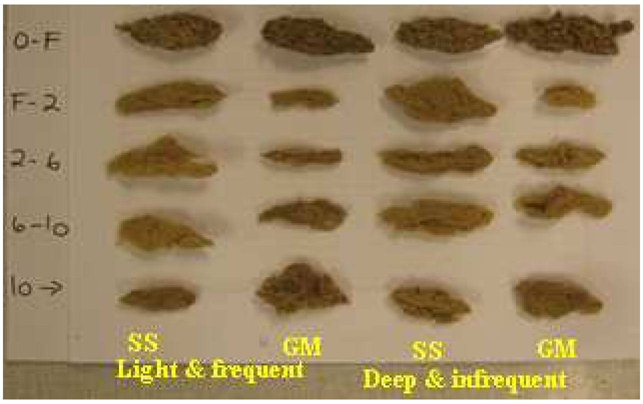

Photo 8. Soil cores, 5 cm in diameter and 30, cm deep were taken on 8 Sept. Roots were divided at different depths and washed from soil.

Soil water content

On average for eight TDR-measurements, the 0-20 cm soil layer on GM and SS plots contained 14.2 and 7.9 % (v/v) water (difference significant at P%<0.1). The difference between irrigation regimes was also significant, average values being 11.8 % for LF and 10.3 % for DI irrigation (data not shown in table or figure).

Soil cores taken on 22-23 September showed 3-4 times higher water content in the thatch/mat layer than at deeper horizons (Fig. 16). On average for rootzones, LF irrigation tended (P% =9), to give more water in the top centimeter. LF irrigation also caused more water at 1-2 cm depth, i.e. just below the thatch/mat. At deeper horizons, only the effect of root zone composition was significant.

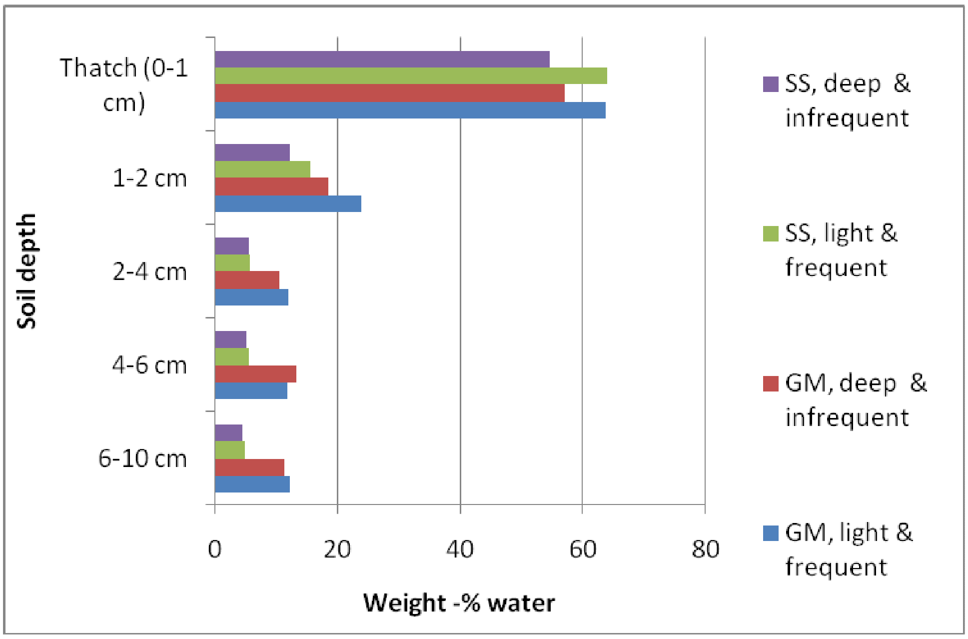

Fig. 16. The effect of rootzone compostion (SS = Straight sand, GM = Green Mix) and irrigation regime on gravimetric soil water content in various layers. Samples were taken on 22-23 September.

Soil organic matter

On 22-23 September, the average soil ignition losses at depths 0-1 cm (thatch/mat), 1-2 cm, 2-4 cm, 4-6 cm and 6-10 cm in GM root zones were 9.3, 4.5, 2.8, 2.0 and 2.0 % (w/w), respectively. For SS rootzones, the corresponding values were 8.1, 2.1, 0.6, 0.5 and 0.5 %. The difference between rootzones was only significant below the thatch/mat layer. As compared with DI irrigation, LF irrigation resulted in higher ignition losses at 0-1 and 1-2 cm depth on GM rootzones, but had no effect on SS rootzones. (Fig. 17)

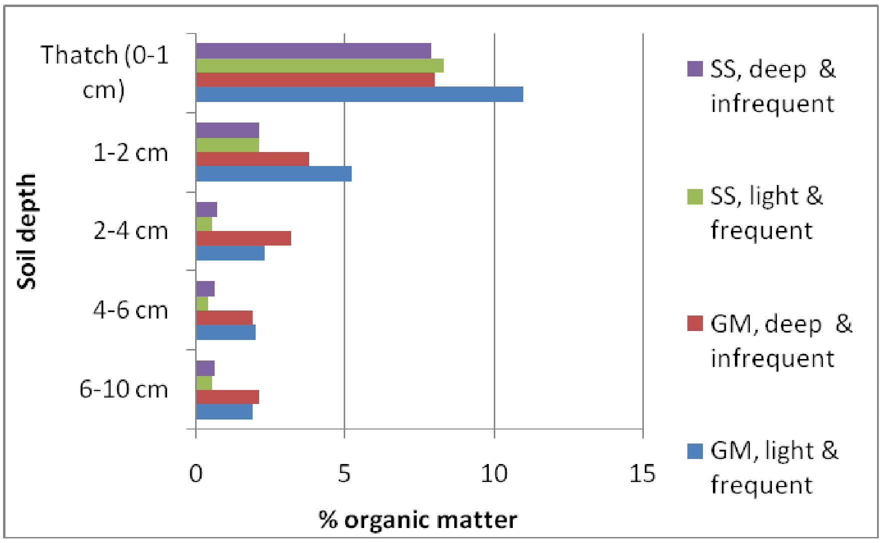

Fig. 17. The effect of rootzone compostion (SS = Straight sand, GM = Green Mix) and irrigations regime on ignition losses in various layers. Samples were taken on 22-23 Sept.

Potential soil water repellency

After the long drought period in May and early June, SS root zones that had been irrigated only at 10 mm water deficit showed extreme soil water repellency at 2 cm depth (Table 15). Plots receiving other treatments also showed strong water repellency, but mostly in the thatch layer. Even in September, i.e. long after the dry period, the thatch/mat layer on both root zones was significantly more water repellent on plots with DI than with LF irrigation.

Table 15. Water droplet penetration time (seconds) at various depths on 13 June and 21-22 September and as affected by root zone and irrigation regime.

	June				September			
	0.5 cm	2 cm	5 cm	10 cm	0.5 cm	2 cm	5 cm	10 cm
SS, light & frequent	76	7	38	5	105	16	5	6
SS, deep & infrequent	215	962	2	145	175	17	11	25
GM, light & frequent	95	4	4	4	100	15	48	17
GM, deep & infrequent	53	12	10	16	138	25	13	5
P-value, rootzone	>20	13	>20	16	>20	>20	>20	>20
P-value, irrigation	>20	12	>20	11	<5	>20	>20	>20
P-value, interaction	12	13	>20	17	>20	>20	>20	>20

Infiltration

On average for treatments, infiltration rates were 98 mm/h in June and 34 mm on September. In June, infiltration was significantly lower on SS plots with LF irrigation than in the other treatments, but this was probably an artifact due to irrigation of the these plots shortly before measurements.

No significant differences between root zones or irrigation treatments were detected in September (data not shown).

Water and nutrient leakage

LF irrigation caused more drainage of water than DI irrigation from SS but not from GM plots (Fig. 18). However, as the mean concentations of nitrate, total nitrogen and phosphorus in leakage water tended to be higher on plots with DI irrigation, total nutrient leakage was not influenced by irrigation regime on any soil type. On average for irrigation regimes, nitrate and phosphorus concentrations were higher in lechate from SS than from GM plots, while the opposite was the case for total N concentration (Table 16). On average fro treatments, the concentration of potassium in leakage water was almost five times higher than the concentration of nitrogen.

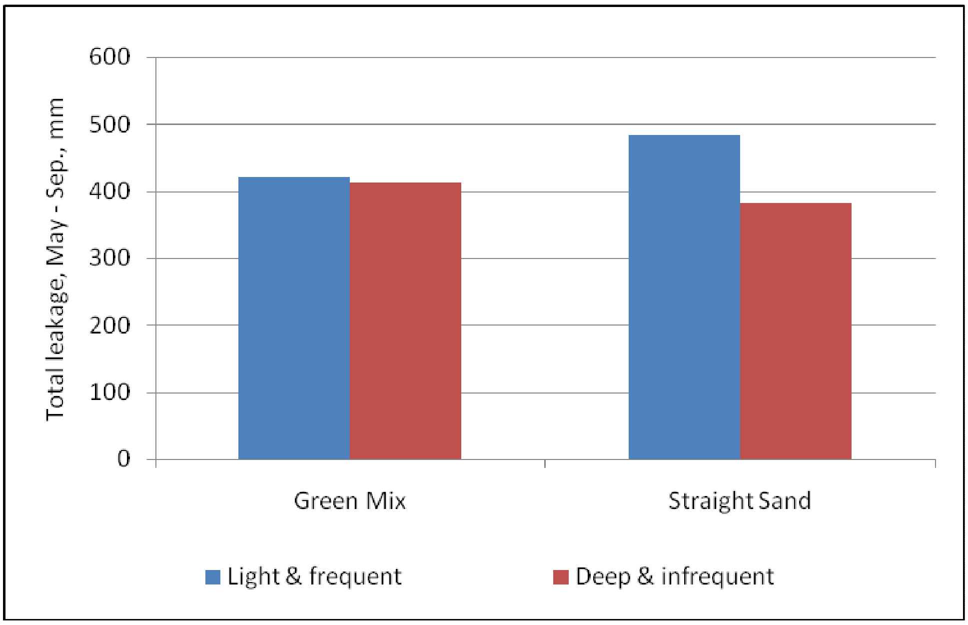

Fig. 18. Interaction root zone x irrigation regime for total water drainage, May -Sept.

Table 16. Main effects of root zone composition and irrigation regime on nitrate, total N, phosphorus and potassium concentrations and on total water and nutrient leakage, May-Sept.

	Total Leakage May-Sep., mm water	Concentration, mg / liter				Total leakage, kg 100 m^{-2}		
		NO_3-N	N	P	K	N	P	K
Straight Sand	433	0.46	2.4	0.68	13.5	1.0	0.30	5.9
Green Mix	416	0.21	3.2	0.35	14.0	1.3	0.14	5.8
P%	>20	*	6	*	ns	15	*	ns
Light & frequent	451	0.31	2.5	0.40	13.8	1.1	0.18	6.2
Deep & infrequent	398	0.36	3.1	0.63	13.7	1.3	0.26	5.5
P%	*	ns	ns	ns	ns	ns	ns	ns

5.3. Discussion and preliminary conclusions

In autumn 2007, the lysimeter green used in this experiment was rather immature with an average ground cover of 92 % on GM plots and 84 % on SS plots. Therefore, the fertilizer plan set up in spring 2008 prescribed a fairly high input of nitrogen especially on SS plots. Combined with LF irrigation, this led to rapid recovery; the green grew dense and gave an acceptable visual appearance from mid June onwards. However, as summer rain started in June, the bentgrass started to build excessive amounts of organic matter, and this was further aggravated as no verticutting was accomplised from late June until late August. The amount of sand dressed on the green was also rather limited. In retrospect, there is little doubt that we realized too late that the green had gone from an late grow-in / repair stage to a maintenace stage with much lower nutrient requirement. Fertilizer inputs should proabably have been cut back in late June/early July, and verticutting and aeration treatments should have been intensified. For 2009 we have devised a maintenance plan with a total nitrogen input of 1.4 kg N/ 100 m^2 to SS plots and 1.0 kg N / 100 m^2 to GM plots, verticutting or aeration every two weeks and a total sand application of 8 mm, i.e. twice as much sand as was applied in 2008. There is little doubt that a an organic content of around 8% in the top layer on SS/LF, SS/DI and GM/DI plots is too much. Around 11% on GM/LF plots is clearly excessive (Fig. 17).

Despite the fact that LF irrigation resulted in thatch build-up on GM root zones, the advantages on LF compared to DI irrigation regimes were greater than the disadvantages on both root zones. Irrigating only at 10 mm deficit (every fouth to fifth night) diminished turfgrass quality and resulted in water repellency problems on SS plots, and irrigating only at 20 mm deficit caused patched of take all to become more apparent on GM plots. As the expected negative impacts of LF irrigation on surface hardness, ball roll distance and root development were mostly smaller than expected, we conclude that LF has been the best irrigation strategy so far in this experiment.

6. Evaluation of the biological product Thatch-less™ at various soil temperatures

6.1. Background

As described in chapter 4 of this report, the biological product 'Thatch-less' (2006 Novozymes Biologicals Inc.) is included as one of the treatments in the experiment comparing thatch control methods on a velvet bentgrass green at Landvik. The present chapter reports briefly from a supplemental experiment with further evaluation of 'Thatch-less' at various temperatures conditions.

6.2. Materials and methods

Plant material and experimental design

In July 2008 ninety-six cores (5 cm diameter and 6-6.5 cm deep) of creeping bentgrass 'Penn A-4' were taken from 5-year old USGA-spec. green at Landvik and placed into drain pipe sections with the same diameter and length. The root zone composition was 'Green Mix' (sand amended with 20 % (v/v) garden compost).

The green foliage on the top of the cores was removed, and the bottom sealed with metal mesh to avoid soil losses (Photo 9). The cores were split into four groups and incubated at four different temperatures: 4-5 °C, 12 °C, 20 °C and 28 °C. One half of the cores in each group were incubated for three months, the other half for six months.

The cores at each temperature were sprayed either with water (control), or with 'Thatch-less' at 100 ml/100 m^2 (recommended rate) or 500 ml/100 m^2 (5-fold rate). The first 3 applications with made at 10 day intervals, further applications at 28 day intervals. The cores were weighed regularly and watered depending on the evaporation rates at the different temperatures. The experimental plan prescribed replenishment of water every time one third of the field capacity had evaporated, but in practicality, cores were often dryer at the highest temperature.

Photo 9. Intake of core-samples from the green, 24 July 2008 (left) and application of 'Thatch-less' by hand sprayer (right).

Measurements

By the start of the experiment, four cores were used for initial measurements of thatch thickness, ignition loss (organic matter content) and microbiological activity in the thatch layer. The same evaluations were made after 3 and 6 months of incubation. The microbial load was estimated using a dilution-plate technique. Soil dilutions were placed on Petri dishes with different media, and the number of microorganisms counted after seven days. Results were expressed as colony-forming units (CFU) per g dry soil. The number of culturable bacteria was determined at 25°C on glucose-peptone–yeast extract agar (GGA) and on cellulose agar (CA), while the number of culturable fungi was determined on potato dextrose agar (PDA) and CA.

Statistical analysis

The experiment was conducted according to a randomized block design with four replicates. Analyses of variance (ANOVA) were performed using STATISTICA software (Version 6.0, 2001). Fisher's LSD was used to indentify differences among treatments at the 5% probability level.

6.3. Results

6.3.1. Microbial numbers

Significant differences among application rates in the amount of microorganisms were found after 3 months of incubation (Table 17). The number of filamentous fungi cultivated on CA increased significantly with the 5-fold rate of 'Thatch-less' compared with the control. However, this effect was not present after 6 months incubation. On PDA, differences in the number of filamentous fungi were insignificant both after 3 and 6 months. This was also the case for total number of bacteria on CA. After 3 months incubation on GGA, both rates of 'Thatch-less' led to lower bacteria numbers compared with the control treatment.

Table 17. Numbers of fungi and bacteria in soil samples at different rates and durations of incubation with 'Thatch-less'. Mean of four incubation temperatures.

	Total filamentous fungi				Total bacteria			
	1/2 PDA		CA		GGA		CA	
	3 months	6 months	3 months	6 months	3 months	6 months	3 months	6 months
	-------CFU g^{-1} dry soil-------							
Unsprayed control	4.3E+04	8.1E+04	1.0E+04 b	1.2E+05	1.8E+06 a	4.0E+06	1.1E+06	6.3E+06
TL , 100 ml / 100 m^2	4.6E+04	8.5E+04	1.3E+04 ab	1.2E+05	1.3E+06 b	3.6E+06	1.0E+06	3.7E+06
TL , 100 ml / 100 m^2	5.1E+04	8.0E+04	1.7E+04 a	1.0E+05	1.4E+06 ab	3.0E+06	1.1E+06	4.3E+06
Sign. level (5 %)	*ns*	*ns*	***	*ns*	***	*ns*	*ns*	*ns*

Increasing temperatures lowered the number of fungi on the PDA medium after 3 months of incubation (Table 18). Although sometimes significant, other effects of temperature were usually inconsistent. To a certain extent, irregular effects at 26 °C may be ascribed to a lower average water content than at the other temperatures.

Table 18. Number of fungi and bacteria in soil samples after incubation at different temperatures. Mean of cores with and without application of 'Thatch-less' at two different rates.

Temperature	Total filamentous fungi				Total bacteria			
	1/2 PDA		CA		GGA		CA	
	3 months	6 months	3 months	6 months	3 months	6 months	3 months	6 months
				-------*CFU g^{-1} dry soil*-------				
4 °C	7.8E+04 a	1.2E+05	1.8E+04 a	9.7E+04	2.1E+06 a	5.6E+06 a	1.1E+06 b	1.1E+07 a
9 °C	5.0E+04 b	7.1E+04	1.8E+04 a	8.2E+04	1.3E+06 b	3.7E+06 a	1.5E+06 a	5.5E+06 b
17 °C	3.9E+04 b	3.7E+04	1.1E+04 b	1.3E+05	1.3E+06 b	4.3E+06 a	8.4E+05 bc	1.8E+06 c
26 °C	1.9E+04 c	1.0E+05	7.7E+03 b	1.3E+05	1.5E+06 b	6.0E+05 b	7.7E+05 c	8.3E+05 c
Sign. level (5 %)	***	*ns*	***	*ns*	***	***	***	***

6.3.1. Thatch thickness and organic matter content

Use of 'Thatch-less' did not have any diminishing effect on the thickness or organic matter content of the thatch layer (Table 19). After six months with regular inputs of 'Thatch-less' at 5-fold recommended rate, the layer was in fact significantly thicker than in the control treatment.

Table 19. Thickness and organic matter content of the thatch layer as affected by application rate, temperature, and duration of incubation.

Treatment		Thatch, mm		Organic matter in thatch layer, % (w/w)	
		3 months	6 months	3 months	6 months
Application rate	Unsprayed control	23.3	23.3 a	6.3	6.5
	TL , 100 ml / 100 m^2	23.9	23.3 a	5.8	6.4
	TL , 500 ml /100 m^2	24.0	24.9 b	6.3	6.6
	Sign. level	*ns*	***	*ns*	*ns*
Temperature	4 °C	23.9 a	23.8	6.6 a	7.2 a
	9 °C	25.3 a	24.8	6.5 ab	7.1 a
	17 °C	22.0 b	22.8	5.8 b	5.8 b
	26 °C	23.8 a	23.9	5.7 b	5.9 b
	Sign. level	***	*ns*	***	***

At the start of the experiment, the initial thickness of the thatch layer was 25.5 mm (mean of four samples, CV=18 %), and the content of organic matter 8.5 % (w/w) (CV=6.8 %). Comparison with the figures Table 19 suggests that both thatch thickness and organic matter content decreased for all treatments during the first three months of incubation, but there was no further decrease during the last three months.

6.4. Discussion and conclusion

Thatch, according to the accepted definition, is a mixture of living and dead organic material that may also contain some mineral constituents (Carrow et al. 2001). Excessive thatch layers on putting greens usually has negative effects on soil profile properties and will therefore decrease the putting green quality (Beard 2002). Some fungi are known for their ability to decompose even the most resistant polymers such as lignocellulose (Deacon 2006). Recent studies have also documented bacterial degradation of lignin (El-Hanafy et al., 2007).

Primarily due to the problems of keeping an optimal soil water content at the highest temperature, the quality of this incubation experiment could have been better. However, the results are in line with those from the field experiment at Landvik (Chapter 4): 'Thatch-less' did not provide any thatch decomposition beyond that naturally occurring in the control treatment. Our data are also comparable with McCarty et al. (2007) who reported no thatch reduction using the biological product 'Thatch-X' in a two year field study. While 'Thatch-X' was reported to contain 'sugar sources, selected microorganisms and other bioactive ingredients', 'Thatch-less' is labelled with a content of *Bacillus licheniformis, B. subtitis,* and cellulase enzymes derived from *Trichoderma reesei.*

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8. Appendix.

Velvet bentgrass in practice (in Norwegian)

Hundekvein i praksis

Oppsummering fra besøk på 4 golfbaner som har greener med hundekvein
(sommer og høst 2008)

Deltakere

<u>Golfklubber</u>

Sted	Kongsberg golfklubb
Kontaktperson	**Eirik Nörgaard**
Greentype	En chipping green av push-up type

Sted	Ballerud golfklubb
Kontaktperson	**Hæge Kranstad**
Greentype	En putting green av push-up type

Sted	Veierland golfklubb
Kontaktperson	**Tor Mjøen**
Greentype	6 jordgreener i ekstensiv, økologisk drift

Sted	Imjelt Pitch & Putt (Drammen)
Kontaktperson	**Jo G. Brand**
Greentype	18 USGA-greener i spill , 3 treningsgreener & en nursery-green

<u>Forskere</u>

Sted	Bioforsk Øst Landvik		
Kontaktperson	**Trygve Aamlid**	**Agnar Kvalbein**	**Tatsiana Espevig** *(stipendiat)*
E-post	trygve.aamlid@bioforsk.no	agnar.kvalbein@bioforsk.no	tanja.espevig@bioforsk.no

Sted	Bioforsk Øst Apelsvoll
Kontaktperson	**Bjørn Molteberg**
E-post	bjorn.molteberg@bioforsk.no

Kongsberg golfklubb

Etablering

I april 2008 ble det øverste laget fra en jordbasert chipping-green fjernet med torvskjærer. Deretter ble det lagt ut og finplanert et lag med ren sand og sådd med hundekvein 'Avalon', såmengde 7.5 g/m2 (3 kg/400 m2). I spireperioden var greenen dekket med agrylduk. Duken lå i nesten tre uker, slik at den ble vanskelig å fjerne. Ifølge greenkeeperen var dette et større problem enn ved etablering av rødsvingel/engkvein-greener.

Greenen etablerte seg raskt og ble åpnet i månedsskiftet juni-juli.

Skjøtsel i 2008 (etableringsåret):

Gjødsling

Greenen ble gjødslet ukentlig i etableringsfasen og deretter, som rødsvingel / engkvein-greenene på banen, annen hver uke fram til oktober. Det ble hovedsaklig brukt Biogolf flytende gjødsel, men i slutten av august også Arena Høst 3-3-15 fordi en gikk tom for Bio Golf. Total mengde NPK var:

N pr 100 m2 / år: 1,78 kg

P pr 100 m2 / år: 0,66 kg

K pr 100 m2 / år: 2,16 kg

I uke 42 blir det, som siste ledd i høstprogrammet, gjødslet med Sustane 5-2-10 organisk gjødsel. Denne antas først å virke fra neste vår.

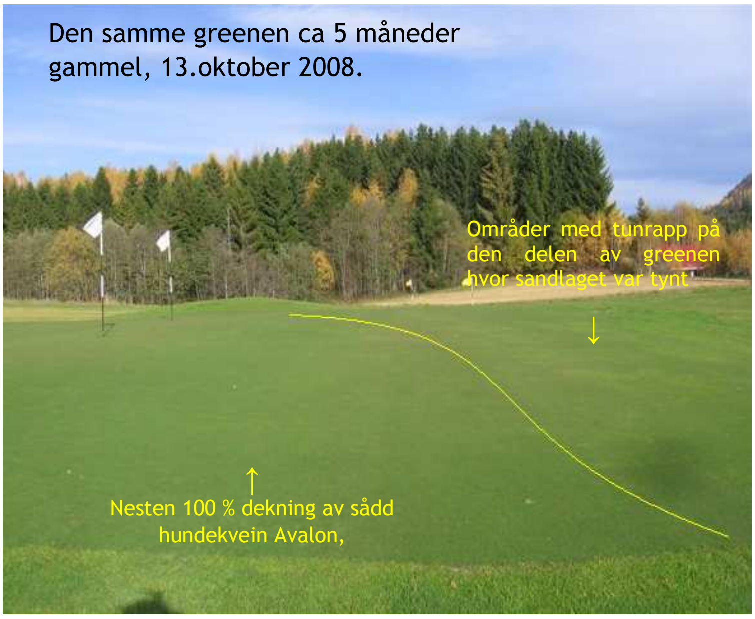
Toppdressing

I starten var det brukt litt grov dressesand, 0-1.5 mm, tilsvarende sanden som var lagt ut før såing. Seinere er det brukt tørka sand, 0-1.0 mm. Toppdressing var utført annen hver uke fram til sist i august med ca 1.2 kg sand pr m2 hver gang (12 tonn på 10 daa greenareal), tilvarende 0.75 mm hver gang. Etter dressing var sanden børstet ned.

Jord profil, 10.juli 2008

6-7 øverste cm av jord profil, 13.oktober 2008

Nesten 3 måneder gammel green, 10.juli 2008



Den samme greenen ca 5 måneder gammel, 13.oktober 2008.

Golfspillerne på Kongberg kunne ha vært flinkere til å reparere nedslagsmerkene på chipping-greenen. 13.okt 2008.

<u>Vanning</u>

Greenen var vannet ofte ved etablering. Seinere var det utført vanning etter behov, bare i tørkeperioder.

<u>Klipping</u>

Greenen ble klipt med Triplex-klipper 2 ganger i uka med klippehøyde 4,0-4,2 mm. Ved etablering og fra uke 41 var klippehøyden 5 – 5.2 mm

<u>Sprøyting</u>

Den 18/8 ble både hundekveingreenen (og de andre greenene på banen) sprøytet med en blanding av Amistar Duo og Stratego. Sprøyting mot overvintringssopp var planlagt i uke 42-43.

<u>Mekaniske og andre behandlinger</u>

Lufting med 12 mm pinner i uke 42-43.

Head greenkeper Eirik Nörgaard, greenkeeper Bengt Sandström og forsker Agnar Kvalbein på greenen, 10.juli 2008

Head greenkeeper Eirik Nörgaard og forsker Trygve S. Aamlid på greenen, 13 .oktober 2008.

<u>Bedømming 13.okt:</u>

Dekning	Tetthet skala fra 1-9, 1 – svært åpen 9 – svært tett	Sopp angrep	Filt, mm	Ballrull (målt med forkortet stimpmeter), cm
Hundekvein 95 % Tunrapp 5 % Tunrapp vokste gjennom fra underliggende jord på den delen av greenen hvor sandlaget var tynt	5	–	7 (pga god dressing må dette laget kalles 'mat', ikke 'filt'. Det består av jevn blanding av gressrøtter og sand)	101

<u>Hovedinntrykket</u> var positivt. Chipping-greenen på Kongsberg har utviklet seg til en passe tett hundekvein green – ikke overdreven frodig, men samtidig med 100 % dekning bortsett fra på den østre delen nærmest bunkeren der tunrapp vokste gjennom på grunn av for tynt sandlag over de gamle jordbaserte vekstmassene.

Vestre del av greenene var noe vannsjuk på grunn av sig/ trykk fra vekstmassene ved siden av. Her bør det absolutt graves en avskjæringsgrøft.

Greenen brukes som chipping green, og det var mange nedslagsmerker. Golferne på Kongsberg har tydeligvis vært vant til at det ikke var så nøye med denne gamle chipping-greenen, men de bør nå lære seg å verdsette det nye flotte gressdekket ved å reparere nedslagsmerkene.

Ballerud golfklubb

Jordprofil
Ballerud puttinggreen
10.juli 2008

Head greenkeeper Hæge Kranstad. Deler av greenen var fremdeles dominert av krypkvein (t.v.) og andre deler - av tunrapp (t.h.)

Opp til 40 % hundekvein ble registrert på noen deler av greenen

Etablering

En jordbasert krypkvein green ble fra og med 2007 sådd med hundekvein 'Avalon' (såmengde som anbefalt for krypkvein). Greenen besto av en eldre del og en nyere del etablert ved nedklipping, resåing med krypkvein og oppdressing av en del av fairwayområdet for tre år siden.

I 2008 var greenen sådd med 'Avalon' 4 ganger: vår, sommer (juni) og høst (september og oktober). Ved såing ble det brukt en slisse såmaskin.

Skjøtsel i 2008

Gjødsling

Greenen ble gjødslet ukentlig. Det ble brukt hovedsaklig Floratine flytende gjødsel men også Andersons og Roots. Fra april til 10.juli ble greenen gjødslet med samme gjødsel plan som tilsvarte krypkveingreener, etter det var gjødsel mengden for den greenen redusert dobbelt.

Total mengde NPK var:
N pr 100 m^2 / år: 1,02 kg
P pr 100 m^2 / år: 0,21 kg
K pr 100 m^2 / år: 1,25 kg

Toppdressing

1 gang hver tredje uke med 80 kg /100 m^2 av Baskarp-sand, (0,2-0,7 mm).

Vanning

Etter gjødsling og i tørkeperioder, så lite som mulig

Sprøyting:
På grunn av *Microdichium*-angrep var hele greenen sprøytet med Stratego den 11.okt (eneste gang i 2008).

Klipping

3,5 mm gjennom mesteparten av sesongen, om høsten øket til 3,7 mm.

Mekanisk behandling:
I 2008 var greenen luftet med knivlufter annenhver uke og med Hydrojet tredjehver uke. To ganger var det kjørt Vertidrain med 8 mm pinner.

Vætemiddel:
I tørkeperioden i mai-juni ble tørkeflekker behandlet med "Retain".


Kay Skogheim og Agnar Kvalbein på greenen, 10.juli 2008


Gresset kommer tilbake etter kjemisk bekjemping mot snø mugg (*Microdochium nivale*), 13.oktober 2008.

Bedømming 13.okt:

	Dekning	Tetthet skala fra 1-9, 1 – svært åpen 9 – svært tett	Sopp angrep	Filt	Ballrull, cm
For hele greenen	Hundekvein 20 % Krypkvein 60 % Tunrapp 20 %	7	Snø mugg 0,5 %	37-40 mm (pga god dressing må dette laget kalles 'mat', ikke 'filt'. Det består av jevn blanding av gressrøtter og sand)	114

Område som ligger litt lavt mellom den gamle og den nye delen av greenen besto av ca 41 % hundekvein, 18 % krypkvein og 41 % tunrapp.

Hovedinntrykk: Vi fikk inntrykk av en green der det kanskje var litt vanskelig for hundekvein å få feste i konkurranse med tunrapp og særlig krypkvein. Muligens ga såmetodene ikke tilstrekkelig vern for de små hundekveinplantene. Andre såing (i juni) var trolig mislykket pga tørke. I enkelte områder av greenen har andelen hundekvein likevel gått betydelig opp fra høsten 2007 til høsten 2008.

Imjelt

Etablering

I 2005 ble det bygd en 18-hulls pay & play bane med USGA profil på alle greener. Vekstmassen var sand, uten tilsetning av organisk materiale. Våren 2006 ble alle greener sådd med blanding av engkvein og rødsvingel. Ved omsåing av greener våren 2007 ble det brukt blanding av krypkvein 'Penn A6' og 'Nordlys' og hundekvein 'Avalon'.
Det var også resådd med raigras, for å få greenene raskere i spill. Våren 2008, pga vinterskader (30 cm is gjennom store deler av vinteren), ble alle greenene sådd med blanding av 50% 'Nordlys' og 50 % 'Avalon'. Denne behandlingen er gjentatt slik at total såmengde i 2008 er kommet opp i 10 g/m^2. Alle såingene er utført med en vanlig drop-seeder etter forutgående stikklufting eller i forbindelse med dyp vertikal skjæring (6mm).

Skjøtsel i 2008

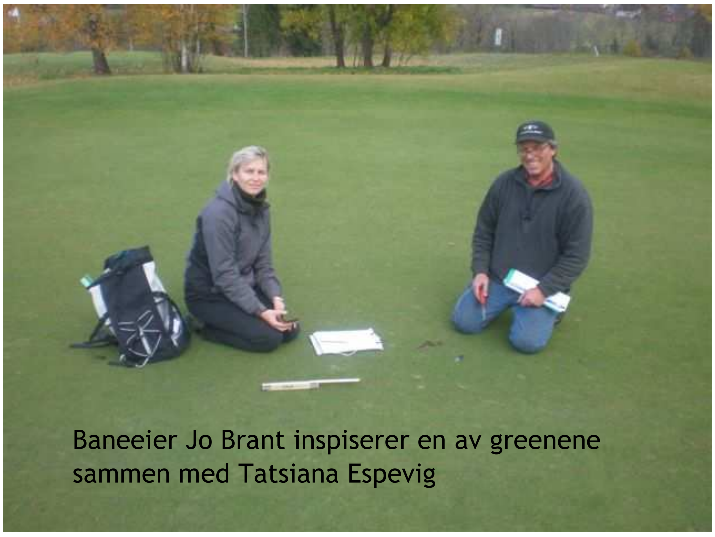
Fast gjødsel (2 ganger per måned):
Vår: GroPower (5-3-1 og 6-0-10)
PEL-lime Calcitic+Dolomitic
Andersons (8-0-16)
Sommer: Andersons (6-0-10 og 13-2-13)
Scott 22-5-10
Høst : Andersons (8-0-16)

Total tilførsel NPK:
N pr 100 m^2 / år: 2,5 kg (Opprinnelig plan: 1,9 kg)
P pr 100 m^2 / år: 1,8 kg (Opprinnelig plan: 1,6 kg)
K pr 100 m^2 / år: 2,0 kg (Opprinnelig plan: 1,7 kg)

Flytende jord gjødsel:
Plant Marvel (28-8-18) 5 ganger fra mai til september
Plant Marvel (15-5-30) 5 ganger fra juni til oktober
Det er i tilegg tilført samtidig totalt 0,2 kg/da Defense Man og 1kg/da Trical-35 SP

Flytende bladgjødsel. Plan er satt opp med 14 dagers intervaller, men har blitt tilført ukentlig.
Det er totalt for hele sesongen benyttet: Floratine - 4 l/daa Knife, 9 l/daa Carbon N, 2 l/daa Astron, 2 l/daa Per-4Max, 4 l/daa Renaissance, 2 l/daa PK Fight, 3 l/daa Carbon K, 4 l/daa Protesyn og 2 l/daa Turgor.

På grunn av tørke i sommer 2008 måtte greenene vannes hver natt i første del av vekstsesongen. Totalt ble det vannet 25 minutter vanning på hver green, noe som sannsynligvis førte til mye utvasking. Derfor ble det tilført 0,6 kg N/100 m^2 ekstra i Scott 22-5-10 (langtidsvirkende gjødsel) den 1.juli, samtidig ble det tilført vætemiddel "Revolution".



Baneeier Jo Brant inspiserer en av greenene sammen med Tatsiana Espevig

Måling av ballrull

Toppdressing
Greenene ble toppdresset 1 gang pr måned med 0,5-1 mm sand, totalt sandforbruk pr sesong var 4 mm.

Vanning
Greenene var vannet daglig i tørkeperioder (kanskje med litt for store vannmengder)

Klipping
Med triplex til 3,5 mm daglig (6 klippinger pr uke). Noen ganger klippes med singel-klipper til 3, 7 mm.

Mekaniske og andre behandlinger

- Børsting av greener annenhver uke fra juli og ut sesongen med piasavavakoster montert på pall.
- Permophore ble tilført etter første stikklufting om våren (6.mai) i områder med dårlig etablering.
- Om våren 2 runder med asfaltvalser.
- 2 ganger pr sesong HydroJect (lufting med vann).
- 4 ganger pr sesong vertikalskjæring.
- Sprøyting med mot sopp Amistar Duo Twin 17/8 og Sportak 25/9.
- Sprøyting med blanding av jernsulfat (1 kg/daa) og ammoniumsulfat (1 kg/daa) flekkvis mot mose 3/9.

Bedømming 13.okt:

	Dekning	Tetthet skala fra 1-9, 1 – svært åpen 9 – svært tett	Sopp angrep	Filt, mm	Ballrull, cm (målt med modifisert stimpmeter)
Green nr. 7	Hundekvein 70 %	8	-	13	135
Green nr. 13	Hundekvein 40 %	7	-	14	123
Green nr. 15	Hundekvein 40 %	7	-	16	133

Hovedinntrykk. Det var stor variasjon i hvor godt hundekveinen hadde etablert seg. Særlig på green 7 var den i ferd med å bre seg i sirkler etter stikkpipelufting + drop seeding, men på green 13 og 15 var tilslaget dårligere. Særlig på green 15 var det mye grovblada engkvein og krypkvein, og både green 13 og 15 hadde en god del mose (ca 5%).

For å øke andelen hundekvein er det ingen annen utvei enn å fortsette med regelmessig lufting, toppdressing og resåing. Bruk av drop-seeder etter lufting med faste tinner eller hullpiper ser ut til å være en god metode.

Veierland golf pitch & put (økologisk)

Agnar Kvalbein tar en prøve fra greenen, 11.juli 2008

Jordprofil, 11.juli 2008

<u>Etablering</u>
Banen ble bygd i 2005 og består av 6 jordbaserte greener i ekstensiv, økologisk drift. Som vekstmasse ble det brukt blanding av sand og park kompost (60 / 40 v/v %). Greenene ble sådd med blanding av hundekvein "Avalon" (15 %) og rødsvingel (85 %).

Skjøtsel i 2008

<u>Gjødsling</u>
Vår: Høne gjødsel (2-1-2) +
Lupin (6-1-1,5)
Sommer: Lupin (6-1-1,5)

N pr 100 m^2 / år: 0,40 kg
P pr 100 m^2 / år: 0,10 kg
K pr 100 m^2 / år: 0,16 kg

<u>Toppdressing</u>
1 gang pr år med samme vekstmedium som ble brukt ved bygging av greenene (60 % sand / 40 % park kompost (v/v %)).

<u>Vanning</u>
Naturlig nedbør

<u>Klipping</u>
Annen hver dag til 5 mm.

<u>Mekaniske og andre behandlinger</u>
Lufting med 8 mm solide pinner ved avslutning av sesongen (september-oktober) utføres samtidig med resåing (samme blanding av hundekvein og rødsvingel) og toppdressing etterpå.

Noen steder var det flekker med sopp, ugress og tørkeflekker. Som bekjempelse mot ugress brukes det lett vertikalskjæring og luking; mot sykdom – duggfjerning hver dag

Hovedinntrykk

Banen ble bare besøkt 11. Juli, og dessverre ble det ikke gjort systematisk vurdering denne sesongen. I juli var banen preget av soppangrep og noe sviktende klipping. På grunn av tørkeperiode i år fikk gresset en del angrep av rotdreper som bare angrep hundekvein, og senket % innehold av den arten på greenene. Det interessante med disse greenene var at det ikke bygget seg opp filt, til tross for lite mekanisk vedlikehold.