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NORSK INSTITUTT FOR  
BIOØKONOMI

# FESCUE-GREEN: Best management of red fescue (*Festuca rubra*) golf greens for high sustainability and playability

FINAL SCIENTIFIC REPORT 2011–2015

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This report gives a summary of results from the STERF-project FESCUE GREEN 2011-2015.

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# Preface

The project 'FESCUE-GREEN: Best management of red fescue (*Festuca rubra*) golf greens for high sustainability and playability' was funded by the Scandinavian Turfgrass and Environment Research Foundation (STERF) and carried out from 2011 to 2015 as a joint effort by researchers and greenkeepers in Norway and Denmark. The project consisted of four subprojects, three of which included field trials on greens at NIBIO Landvik Research Station in Norway and Smørum Golf Course in Denmark. The fourth subproject was devoted to technology transfer through international workshops/seminars, a number of talks and popular articles in Scandinavian and English languages, and a handbook on red fescue management.

This NIBIO report has been written following the template for final scientific reports from STERF-funded projects. It gives the most important results from the field experiments in SP 1-3.

On behalf of the project group, I thank STERF for funding this project.

Landvik, Norway, 20.01.17

Trygve S. Aamlid

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# Conclusions and advice for the golf and turfgrass sector

The project 'FESCUE GREEN' confirmed that red fescue is good alternative for sustainable management of golf course putting greens in the Nordic countries.

Our conclusions are:

1. Red-fescue putting greens do not develop distinct dry spots as easily as creeping bentgrass (*Agrostis stolonifera*) putting greens. Even without using soil surfactants, greenkeepers therefore have more freedom to choose among water-saving irrigation strategies. In this project, light and frequent deficit irrigation to 60 % of field capacity three times per week (DEF3) and deep and infrequent irrigation to FC once a week (FC1) saved, in turn, 72 and 49 % water relative to saturation-based irrigation to field capacity three times per week (FC3). Both DEF3 and FC1 reduced annual bluegrass (*Poa annua*) and moss encroachment, increased surface hardness and reduced thatch thickness significantly compared with FC3, but the reduction in moss encroachment tended to be stronger for FC1 than for DEF3 irrigation. Unless the irrigation system distributes water with higher-than-average uniformity, the most water-saving irrigation strategy (DEF3) will usually be hard to practice without hand-watering.
2. A fertilizer regime with most of the annual nitrogen input (in this project 11 g N m<sup>-2</sup>) in May and early June gave better visual quality, less annual bluegrass, less moss and deeper roots than the opposite regime with most fertilizer from mid August to late September. The latter treatment with high fertilizer inputs in late summer and early autumn resulted in faster green-up in spring but the turfgrass quality was lower for the growing season as a whole. A flat fertilizer regime with constant weekly fertilizer rates from early May to late September produced intermediate results. We conclude that the highest fertilizer rates on fescue greens should be given from mid May to mid June.
3. Measurements of golf ball roll distance over three years showed that the mowing height could be raised from 5 to 6 mm with no compromise in green speed if the plots were rolled four times per week. The average reduction in ball roll distance was only 7 cm, which is about one half of what can be detected by most players. Rolled plots were harder than unrolled plots, but there was no effect of rolling on dollar spot (*Sclerotinia homeocarpa*) or microdochium patch (*Microdochium nivale*). Roots were deeper at 6 than at 5 mm mowing height.
4. Substitution of peat with composted garden waste (Green Mix; both at 2.6-2.9 % OM (w/w)) as organic amendment to the USGA-green rootzone resulted in faster grow-in, better visual quality, harder surfaces and higher percentages of roots colonized by mycorrhiza during the first two years after grow-in. Leaching of NO<sub>3</sub><sup>-</sup> was negligible except in spring 2013 after winter damage, but leaching of P was high from Green-Mix rootzones throughout the trial.
5. Regular use of compost-amended (Green Mix, OM ~ 1.0-1.2 %) topdress for a total rate of 8 mm sand per year resulted in better turfgrass quality, but more annual bluegrass and a higher organic matter content in the thatch/mat layer. On Green Mix rootzones, there were, in the second year after establishment, indications of a higher nutrient uptake after topdressing with straight sand than with Green Mix topdress. All in all, this speaks in favour of limiting the use of Green Mix compost as organic amendment to the sand used for construction and in topdressing to be used in conjunction with ridding. For regular maintenance, we rather recommend topdressing with straight sand.

# Background

Red fescue (*Festuca rubra* L.) requires less pesticides, fertilizers and irrigation than annual bluegrass (*Poa annua* L.) and bentgrasses (*Agrostis* sp.) and may therefore lead to a more sustainable management of golf course putting greens. The scientific documentation for optimal management of red fescue putting greens is, however, fragmentary, and issues such as irrigation, fertilization, mowing, rolling, and the use of compost in the rootzone or topdress have often been debated. STERF's project FESCUE GREEN was set up in 2011 to develop strategies for management of Scandinavian golf greens with a predominant turf cover of red fescue for optimal playability and sustainability. This included the following subgoals, each corresponding to one subproject (SP):

1. To determine how various irrigation and seasonal fertilizer distribution strategies affect turfgrass quality, playability and competition from annual bluegrass and moss on fescue greens (SP 1)
2. To clarify the impact of increased mowing height and to what extent mowing can be replaced by rolling on mature greens with a predominant cover of fescue (SP 2)
3. To determine the impact of garden compost (Green Mix) in the rootzone or in the topdress on turfgrass quality, playability, competition from annual bluegrass, nutrient losses and potential fertilizer savlings on red fescue putting greens (SP 3).
4. To actively disseminate results to the golf industry and create meeting places for exchange of experiences regarding red fescue management (SP 4).

The following report summarizes the most important findings in SP 1-3 during the four-year project period. For mord through documentation, readers are referred to the scientific papers that have been, or will be published from the project.



# 1 Irrigation and seasonal fertilizer distribution

## 1.1 Materials and methods

A field trial was conducted from 12 Aug. 2013. to 10 Aug. 2015 under a mobile rainout shelter covering a USGA-spec. green at NIBIO Landvik, Norway. The turf cover had been seeded in 2012 and re-established in spring 2013 after winter damage. The volumetric soil water content (SWC) at FC was 20 % (v/v) corresponding to 40 mm water at 20 cm effective root depth.

The trial had four blocks, four irrigation treatments on main plots and three seasonal fertilizer distribution treatments on subplots. The four irrigation treatments were:

- 1) FC3: Irrigation to Field Capacity (FC) three times per week (Monday, Wednesday, Friday)
- 2) DEF3: Deficit irrigation to 60 % of FC three times per week
- 3) FC1: Irrigation to FC once per week (Mondays)
- 4) DEF-FC: As treatment 2 but with irrigation to FC once per week in every other week from 12 Aug. 2013 to 10 Aug. 2014 (= first experimental year)  
DEF1: Deficit irrigation to 60 % of FC once per week from 11 Aug. 2014 to 10 Aug. 2015 (= second experimental year).

The rainout shelter was activated and irrigation treatments carried out from 12 Aug. to 29 Sept. 2013, 5 May to 28 Sept. 2014 and 4 May to 10 Aug. 2015. Apart from these periods, the green received natural precipitation. The reason for the change in irrigation treatment 4 was the need for a more severe drought treatment as there was no significant effect of irrigation on turf quality in the first experimental year. The SWC at 0-20 cm depth was measured with a TDR instrument before irrigation and used to calculate irrigation amounts. The soil surfactant Revolution was used three times before the start of the experiment in 2013 and two times in April 2014, but not after that.

For the fertilizer distribution treatments, the growing season was divided into the five periods (1) 'Early spring' (1 Apr.- 3 May); (2) 'Late spring/early summer' (4 May-21 June); (3) 'Summer' (22 June - 9 Aug.); (4) 'Late summer/early fall' (10 Aug.-28 Sept.) and (5) 'Late fall' (29 Sept. – 16 Nov.). Each period except 'Early spring' had a duration of seven weeks. The fertilizer inputs in 'Early spring', 'Summer' and 'Late fall' were the same in all treatments, but the inputs in 'Late spring /early summer' and 'Late summer /early fall' varied between the three treatments:

- A. FALL+: 4 May-21 June:  $0.23 \text{ g N m}^{-2} \text{ wk}^{-1}$ ; 10 Aug.-28 Sept.:  $0.68 \text{ g N m}^{-2} \text{ wk}^{-1}$
- B. FLAT: Both periods  $0.45 \text{ g N m}^{-2} \text{ wk}^{-1}$
- C. SPRING+: Opposite to treatment A.

In all treatments, liquid, mineral fertilizer was applied every Monday as the complete fertilizer solution Wallco 5:1:4. The annual N input was  $11.0 \text{ g N m}^{-2}$  in all treatments.

## 1.2 Results and discussion

The effect of irrigation and seasonal fertilizer distribution treatments will be presented and discussed separately as there was no significant interaction between the two factors.

### 1.2.1 Effects of irrigation

The seven-week 'Summer' period in 2014 was warm with a mean temperature of 18.5°C, 2.4°C higher than the 30 normal (1961-90). During this period, FC1 irrigation gave the lowest SWC with values occasionally down to 5%. In the second experimental year, the average SWC on plots irrigated according to FC3 was significantly higher (mean 12.7%) than on plots irrigated according to DEF3, FC1, or DEF1 (average SWC 9.9, 9.9 and 8.6%, respectively). DEF3 irrigation saved approximately 45% water compared with FC1 irrigation in both experimental years.

The irrigation treatments had no effect on turfgrass quality in the first experimental year (data not shown) or during 'Early spring' and 'Late spring/early summer' in the second year (Table 1). FC3 irrigation produced the best turfgrass quality in the 'Late summer/early fall' and 'Summer' of the second year. DEF3 and FC1 irrigation produced approximately the same quality in all periods (Table 1).

Annual bluegrass or moss coverage were not affected by irrigation treatments in the first experimental year and 'Late summer/early fall' of the second year (data not shown). In the 'Summer' of the second experimental year, FC3 resulted in significantly more annual bluegrass and moss than the other irrigation treatments (Table 1). DEF3 gave four times more moss than FC1, although this difference was not statistically significant.

Table 1. Effect of irrigation treatments during different periods in the second experimental year.

Irrigation treatments	Total irrigation mm	Turfgrass quality (1-9)				Annual bluegrass coverage, %	Moss coverage, %	Daily height growth, mm	Surface hardness (gravities)
		10 Aug.- 28 Sept. 2014	1 Apr. - 3 May 2015	4 May- 21 June 2015	22 June- 10 Aug. 2015				
FC3	930 a <sup>1</sup>	6.1 a	4.9	5.0	5.5 a	20.8 a	4.7 a	0.61 a	78.6 b
DEF3	288 c	5.4 b	5.2	5.1	5.1 b	15.2 b	1.3 b	0.54 a	82.6 a
FC1	511 b	5.5 b	5.4	5.1	5.0 b	14.2 bc	0.3 b	0.33 b	82.3 a
DEF1	211 c	5.4 b	5.3	4.7	4.6 c	10.7 c	0.1 b	0.14 c	83.9 a
<i>P</i> -value	<0.001	<0.05	NS	NS	<0.01	<0.001	<0.001	<0.001	<0.05

<sup>1</sup>Within each column, means followed by the same letter are not significantly different at  $P \leq 0.05$ .

On average for three periods during the first experimental year, the height growth on plots irrigated with DEF3, FC1 and DEF-FC were, in turn, 14, 25 and 17 % less than on plots irrigated with FC3 (data not shown). In the second experimental year, there were no differences in growth rate during 'Late summer/early autumn' (data not shown) but DEF3, FC1 and DEF1 reduced the growth rate by 11, 46 and 77 % compared with 'FC3' irrigation on average for the period 4 May – 10 Aug. (Table 1).

Irrigation treatments had no effect of golf ball roll distance (data not shown), but the playing surfaces were softer with FC3 with the other irrigation treatments (Table 1).

By the end of the trial in August 2015 the thatch/mat layer was significantly thicker after FC3 irrigation (27.5 mm) than after DEF3 (24.8 mm), FC1 (24.9 mm) and DEF-FC/DEF1 irrigation (23.7 mm). The average concentration of soil organic matter in the top 0-2 cm increased from 4.3% in August 2013 to 5.4% August 2015, but was not significantly affected by irrigation treatments.



### 1.2.2 Discussion

In the first year of this study, red fescue greens had the same high visual quality in all irrigation treatments in spite of a very high temperature in 'Summer' and a SWC going down to 5% in the FC1 treatment. The most likely reason for this is the use of soil surfactant in 2013 and early spring 2014. Other research has shown Revolution to lower the SWC of the top layer on putting greens (Soldat 2010, Aamlid et al. unpublished) and this explains why it was possible to control annual bluegrass and moss even with FC3 irrigation in the first experimental year. It appears that the soil surfactant levelled out most of the differences between the irrigation treatments in the first year, and this is in agreement with earlier research comparing irrigation strategies with and without soil surfactant on a soil-based fairway (Aamlid et al. 2012a).

Partly due to the change from DEF-FC to DEF1 in treatment 4, but more to the abolishment of surfactant and the fact that the green was one year older, irrigation had significant effects on turfgrass quality and annual bluegrass and moss encroachment in the second year. An increase in annual bluegrass contamination was avoided only in the driest treatment DEF1, which also had the lowest turf quality. This suggests that control of annual bluegrass is not possible without sacrifices the visual quality/greenness of the red fescue. Frequent irrigation to FC, is, on the other hand, likely to exacerbate the competition from annual bluegrass.

Moss encroachment is a common phenomenon on fescue greens receiving limited amounts of nitrogen (Aamlid et al. 2012b). While the only significant difference was between FC3 and the other irrigation treatments, it is also interesting to observe that DEF3 had two to four times more moss than FC1 despite 42% less use of irrigation water. This observation is in agreement with (Lyons et al. 2012) and suggests that not only irrigation quantity, but also irrigation frequency, are important for moss encroachment.

The reduction in daily height increments was stronger with FC1 than with DEF3 irrigation, in spite of more use of irrigation water. This difference is, however, most likely an artefact as the height increment was always measured from Friday to Monday, i.e. when plots receiving irrigation only on Mondays were at the driest. On average for the whole week, our results suggest that withholding irrigation will not reduce the growing rate of red fescue more than 15% if the visual turf quality is to be maintained at an acceptable level.

Red fescue greens are usually characterized by harder surfaces allowing the golf ball to bounce longer than on annual bluegrass or bentgrass greens. One of the most important factors determining surface hardness is SWC (Windows et al. 2010). Even though our measurements were always conducted at least 24 h after irrigation, it is therefore not surprising that the greens were softer with FC3 than with the other irrigation treatments. The effect can also be explained by the thatch/mat layer, which at the end of the trial was significantly thicker with FC3 irrigation.

Finally, in this research, we found that direct monitoring of SWC was a useful tool to produce putting greens with acceptable quality and minimal use of irrigation water. For USGA-spec. putting greens with a turf cover of red fescue, this can be achieved with either DEF3 or with FC1 irrigation. DEF3 irrigation will save most water, but FC1 irrigation is easier to practice without hand-watering and also likely to result in less moss.

### 1.2.3 Effects of fertilizer distribution

FALL+ fertilization caused higher turfgrass quality than the other fertilization distributions treatments in the 'Late summer/ early fall' and 'Early spring' of the first experimental year, and in the 'Late fall' of the second year (Table 2). In contrast, the turf quality in this treatment dropped below the minimum acceptable level of 5.0 in the 'Late spring/early summer' and 'Summer' of the second year. SPRING+ fertilization produced the highest turfgrass quality not only in the 'Late spring/early summer' of both years, but there was also an after-effect into the 'Summer' when all treatments received the same

amount of fertilizer. In the second year, SPRING+ distribution produced the best turfgrass quality on average for all periods.

Table 2. Mean values for turfgrass quality (1-9, 5 is lowest acceptable value) of red fescue during different seasonal periods in two experimental years as influenced by three fertilizer distribution treatments.

	First experimental year 12 Aug. 2013 – 10 Aug. 2014					Second experimental year 11 Aug. 2014 – 10 Aug. 2015					
	12 Aug.- 29 Sept.	2 Apr. - 4 May	5 May- 22 June	23 June- 10 Aug.	Mean	11 Aug.- 28 Sept.	29 Sept.- 16.Nov.	1 Apr.- 3 May	4 May- 21 June	22 June- 10 Aug.	Mean
FALL+	7.0 a <sup>1</sup>	6.8 a	6.3 c	5.9 c	6.5 a	5.7 a	4.8 a	5.3	4.5 c	4.8 c	5.0 c
FLAT	6.7 b	6.6 b	6.7 b	6.2 b	6.6 a	5.7 a	4.4 b	5.2	4.9 b	5.0 b	5.2 b
SPRING+	6.3 c	5.6 c	7.0 a	6.5 a	6.6 a	5.4 b	3.7 c	5.2	5.5 a	5.4 a	5.4 a
P-value	<0.001	<0.001	<0.001	<0.001	NS	<0.05	<0.001	NS	<0.001	<0.001	<0.001

<sup>1</sup>Within each column, means followed by the same letter are not significantly different at  $P \leq 0.05$ .

No effect of fertilizer distribution on annual bluegrass encroachment was detected in the first experimental year (data not shown). In the second year, percent annual bluegrass increased strongly with FALL+ distribution from late September to early November 2014 and in late April and early May 2015 (Fig. 1). The latter increase also occurred with 'FLAT' fertilization, although to a lesser extent. After a temporary drop in May and early June, the contamination of annual bluegrass increased significantly in all treatments from late June until the end of the trial in early August. Moss encroachment was not affected by seasonal fertilizer distribution in either experimental year (data not shown).

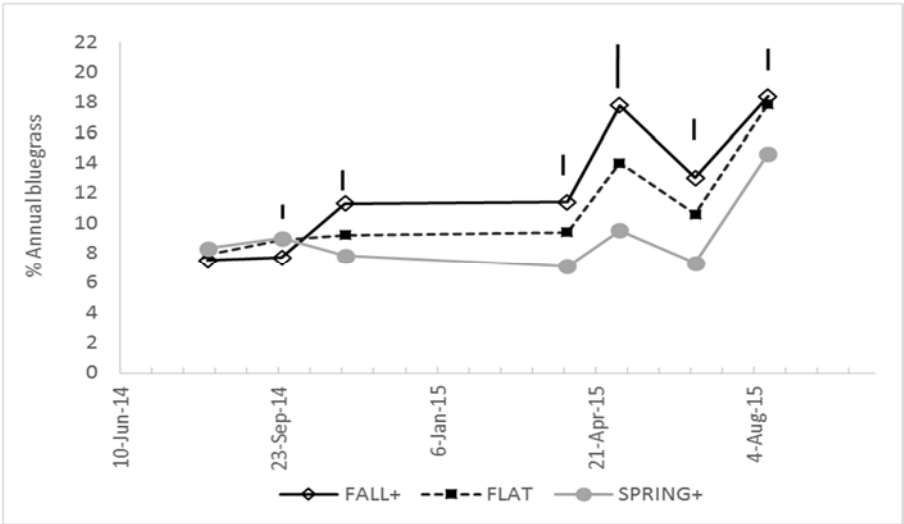


Fig. 1. Annual bluegrass as per cent of turfgrass coverage in the second experimental year. Vertical bars indicate  $LSD_{0.05}$

On average for two experimental years, red fescue height growth in 'Late summer/early fall' was 12% lower with SPRING+ fertilization and 12% higher with FALL+ fertilization than with FLAT fertilization. In 'Late spring/early summer' the corresponding values compared with FLAT rate were 13% lower for FALL+ and 23% higher for SPRING+ fertilization. This pattern also lasted into the SUMMER which had values of -10% and +15 % for FALL+ and SPRING+, respectively (data not shown).

Variations in turfgrass ball roll during the two growing seasons reflected the aforementioned variation in turfgrass height growth, but with a lower amplitude. The deviations from the FLAT fertilization were mostly within the range  $\pm 5\%$ . Fertilizer distribution treatments had no effect on thatch thickness or organic matter content at 0-2 or 2-4 cm depth by the end of the trial.

#### 1.2.3.1 Discussion

The encroachment of annual bluegrass into red fescue in the 'Late summer/early fall' and especially 'Late fall' of the second experimental year was higher with FALL+ than with the two other fertilizer distribution treatments. The mean temperature for the seven weeks 'Late fall' period in 2014 was 9.7 °C as compared with a 30-year normal value of 6.8 °C, and the combination of high temperature, low light intensity and high fertilizer input during the preceding period probably favored both the growth of existing bluegrass plants and the emergence of new bluegrass seedlings. This is compatible with a study from Maryland, USA, showing that the peak emergence period for new annual bluegrass seedlings was from September to November (Kaminski and Dernoden 2007).

In agreement with US research on fall and late fall fertilization (for a review see Bauer et al. 2012) FALL+ distribution also resulted in proliferation of annual bluegrass at the expense of red fescue in 'Early spring'. The drop in annual bluegrass coverage in May and early June coincided with the flowering season during which annual bluegrass' resources were used for generative development rather than for vegetative expansion (Vargas and Turgeon 2004). After flowering, the encroachment continued and was probably exacerbated by the combination of repeated wear treatments and a 'Summer' period during which the average temperature was 2.9 °C lower than in 2014.

In conclusion, our results show that it is difficult to control annual bluegrass on red fescue greens by fertilizer treatments alone. Other factors, such as, mowing height and competitive ability of the red fescue varieties will also have a major impact (Aamlid et al. 2012b, Calvache et al. 2016). Our results nevertheless point to SPRING+ as the preferable fertilizer distribution for putting greens aiming for pure stands of red fescue.

## 2 Turf health and playability at high mowing and replacement of mowing with light weight rolling

### 2.1 Materials and methods

A field trial was conducted from May 2012 to September 2014 on green no 2 of the PAR 3 course at Smørum GC, Copenhagen. The green had been established in 1993 on a sand-based rootzone amended with garden compost (Green Mix, Solum, DK). The turf cover at the start of the trial was 86 % red fescue, 13 % colonial bentgrass and 1 % annual bluegrass. The experimental plan included three replicates and the following factors: (1) Mowing height (5 or 6 mm); (2) Mowing frequency (5 or 3 times a week), and (3) Light weight rolling (0, 2 and 4 times a week). The annual fertilizer rate was 3.5 g N m<sup>-2</sup> split into three applications in 2012, and 4.8 g N m<sup>-2</sup> split into three applications in 2013 and 2014.

### 2.2 Results and discussion

Measurements of golf ball roll distance over three years showed that the mowing height could be raised from 5 to 6 mm with no compromise in green speed if the plots were rolled 4 times per week (Table 3). The average reduction in ball roll distance was only 7 cm, which is only about one half of what can be detected by most golf players (Karcher et al. 2001). Our result are in agreement with Richards et al. (2009) who found that rolling had a greater impact on ball roll distance than mowing height and mowing frequency. Changing the maintenance operations from mowing at 5 mm to 6 mm combined with 4 times rolling per week will, however, be associated with additional cost. For the actual golf GC at Smørum, rolling of 18 greens four times per week will require almost 9 hours of extra labor per week.

Table 3. Average ball roll distance in two selected treatments in the trial at Smørum GC. The results refer to plots mowed five times per week.

Mowing height, mm	Rolling frequency per week	Ball roll, cm
5	0	237
6	4	230

There was a tendency for plots that were rolled two or four times per week to be harder than unrolled plots. At the same time, measurements with a TDR instrument showed that rolling created slightly dryer greens. These differences between rolling treatments were, however, much less than the difference between observations dates. As measured with a Clegg hammer, the average surface hardness ranged from 74 in April 2014 to 96 in July 2013, while the average soil water content ranged from 15 to 24 %

Unlike in American studies on annual bluegrass/creeping bentgrass greens (Giordano et al. 2012), there was no effect of mowing height, mowing frequency or rolling on dollar spot (*Schlerotina homeocarpa*) or microdochium patch (*Microdochium nivale*). The coverage of annual bluegrass was always less than 1.5 % and not affected by treatments. The increase in mowing height from 5 to 6 mm resulted in significantly deeper roots, especially in the dry spring of 2013, but rolling had no effect on this character.

## 3 Use of compost in the rootzone AND/or topdress on red fescue greens

Use of compost in the rootzone AND/or topdress on red fescue greens. The background for this subproject was the widespread use of 'GreenMix' garden compost (Solum AS, Denmark) as organic amendment to the sand in rootzones and as topdress on golf greens, especially in Denmark, but to some extent also in Norway and Sweden. Two trials were conducted, one at NIBIO Landvik, Norway and one at Smørum GC, Denmark

### 3.1 Experiment at NIBIO Landvik

#### 3.1.1 Materials and methods

The experiment was conducted from Aug. 2011 to Oct. 2014 in a lysimeter facility developed for USGA-spec. rootzones. The trial had four replicates and two experimental factors, each with two levels.

##### Factor 1: Organic amendment to the rootzone sand at construction in 2011

1. Sphagnum peat (OM = 2.85 % w/w).
2. Garden compost (Green Mix) (OM = 2.63 % w/w).

##### Factor 2: Topdressing material used in 2012-2014:

- A. Straight sand (OM = 0.10 % w/w).
- B. Garden compost (Green Mix) (OM = 0.95 % w/w).

Chemical analyses of the rootzone and topdressing materials are shown in Table 4. The experiment was seeded on 17 Aug. 2015 with a seed mixture containing 97 % red fescue and 3 % annual bluegrass (unspecified seed sold to golf course by the Norwegian company Felleskjøpet Agri). The topdressing was applied every other week in 2012, 2013 and 2014 for a total annual rate of 8.5 mm sand.

During grow-in in 2011, the plots established on peat-amended and compost-amended rootzones received 16.5 and 8.5 g N m<sup>-2</sup>, 2.1 and 1.1 g P m<sup>-2</sup> and 14.2 and 7.3 g K m<sup>-2</sup>, respectively. Different fertilizer rates during grow-in were applied to compensate for the higher nutrient content in the compost and provide a uniform turf cover on all plots in spring 2012. In 2012 and 2014 all plots received the same amount of biweekly fertilizer inputs adding up to an annual rate of 13 g N, 1.2 g P and 18 g K m<sup>-2</sup>. In spring 2013 the experiment had to be reseeded due to ice damage, hence the fertilizer rate was increased to 21 g N, 2.4 kg P and 17 g K m<sup>-2</sup> to all plots.

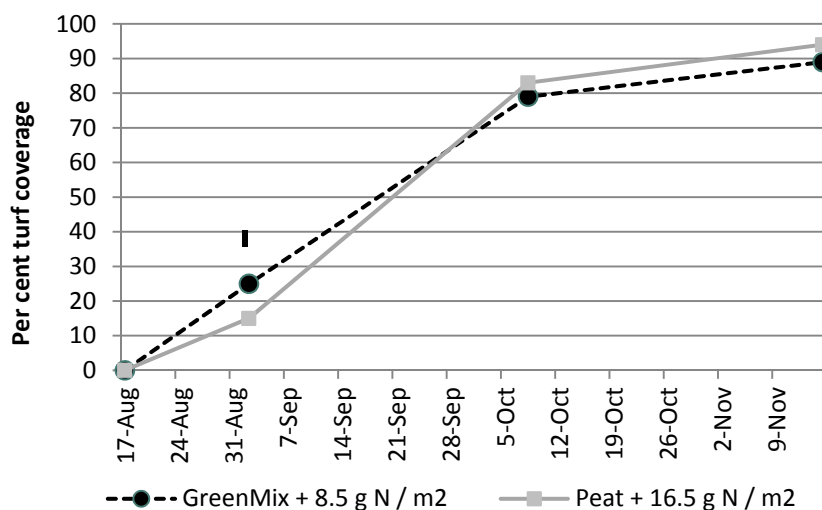
**Table 4. Chemical soil analyses of rootzone materials used at establishment in August 2011, and of topdressing materials used in 2012-2014.**

Parameter	Unit	Rootzone		Topdressing	
		Peat	Green Mix	Straight sand	Green Mix
Ignition loss	% of DW	2.85	2.63	0.10	0.95
pH (H <sub>2</sub> O)		5.6	7.8	6.5	8.0
P-AL	mg/100g	1.7	6.4	< 1.0	5.9
K-AL	mg/100g	2.3	25	< 2.0	24
Mg-AL	mg/100g	2.4	6.8	< 1.0	4.9
Ca-AL	mg/100g	14	95	< 10	111
Na-AL	mg/100g	2.2	3.1	< 5.0	< 5.0
Mineral N	mg/100g	0.06	3.0	0.17	3.2
Total N	% of DW	< 0.1	0.14	< 0.11	< 0.11
Total C	% of DW	1.5	1.9	< 0.5	0.58

### 3.1.2 Results

#### 3.1.2.1 Turfgrass grow-in

The turf coverage two weeks after seeding was significantly higher on rootzones amended with compost than on rootzones amended with peat. However, from mid-September until the last assessment in November, the higher nutrient content in compost was more than offset by the double fertilizer rate given to peat-amended rootzones. Thus, both treatments had an average coverage of about 90 % by the end of the grow-in year (Fig. 2).



**Fig. 2. Development of turfgrass coverage on peat-amended and compost-amended rootzones in fall 2011. Vertical bar shows LSD<sub>0.05</sub>**



Nutrient losses in leachate was measured during two periods in fall 2013 (Table 5). In spite of 50 % lower fertilizer inputs, the concentrations, and thus losses, of total N, NO<sub>3</sub>-N, and total P in leachate were 2-6 times higher from Green Mix rootzones than from peat-amended rootzones during both periods. For K, the corresponding difference was 18-23 times. Higher losses in September than in October can mostly be explained by higher precipitation, but also by the fact that the turfgrass coverage was only 30-40 % in early September as opposed to 75-85 % in mid-October.

**Table 5. Concentration of total N, nitrate-N, total P and total K in leachate and total nutrient losses from rootzones during two periods in autumn 2011. Natural rainfall was 91 mm from 6 to 13 September and 16 mm from 11 to 26 October.**

	Concentration, mg L <sup>-1</sup>				Total loss g m <sup>-2</sup>		
	Total N	NO <sub>3</sub> -N	P	K	Total N	P	K
<i>6-13 Sept. 2011</i>							
Peat	7.4	7.2	0.7	13	0.58	0.06	1.1
Compost	18.9	16.5	2.4	295	1.63	0.21	25.4
<i>P</i> -value	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
<i>11-26 Oct. 2011</i>							
Peat	1.7	1.4	0.6	8	0.02	0,01	0.11
Compost	7.5	6.3	2.0	121	0.12	0.03	1.91
<i>P</i> -value	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001

### 3.1.2.2 Established turf

Because of winter damage in spring 2013, only turfgrass characteristics from 2012 and 2014 are shown in Tables 6 and 7, respectively. Use of compost in the rootzone and/or topdress resulted in significant improvements in turfgrass quality, density and color throughout the experimental period. Significant interactions, notable for the older turf in 2014, indicated that the positive effect of using compost in topdress on these visual characteristics was larger on plots with peat in the rootzone than on plots with compost in the rootzone. There was more annual bluegrass on the compost-amended than on the peat-amended rootzone in 2012, but this was reversed in 2013 and 2014 when the assessment by the end of the trial showed most annual bluegrass on plots where Green Mix topdressing had been added on the top of rootzones containing peat. Green Mix topdressing on top of Green Mix rootzones resulted in a high invasion of voluntary creeping bentgrass in the last year of the study.

The infiltration capacity of greens was higher on compost-amended than on peat-amended rootzones in 2012 (Table 6) and 2013 (not shown), but the rates dropped markedly during the trial period and there were no significant differences in 2014 (Table 7). Per cent organic matter in the thatch/mat layer did not increase during the experimental period and was usually more affected by the topdressing than by the rootzone material. The playing characteristics of the green were only determined in 2012; these values showed firmer surfaced but slower ball roll on greens with compost than on greens with peat in the rootzone. The latter was probably a reflection of higher growth rates, as the ball roll distance was always measured 24 h after mowing to 5 mm.

**Table 6. Combined effect of organic amendments to the sand used in rootzone and topdress on turfgrass visual and playing quality characteristics, and on infiltration and organic matter accumulation in thatch/mat layer in 2012. Color was assessed from August to November and infiltration and ignition loss only in October/November; otherwise values are means of 6-7 observations during the growing season.**

Amendment to rootzone sand	Amendment to topdress sand	Turf-grass quality (1-9)	Turf-grass density (1-9)	Turf-grass color (1-9)	Annual blue-grass, %	Ball roll distance cm	Surface hardness (gravities)	In-filtration, mm/h	% OM in thatch / mat	
									0-2 cm	2-4 cm
Peat	No	3.4 d <sup>1</sup>	4.0 d	2.7 d	5.6 b	111 b	62 b	258 b	4.9	3.4 b
Peat	Compost	4.1 c	4.7 c	4.4 c	6.0 b	113 a	61 b	258 b	6.1	3.6 b
Compost	No	5.1 b	5.5 b	6.2 b	8.7 a	104 c	71 a	390 a	5.3	4.1 a
Compost	Compost	5.8 a	6.3 a	7.0 a	8.4 a	106 c	71 a	381 a	5.6	3.7 ab
ANOVA ( <i>P</i> -values)										
Rootzone		<0.001	<0.001	<0.001	<0.01	<0.001	<0.001	<0.001	>0.10	<0.05
Topdress		<0.001	<0.001	<0.001	>0.10	<0.05	>0.10	>0.10	<0.05	>0.10
Interaction		>0.10	>0.10	<0.01	>0.10	>0.10	>0.10	>0.10	>0.10	<0.05

<sup>1</sup>Within each column, means followed by the same letter are not significantly different at  $P \leq 0.05$ .

**Table 7. Combined effect of organic amendments to sand used in rootzone and topdress on turfgrass visual and playing quality characteristics and on infiltration and organic matter accumulation in the thatch/mat layer in 2014.**

Amendment to rootzone sand	Amendment to topdress sand	Turf-grass quality (1-9)	Turf-grass density (1-9)	Turf-grass color (1-9)	Annual blue-grass, %	In-filtration, mm/h	% OM in thatch / mat	
							0-2 cm	2-4 cm
Peat	Sand	3.5 c <sup>1</sup>	3.3 d	4.1 d	7.4 ab	93 a	3.5 b	3.2 b
Peat	Compost	4.9 b	4.6 c	5.1 c	9.4 a	145 a	4.1 ab	3.2 b
Compost	Sand	6.3 a	6.1 b	6.8 b	5.2 bc	128 a	5.0 a	3.7 ab
Compost	Compost	6.6 a	6.8 a	7.3 a	2.9 d	135 a	5.0 a	3.9 a
ANOVA ( <i>P</i> -values)								
Rootzone		<0.001	<0.001	<0.001	<0.001	>0.10	>0.10	>0.10
Topdress		<0.001	<0.001	<0.001	>0.10	>0.10	<0.001	<0.01
Interaction		<0.001	<0.001	<0.001	0.023	>0.10	>0.10	>0.10

<sup>1</sup>Within each column, means followed by the same letter are not significantly different at  $P \leq 0.05$ .

Analyses of red fescue roots showed only 1% colonization with mycorrhiza in June 2012. Four months later, the colonization had increased to 22 and 59% on rootzones containing peat and compost, respectively (difference significant at  $P < 0.001$ ). Topdressing materials had no effect on this character (data not shown).

Tables 8 and 9 show the main effect of rootzone composition on clipping yields, nutrient removal in clippings and nutrient losses in leachate in 2012 and 2013. Because of the winter damage, the latter year was divided into one reestablishment phase and one maintenance phase. Referring to the maintenance phases, the average clipping yields were 33 and 22 % higher on compost-amended than on peat-amended rootzones in 2012 and 2013, respectively. The corresponding relative differences in nutrient removal were larger than this because the concentrations of N, K and especially P in turfgrass dry matter were also higher on compost-amended rootzones. At the same time, the leaching losses of N were 275 and 57 % larger from compost-amended than from peat-amended rootzones in 2012 and 2013, respectively, whilst and corresponding differences in the leaching of P were 206 and 966 %, and in leaching of K 319 and 32 %, respectively.

There was no significant effect on type of topdress on turfgrass clipping yields, nutrient removal or leaching losses in 2012. In 2013, leaching losses were also not significantly affected, but to our surprise, the clipping yields and the removal of N, P and K in clippings during the maintenance phase was around 10 % higher on plots receiving straight sand topdress than on plots receiving Green Mix topdress. There were also significant interactions suggesting that the increase in growth and nutrient uptake due to straight sand vs Green Mix topdress was more pronounced on Green Mix than on peat-amended rootzones (data not shown).

**Table 8.** Effect of rootzone composition on average dry matter production in clippings per day and on the removal of N, P and K in clippings and on losses of the same nutrients in leachate during the growing season 2012. The seasonal fertilizer inputs of N, P and K have been indicated.

Maintenance period 21 March – 13 Nov.								
Input in fertilizer	Production of clippings, g DM m <sup>-2</sup> d <sup>-1</sup>	g N m <sup>-2</sup>		g P m <sup>-2</sup>		g K m <sup>-2</sup>		
		Clippings	Leachate	Clippings	Leachate	Clippings	Leachate	
Peat	1.23	8.4	0.8	1.08	0.93	5.2	6.7	
Compost	1.64	12.9	2.2	1.87	1.92	7.9	21.4	
<i>P</i> -value	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	

Table 9. Effect of rootzone composition on average dry matter production in clippings per day and on the removal of N, P and K in clippings and losses of the same nutrients in leachate during the growing season 2012. The seasonal fertilizer input of N, P and K has been indicated.

Input in fertilizer	Reestablishment period, 25 April – 24 June <sup>1</sup>			Production of clippings, g DM m <sup>-2</sup> d <sup>-1</sup>	Maintenance period, 25 June – 26 Nov.					
	g N m <sup>-2</sup>	g P m <sup>-2</sup>	g K m <sup>-2</sup>		g N m <sup>-2</sup>		g P m <sup>-2</sup>		g K m <sup>-2</sup>	
Rootzone	Leachate				Clipp-ings	Leach-ate	Clipp-ings	Leach-ate	Clipp-ings	Leach-ate
Peat	1.4	0.19	4.2		1.45	5.3	0.7	0.79	0.12	4.5
Compost	4.8	0.84	4.7	1.77	7.9	1.1	1.24	1.16	6.3	7.0
P-value	<0.001	<0.001	>0.10	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.01

<sup>1</sup>Clippings were not collected during this period due to winter damage

## 3.2 Experiment at Smørum GC

### 3.2.1 Materials and methods

The experiment was conducted from April 2012 to October 2014 on a practice green at Smørum GC, Copenhagen. The green had been established in 1993 on a Green Mix rootzone and also topdressed regularly with Green Mix topdress during the past 20 years. The basic maintenance program during the experimental period included 2-3 aerations and 1-3 overseedings with pure fescue seed per season. The basic fertilization to the entire green was three applications of a balanced granular fertilizer for an annual rate of 3.5 g N m<sup>-2</sup> in 2012 and two applications for an annual rate of 4.8 g N m<sup>-2</sup> in 2013 and 2014. A liquid formulation of iron was applied 7-8 times per year.

The experiment had two replicates and followed a split-plot design with straight sand or 'Green Mix' topdress (1.2 % OM w/w) on main plots and an extra fertilizer application of 0, 1.0, 2.0 or 3.0 g N m<sup>-2</sup> in a complete, liquid balanced fertilizer in August on subplots. The topdressing was given at 3-5 week intervals for a total rate of 8 mm sand per year.

### 3.2.2 Results

Type of topdressing material had no significant effect on turfgrass quality during the three year experimental period. The additional fertilizer application of 2.0 og 3.0 g N m<sup>-2</sup> in August resulted in significant improvement in turfgrass color for a few weeks after the application but had no effect on turfgrass quality or color in the following year.

Plots topdressed with Green-Mix topdress developed significantly less microdochium patch than plots topdressed with straight sand. Per cent annual bluegrass varied over the season with lower percentages in July than in April and October, but the encroachment was always larger after topdressing with Green Mix than after topdressing with sand (Fig. 3).

Measurements of thatch thickness was not possible because visual inspection of cylinder samples showed no distinct thatch layer in any of the treatments. Differences in organic mater content of the 0-2 cm top layer showed up after one year of topdressing. By the end of the trial, OM concentrations on plots topdressed with straight sand Green Mix were 2.8 and 3.7 %, respectively.

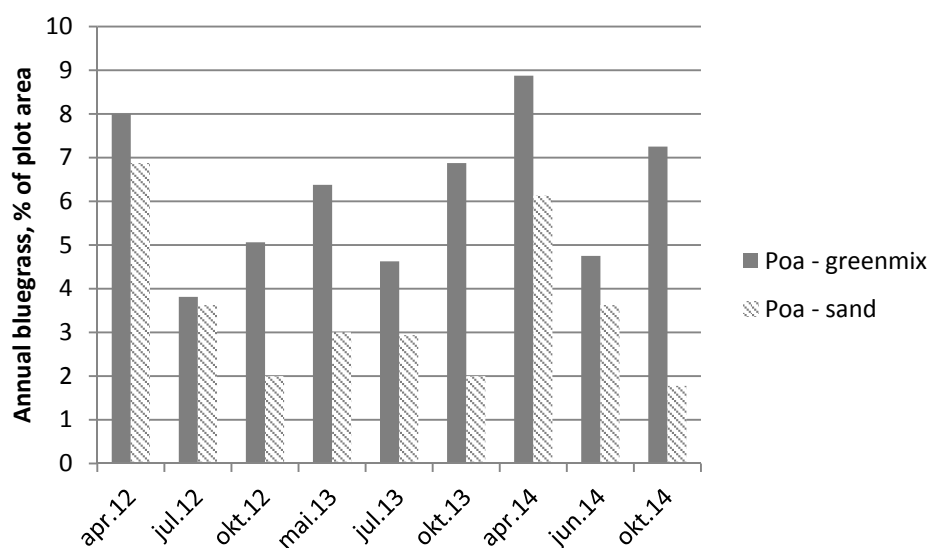


Figure 3. Main effect of type of topdress on annual bluegrass encroachment in the experiment at Smørum GC.

### 3.2.2.1 Discussion

The experiment at Landvik showed clear advantages of replacing peat with a well defined compost as organic amendment in the USGA-spec. rootzone. The advantages were related not only to color, but also to functional characters such as surface hardness and infiltration. Our results also suggested that replacement of peat with compost in the rootzone can be accompanied with significant savings in the need for fertilizer. While the savings for N and K, mostly seem to apply to the first one to two years after seeding, the high content of P in compost will most likely eliminate the need for P fertilizer for a long time after establishment.

On the negative side, the high content of water-soluble P in a Green-Mix rootzone also causes a high risk for P leaching, and thus eutrophication of ponds, streams and rivers. From an environmental standpoint, this gives reason for more concern than the leaching of N which, even on compost-amended rootzones, is mostly limited to periods with turfgrass establishment or incomplete turf cover.

The inclusion of compost in the topdress also showed certain differences such as better visual quality of the young turf at Landvik, and less microdochium patch on the older and more mature green at Smørum. However, at both locations it is a noteworthy observation that any possible increase in the decomposition by soil microorganisms due to Green Mix topdress could not compensate for the fact that this type of topdress added more OM to the thatch layer. Moreover, partly due to the higher nutrient content, or perhaps even more to the higher water holding capacity, the GreenMix topdress also resulted in more annual bluegrass encroachment, especially when added on the top of a rootzone with limited reserves of nutrients. All in all, this speaks in favor of limiting the use of Green Mix compost to the construction phase, and not as an inclusion in the topdressing used for ordinary maintenance. Green Mix topdress probably has more of an advantage when used in conjunction with reestablishment after winter damage.

# References

- Aamlid, T.S., A. Kvalbein and T. Pettersen 2012a. Irrigation strategies and soil surfactant on golf course fairways. In: A. Zuin & T.S. Aamlid (eds): Reviewed Abstracts Presented at The 3rd European Turfgrass Society Conference 'Quality Turf and Efficient Utilization of Resources'. Kristiansand, Norway 24-26 June 2012. *Bioforsk Fokus* 7(8): 55-57.
- Aamlid, T.S., G. Thorvaldsson, F. Enger and T. Pettersen 2012b. Turfgrass species and varieties for Integrated Pest Management of Scandinavian putting greens. *Acta Agriculturae Scandinavica Section B Soil & Plant Science* 62 (Supplement 1): 10-23.
- Bauer, S., D. Lloyd, B.P. Horgan, and D.J. Soldat 2012. Agronomic and physiological responses of cool-season turfgrass to fall-applied nitrogen. *Crop Science* 52: 1-10
- Calvache, S., T. Espevig, T. E. Andersen, E.J. Joner, A. Kvalbein, T. Pettersen & T.S. Aamlid 2016. Nitrogen, phosphorus, mowing height, and arbuscular mycorrhiza effects on red fescue and mixed fescue–bentgrass putting greens. *Crop Science* doi:10.2135/cropsci2016.04.0240.
- Giordano, P. R., J.M. Vargas Jr., T. Nikolai & R. Hammerschmidt 2012. Why lightweight rolling decreases dollar spot: Daily rolling can result in significant dollar spot reductions regardless of the time of day the practice is implemented *Golf Course Management*. February. 80(2): 138-142
- Kaminski, J.E. and P.H. Dernoden 2007. Seasonal *Poa annua* L. seedling emergence patterns in Maryland. *Crop Science* 47: 775–781.
- Karcher, D., T. Nikolai, and R. Calhoun 2001. Golfer's perceptions of greens speeds vary. *Golf Course Management* 69(3):57-60
- Lyons, E.M., K.S. Jordan, I.T. James, D.M. Hudner and D. McGowan. 2012. Irrigation frequency influences establishment of silvery thread moss (*Bryum argenteum* Hedw.) and rooting of creeping bentgrass (*Agrostis stolonifera* L.) on simulated golf greens. *Acta Agri. Scandinavica: Section B, Soil and Plant Sci.* 62 (Supplement 1): 79-85.
- Richards J., D. Karcher, T. Nikolai, M. Richardson, A. Patton & J. Summerford 2009. Mowing height, mowing frequency and rolling frequency affect putting green speed and quality. *Arkansas Turfgrass Report 2008*, Ark. Ag. Exp. Stn. Res. Ser. 568: 86-92.
- Soldat, D. 2010. Wetting agent research update: Wetting agents in wet conditions. *The Grass Roots*. 39(5): 18-19, 21.
- Vargas, Jr. J.M. and A. J. Turgeon. 2004. *Poa annua*, physiology, culture, and control of annual bluegrass. John Wiley and Sons, Hoboken, NJ. USA.
- Windows, R., H. Bechelet, C. Spring and J. Dobson 2010. Firmness first. *Bulletin for Sport Surface Management* 249: 5-9.



## NOTES

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Norsk institutt for bioøkonomi (NIBIO) ble opprettet 1. juli 2015 som en fusjon av Bioforsk, Norsk institutt for landbruksøkonomisk forskning (NILF) og Norsk institutt for skog og landskap.

Bioøkonomi baserer seg på utnyttelse og forvaltning av biologiske ressurser fra jord og hav, fremfor en fossil økonomi som er basert på kull, olje og gass. NIBIO skal være nasjonalt ledende for utvikling av kunnskap om bioøkonomi.

Gjennom forskning og kunnskapsproduksjon skal instituttet bidra til matsikkerhet, bærekraftig ressursforvaltning, innovasjon og verdiskaping innenfor verdikjedene for mat, skog og andre biobaserte næringer. Instituttet skal levere forskning, forvaltningsstøtte og kunnskap til anvendelse i nasjonal beredskap, forvaltning, næringsliv og samfunnet for øvrig.

NIBIO er eid av Landbruks- og matdepartementet som et forvaltningsorgan med særskilte fullmakter og eget styre. Hovedkontoret er på Ås. Instituttet har flere regionale enheter og et avdelingskontor i Oslo.