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Use of compost in the root zone or in the topdressing sand on red fescue greens

Results from the period August 2011 - November 2012

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Landvik, 25 aug. 2012
Photo: Trygve S. Aamlid

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Summary:

This report presents results from the first two experimental years in workpackage 3 of the project 'FESCUE-GREEN: Best management of red fescue (*Festuca rubra*) golf greens for high sustainability and playability'

Sammendrag:

Denne rapporten inneholder resultater fra de to første forsøksår i arbeidspakke 3 i prosjektet 'FESCUE GREEN: Bærekraftig skjøtsel av rødsvingelgreener med best mulig spillekvalitet.'

Bioforsk Landvik,
27 Dec. 2013

Trygve S. Aamlid

Project leader

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1. Abstract

Red fescue (*Festuca rubra*) requires less pesticides, fertilizers, irrigation water and energy for mowing than alternative species used on golf greens in Scandinavia. Conversion to red fescue may therefore lead to more sustaiable management of golf course putting greens. Red fescue putting greens must be established on sand-based rootzones since good drainage is needed for red fescue to be competitive with other grasses. USGA spec. golf greens have traditionally been constructed with Sphagnum peat as organic amendment to the sand-based rootzone, but a more sustainable alternative that will reduce the irreversible exploitation of bogs and help to solve organic waste problems, is to use compost. The objective of this research was to evaluate composts based on garden litter, in Scandinavia marketed under the name 'Green Mix', as organic amendments in rootzones and/or topdress used on golf greens.

A field trial was established in August 2011 in the golf green field lysimeter facility at Bioforsk Landvik, SE Norway. Green Mix rootzones were compared with peat-amended rootzones and Green Mix topdress was compared with straight sand topdress in a factorial design with four replicates (blocks). The 2m x 3m plots were seeded with a mixture of 97 % red fescue and 3 % annual bluegrass which was added to study the impact of compost on competition between the two species. The organic matter content at construction was similar (2.63 % in the Green Mix rootzone and 2.85 % in peat-amended rootzone), but soil analyses showed 50 times more mineral N, 4 times more P, 21 times more K, 3 times more Mg and 7 times more Ca in the Green Mix rootzone. During grow-in from August to November 2011 this was tried offset by a 50 % reduction in fertilizer rates to Green Mix rootzones, but this resulted in 34 % lower tiller number on Green Mix than on peat-amended rootzones, and it was therefore concluded that at a 20-30 % reduction would be more appropriate.

Topdressing treatments started in spring 2012. Ignition losses in the straight sand topdress and Green Mix topdress were 0.10 and 0.95 %, respectively, and both materials were applied 13 times at a total rate of 8.2 mm sand. Fertilizer was also applied at 1-2 week intervals at a total rate of 13.3 g N, 0.6 g P and 10.8 g K per m^2 to all treatments. In this year Green Mix rootzones produced greens with significantly better general appearance, higher tiller density, more intensely green color, less red thread disease and harder surfaces than peat-amended plots, but clipping yields were, on average for seasons, 35 % higher which resulted in 6 % lower green speed. Annual bluegrass contamination was higher on Green Mix rootzones than on peat-amended rootzones until it was outcompeted by red fescue in all treatments during a warm and dry period in late July. The total removal of N in clippings in spring, early summer, late summer and autumn were, in turn, 32, 40, 112 and 67 % higher on Green Mix rootzones than on peat-amended rootzones, indicating that late July and August is the period with the greatest potential for fertilizer reductions due to use of compost. Significant nitrogen losses in drainage water were limited to the grow-in period in 2011, but losses of P and K were high from Green Mix rootzones during the entire experiment suggesting no need for fertilization with these elements on Green Mix rootzones during the first two years after establishment. Root dry weight in the 0-5 cm top layer was lower on Green Mix rootzones than on peat-amended rootzones, but the percentage of roots colonized with mycorrhiza was almost three times higher in spite of the higher nutrient content in the rootzone.

Compared with the main effect of rootzone, topdressing materials only had minor effects on the nutritional balance in the first year after establishment. Green Mix topdress resulted, however, in significant improvements in turfgrass general appearance and color that showed up already 1-2 months after dressing treatments had started. By November 2012 replacement of straight sand with Green Mix topdress had increased the ignition loss in the thatch mat layer from 4.9 to 6.1 % on peat-amended rootzones and from 5.3 to 5.6 % on Green Mix rootzones.

If funding permits, this experiment will continue to produce results on the long-term effect of compost amendments on red fescue putting greens.

2. Introduction

Many Scandinavian golf clubs have economic problems and there is a strong demand to reduce the annual costs for turfgrass maintenance. This suggests less use of fertilizers, pesticides, and energy for irrigation, mowing and mechanical operations. The golf sector is also challenged by national and EU legislations restricting the use of pesticides and irrigation water. Projects funded by the Scandinavian Turfgrass and Environment Research Foundation (STERF), e.g. the continuous evaluation of turfgrass species and varieties under various climate conditions (Aamlid et al. 2012), suggest that conversion from annual bluegrass (*Poa annua*) or bentgrasses (*Agrostis* sp.) to red fescue (*Festuca rubra*) will of open for more Integrated Pest Management (IPM) and reduced maintenance costs on Nordic golf courses.

Although it is no longer absolutely required by the Unites States Golf Association's guidelines for putting green construction (USAA Green Section Staff 2004), most golf greens in Scandinavia are still constructed with organic amendment to the sand-based root zone. The type or organic material has traditionally been peat, but this resource is not renewable and peat harvest from bogs results in high CO_2 emissions contributing to global warming. A more sustainable alternative that would also help to solve the waste problem of urban communities is to replace peat with recycled organic matter in the form of compost.

Many greenkeepers are skeptical to using composts in the rootzone or topdress as they consider the organic matter to be unstable, not uniform and with an unpredictable content of nutrients. It is also often claimed that the macroporosity, and thus the infiltration rates, of golf greens will decline with increasing age, although it is debatable if this is due to the organic material added in compost or if it's due to the production of residues by the turfgrass itself (Blombäck et al. 2009). A third objection is that composts usually has a high pH that may inhibit plant uptake of micronutrients, and a high content of phosphorus (P) that may increase the risk for annual bluegrass encroachment on golf greens (Vargas & Turgeon 2004,Raley net al. 2013). On the other hand, if most of the P in compost is in a form that can only be taken up by roots colonized by mycorrhiza, red fescue might will have an advantage, as the colonization of annual bluegrass roots is supposed to be limited (Gange et al. 1999). From other turf grasses there is also evidence that compost may suppress infection of *Microdochium nivale* and other diseases (Boulter et al. 2002, Espevig & Aamlid 2012), but this information needs to be verified in red fescue.

In Denmark and Norway, sands amended with compost for use on putting greens are produced and sold under the trade name 'Green Mix' by the companies Solum AS and Høst AS, respectively. In both countries, the compost is produced from garden waste and the products are always followed with a declaration of pH and nutrient content. The products have been used successfully by a number of Danish greenkeepers trying to promote red fescue as the predominant species on putting greens (Kvalbein et al. 2012). There is, however, a continuous debate about how much nutrients the compost in Green Mix rootzone and topdress will provide in the short and long term and how this will influence competition between red fescue and annual bluegrass. Studies in other grasses in the lysimeter facility at the Bioforsk Turfgrass Research Centre Landvik, Norway, showed Green Mix rootzones to produce faster grow-in than other rootzones, but they also showed higher leaching losses of N, P and K than from rootzones with peat or no amendment (Aamlid 2005, Espevig & Aamlid 2012). To the best of our knowledge, there has been no investigation into the short and long term effects of using Green Mix topdress instead of straight sand topdress which has been the most common practice on Scandinavian golf greens up to now.

The objective of the field trial reported in this paper was to document the effect of a well-defined compost ('Green Mix') in the rootzone or in the topdress on the turf quality, mycorrhiza colonization, nutrient balance and competition against annual bluegrass on putting greens with red fescue as the predominant species. The study was initiated as part of the project 'FESCUE-GREEN: Best management of red fescue (*Festuca rubra*) golf greens for high sustainability and playability' (2011-2015). The report should be looked upon as a preliminary progress report as only results from the grow-in phase and immature greens up to 15 months age are presented.

3. Materials and methods

3.1 Location and weather conditions

The study was conducted at Bioforsk Landvik, Grimstad, on the Norwegian south coast (58°20’ N, 12 m a.s.l.). The location has a temperate, coastal climate. Table 1 shows the mean monthly temperature and monthly precipitation from construction in August 2011 and to the end of the growing season in October 2012. September and October 2011 had high temperatures conducive to turfgrass grow-in, and the winter was mild with snow cover only from 21 Jan. to 23 Feb. March 2012 was exceptionally mild with a monthly mean of 6.8 °C and a maximum of 23.1 °C on 27 March, which is the highest temperature for March ever recorded at any official weather station in Norway.

Table 1: Mean monthly temperature and precipitation at the official weather station Landvik from August 2011 to December 2012. Data are compared with thirty year normal values (1961 – 90).

	Temperature, °C			Precipitation, mm		
	2011	2012	30yr norm.	2011	2012	30yr norm.
January		0.1	-1.6		144.4	113.0
February		-0.5	-1.9		14.7	73.0
March		6.8	1.0		27.2	85.0
April		5.2	5.1		130.1	58.0
May		11.8	10.4		53.3	82.0
June		12.9	14.7		118.8	71.0
July		15.8	16.2		83.0	92.0
August	15.5	15.8	15.4	188.5	106.8	113.0
September	12.9	11.6	11.8	234.5	132.2	136.0
October	8.9	6.8	7.9	74.0	217.6	162.0
November	6.5	4.8	3.2	53.7	239.0	143.0
December	2.1	-3.3	0.2	155.8	285.9	102.0
Sum				706.5	1553.0	1230.0
Average	9.2	7.3	6.9			

3.2 Establishment, soil analyses and experimental design

The green was constructed in August 2011 in a USGA Green field lysimeter facility. The existing turf and rootzone was removed down to the gravel layer and new material added (Photo 1). The sand was amended with 17 % (v/v) sphagnum peat or 17.5 % composted garden waste (‘Green Mix’- Høst AS, Grimstad, Norway) in alternating plots. Based on previous trials, the volume percentage had been adjusted to reach a target ignition loss of 2.5 (w/w) on all plots, but the realized values were 2.85 % and 2.63 % (w/w) in root zones with peat and Green Mix, respectively (Table 2). Green Mix rootzones contained approximately 50 times more mineral N, 4 times more P, 21 times more K, 3 times more Mg and 7 times more Ca than rootzones amended with peat.

Photo 1: One of the lysimeters during construction in August 2011. The old rootzone was removed down to the gravel layer and USGA-spec. sand amended with either peat or compost was added. The lysimeters were 40-45 cm deep with a drain pipe located in the middle and a 10-15 cm gravel layer. Photo: Trygve S. Aamlid.

Table 2: Chemical soil analyses of rootzone materials used at establishment in August 2011, and of topdressing material used in 2012.

Parameter	Unit	Rootzone, August 2011		Topdressing 2012*		Reference/method
		Peat	Green Mix	Straight sand	Green Mix	
Volume weight	kg/L	1.5	1.5	1.7	1.6	
Ignition loss	% of DW	2.85	2.63	0.10	0.95	
pH (H_2O)		5.6	7.8	6.5	8.0	H_2O
P-AL	mg/100g	1.7	6.4	< 1.0	5.9	AL
K-AL	mg/100g	2.3	25	< 2.0	24	AL
Mg-AL	mg/100g	2.4	6.8	< 1.0	4.9	AL
Ca-AL	mg/100g	14	95	< 10	111	AL
Na-AL	mg/100g	2.2	3.1	< 5.0	< 5.0	AL
K-HNO_3	mg/100g	47	72	-	-	
Mineral N	mg/100g	0.06	3.0	0.17	3.2	
Total N	% of DW	< 0,1	0,14	< 0.11	< 0.11	CENTS15104/1540
Total C	% of DW	1.5	1.9	< 0.5	0.58	CENTS15104/1541
Cu	mg/kg	0.26	1.3	< 0.20	0.84	EDTA
B	mg/kg	< 0.10	0.56	0.36	< 0.10	Hot water extr.
Fe	mg/kg	6.7	2.5	10	3.8	NH_4-acetate
Mn	mg/kg	4.5	0.60	< 0.50	< 0.50	$Mg(NO_3)_2$
Zn	mg/kg	< 1.0	6.7	< 1.0	4.4	0.2 M HCl
Mo	mg/kg	< 0.20	< 0.20	< 0.20	< 0.20	Tamms solution

* Mean of May and September deliveries

Results from mechanical and physical analyses of undisturbed soil cores, 58 mm in diameter and 37 mm high, are shown in Table 3. Due to the fact that the garden compost used as additive to the USGA-spec. sand did not only contain organic matter, but also mineral particles, the content of coarse sand was lower and the content of medium sand and silt higher in the Green Mix rootzone than in the peat-amended rootzone. The peat-amended rootzone also had about 3 per cent units higher porosity, of which about 1/3 were air-filled macropores and 2/3 capillary micropores.

Table 3: Physical and mechanical soil analyses of undisturbed soil cores taken from the rootzones in November 2011, three months after construction. Means of four cylinder samples per rootzone.

	Gra-vel >2 mm	Coarse sand 0.6-2 mm	Medium sand 0.2-0.6 mm	Fine sand 0.06-0.2 mm	Silt 0.002-0.06 mm	Clay < 0.002 mm	Soil density, kg dm^{-3}	Total poro-sity, %	Air filled porosity (tension < 3 kPa), %	Water capacity (tension 3-1500 kPa), %	Unavailable water (tension > 1500 kPa)
Peat	2.1	22.0	51.9	21.4	1.7	0.9	1.31	47.2	22.4	21.1	3.7
Green Mix	1.3	11.9	61.2	21.5	3.2	0.9	1.38	44.4	21.6	19.2	3.6

The trial was laid out according to a factorial design with 2 experimental factors and 4 blocks. The experimental factors were:

<u>Factor 1: Root zone at construction in 2011</u>

1. USGA – sand + sphagnum peat (OM = 2.85 % w/w).
2. USGA – sand + Green Mix (OM = 2.63 % w/w).

<u>Factor 2: Topdressing material used from spring 2012</u>

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

With 4 blocks, this equaled 2 x 2 x 4 = 16 treatment plots of 2 x 3 m. All assessments were done in the central 1 x 2 m, corresponding to the surface of the lysimeters (Photo 1)

The trial was seeded with a drop seeder on 17 Aug. and covered with agryl tarp until 25 Aug. 2011. The realized seeding rate was 29.3 g/m^2. The seed mixture consisted of 3 % annual bluegrass (unspecified ecotype provided by Felleskjøpet Agri, Holstad, Norway), 38.8 % slender creeping red fescue (*F. rubra* ssp. *litoralis*) 'Cezanne' and 19.4 % of each of chewings fescues (*F.rubra* ssp. *commutata*) 'Musica', 'Bargreen' and 'Calliope'. Seed of annual bluegrass was mixed with red reduce seed to provide a uniform starting point for studying the competition between the two species.

3.3 Implementation and general maintenance

Mowing: After removing the tarps, the experiment was mowed for the first time to 10 mm on 7 September 2011. When subsequently mowing the experiment two or three times per week, mowing height was gradually reduced to 6 mm on 3 October and then gradually returned to 7 mm at the last mowing on 26 October. In 2012, the green was mown every Monday, Wednesday and Friday in weeks without topdressing, but only on Monday and Friday in weeks with topdressing. Mowing height started at 9 mm on 26 March, and was gradually lowered to 5 mm on 7 May, at which height it was kept for the rest of the season until the last mowing on 22 October 2012. Mowing was always performed with a walk-behind greens mower.

Topdressing: The experiment was not topdressed in 2011. in 2012, dressing was carried out every other Tuesday. The sand was applied by hand followed by brushing, the first time on 25 April and the last time on 10 October. The amount of sand applied at each dressing was 0.63 L/m^2. With 13 applications, this equaled 8.2 mm of sand applied over the season.

Aeration and overseeding: The green was aerated with 6 mm solid tines to 6 cm depth on 23 April, 5 June and 14 August 2012. Following aeration on 23 April and 14 August, the green was overseeded with 20 g/m^2 of the same seed mixture as used for establishment.

Photo 2. Friction wear drum used in trial in 2012. Photo: Trygve S. Aamlid

Wear: The experimental green was not subjected to play but in 2012 it was subjected to artificial wear and compaction using a friction wear drum with golf spikes and weight corresponding to an adult player (Photo 2). Wear started once turf coverage was close to 100% in mid-July, and went on until early October. On average there were four passages (two times back and forth) per week over the fifteen week period, corresponding to approximately 20000 rounds of golf for the period July-October.

Fertilization: To ensure fast and uniform establishment on both rootzones, and based on the soil chemical analyses presented in Table 2, it was decided to use twice as high fertilizer rats on peat-amended rootzones as on Green Mix rootzones during grow-in in 2011 (Table 4). Application started with the poultry-based organic fertilizer Binadan (Binadan A/S, Nørre Snede, Denmark) before seeding and continued with alternations between the liquid fertilizer Wallco (Cederroth International AB, Falun, Sweden)' and the granular fertilizer Andersons 13-2-13 (The Andersons, Maumee, Ohio, USA)' at weekly intervals for the first five weeks after tarp removal and then at two week intervals until 27 October. At the last autumn fertilization on 15 November (after growth cessation) all plots received the same amount of fertilizer irrespective of rootzone composition.

Table 4: Total fertilizer inputs and amount of N, P and K given at each application date during grow-in from August to November 2011.

Date	Fertilizer type	g/m^2							
		Product		N		P		K	
		Peat	Gmix	Peat	Gmix	Peat	Gmix	Peat	Gmix
16 Aug (preseeding)	Binadan organic*	100.0	50.0	8.5	4.3	1.00	0.50	7.5	3.8
26 Aug	Wallco liquid	23.5	11.8	1.2	0.6	0.24	0.12	1.0	0.5
31 Aug	Andersson 13-2-13	9.2	4.6	1.2	0.6	0.08	0.04	1.0	0.5
06 Sep.	Wallco liquid	23.5	11.8	1.2	0.6	0.24	0.12	1.0	0.5
12 Sep.	Andersson 13-2-13	9.2	4.6	1.2	0.6	0.08	0.04	1.0	0.5
27 Sep.	Wallco liquid	23.5	11.8	1.2	0.6	0.24	0.12	1.0	0.5
11 Oct.	Andersson 13-2-13	7.7	3.8	1.0	0.5	0.07	0.03	0.8	0.4
27 Oct.	Wallco liquid	9.8	4.9	0.5	0.3	0.10	0.05	0.4	0.2
15 Nov.	Andersson 13-2-13	3.8	3.8	0.5	0.5	0.03	0.03	0.4	0.4
SUM				**16.5**	**8.6**	**2.08**	**1.05**	**14.2**	**7.3**

* 50/50 mixture of Binadan Green 11-1-3 and Binadan Blue 6-1-12.

In 2012, fertilization was the same to all plots (Table 5). As the turf cover was not complete until the middle of July, fertilizer was applied every week from 20 March to 10 July, and every other week for the rest of the season. The fertilizer types were all in liquid formulation, partly Greenmaster liquid NK 10-0-10 (Everris International, Geldermalsen, The Netherlands) and partly Arena Crystal 19-2-15 and Arena Calcium (Yara AB, Landskrona, Sweden).

Table 5: Total fertilizer inputs and amount of N, P and K given at each application date during the experimental season lasting from March to October in 2012.

			g/m^2			
Week	**Date**	**Fertilizer type**	**Product**	**N**	**P**	**K**
12	Mar.20	Arena Calcium	2.5	0.00	0.00	0.00
12	Mar.20	Arena Crystal 19-2-15	0.5	0.10	0.01	0.08
13	Mar.26	Greenmaster liquid NK 10-0-10	1.5	0.15	0.00	0.12
14	Apr.04	Arena Crystal 19-2-15	1.1	0.20	0.02	0.16
15	Apr.10	Greenmaster liquid NK 10-0-10	2.5	0.25	0.00	0.21
16	Apr.17	Arena Crystal 19-2-15	1.6	0.30	0.03	0.24
17	Apr.26	Greenmaster liquid NK 10-0- 10	3.5	0.35	0.00	0.29
18	May 02	Arena Crystal 19-2-15	2.1	0.40	0.04	0.32
19	May 08	Greenmaster liquid NK 10-0-10	0.7	0.68	0.00	0.84
20	May 13	Arena Crystal 19-2-15	3.9	0.74	0.07	0.59
21	May 22	Greenmaster liquid NK 10-0-10	8.3	0.83	0.00	0.68
22	May 30	Greenmaster liquid NK 10-0-10	9.0	0.90	0.00	0.75
23	June 05	Arena Crystal 19-2-15	4.8	0.91	0.09	0.72
24	June 12	Arena Crystal 19-2-15	4.8	0.91	0.09	0.72
25	June 20	Greenmaster liquid NK 10-0-10	9.0	0.90	0.00	0.75
26	June 28	Greenmaster liquid NK 10-0-10	7.0	0.70	0.00	0.58
27	July 04	Arena Crystal 19-2-15	4.0	0.76	0.08	0.60
28	July 10	Arena Crystal 19-2-15	3.2	0.61	0.06	0.48
30	July 24	Greenmaster liquid NK 10-0-10	6.0	0.60	0.00	0.50
32	Aug.07	Arena Crystal 19-2-15	3.2	0.61	0.06	0.48
34	Aug.23	Greenmaster liquid NK 10-0-10	6.0	0.60	0.00	0.50
36	Sep.05	Arena Crystal 19-2-15	2.6	0.49	0.05	0.39
36	Sep.05	Arena Calcium	2.5	0.00	0.00	0.00
38	Sep.18	Greenmaster liquid NK 10-0-10	4.0	0.40	0.00	0.33
40	Oct. 02	Arena Crystal 19-2-15	1.5	0.29	0.03	0.23
42	Oct. 17	Greenmaster liquid NK 10-0-10	2.0	0.20	0.00	0.17
44	Oct. 31	Arena Crystal 19-2-15	0.5	0.10	0.01	0.08
Sum				**13.32**	**0.64**	**10.81**

Irrigation: During grow-in in 2011, the green was irrigated with 1-2 mm of water up to five times a day except on days with natural rainfall. Even in 2012, the plant-available water capacity in the two rootzones (Table 3) was considered sufficiently similar to justify the same irrigation regime. This implied an input of 5 mm after dressing or fertilizing on alternate Tuesdays, except on Tuesdays with at least 5 mm of natural rainfall. Beyond this,10 mm water was given each time the volumetric soil moisture content in the upper 12 cm became lower than 10 %, as measured with a TDR probe (Delta T Devices, Cambridge, UK).

3.4 Registrations

The following characters were recorded during grow-in from August to November 2011:

- *Per cent turf coverage* of plot area was assessed visually on 2 September, 9 October and 15 November. No distinction was made between annual bluegrass and red fescue.
- *Tiller numbers and botanical composition*: Two cylinder samples, each 5.6 cm in diameter, were taken to 5 cm depth from two representative plots per rootzone on 22 November. Tillers were counted and the proportion of red fescue and annual bluegrass tillers determined.
- *Mycorrhizal colonization*: On 18 October, root samples of 2.1 cm diameter were taken to 20 cm depth from patches with each of the two turfgrass species in each plot. Roots were washed carefully from the cylinders, heated with KOH and stained. Per cent mycorrhizal colonization in each sample was estimated by the 'grid-line intersect method' through a binocular loupe (Giovanetti & Mosse 1980).
- *Nutrient leakage:* All drainage water from the lysimeters was collected during the periods 6-12 September (following fertilization on 6 September) and 11-26 October (following fertilization on 11 October). The leachate was analyzed for total N, NO_3-N, total P and total K by the Eurofins Food & Agro Laboratory (Moss, Norway).

The following characters were recorded from March to October 2012:

- *Turf coverage and botanical composition:* Per cent coverage of red fescue, annual bluegrass, creeping bentgrass and bare soil was assessed monthly between 3 April and 2 November (eight observations)
- *Turfgrass general appearance* (visual merit, 1-9, 9 is best quality) was assessed monthly between 3 April and 2 November (eight observations) based on turf uniformity, coverage, tiller density, color, weed infestation (including annual bluegrass), bare soil and diseases.
- *Turfgrass density* (1-9, 9 is the most dense red fescue) was assessed monthly between 3 April and 2 October (seven observations).
- *Turfgrass color intensity* (1-9, 9 is the most intense/freshly green color) was assessed three times in autumn, from 4 September to 2 November.
- *Turfgrass diseases: Per cent of plot areas affected by disease was assessed* on the same dates as turfgrass coverage and general appearance.
- *Tiller numbers and botanical composition:* Four cylinder samples, 5.6 cm wide and 5 cm deep, were taken from each plot on 2 May and the number of tillers of red fescue and annual bluegrass counted. On 10 October, eight samples with a diameter of 2.7 cm was taken to a depth of 5 cm and tillers counted of red fescue and annual bluegrass in addition to some creeping bentgrass that had invaded some of the plots in the late summer.
- *Per cent ignition loss* was determined in soil samples taken at 0-2 cm and 2-4 cm depth from each plot on 16 October.
- *Green speed and surface hardness*: Turfgrass ball roll distance and surface hardness were measured four times from June to October. Ball roll distance was measured using a short stimpmeter modified for research plots (Gaussion et al. 1995). The stimpmeter had its ball release notch 38 cm rather than 76 cm from the beveled end. Measurements were taken in two directions, 24-30 hours after mowing. Green hardness was measured in gravities, using a Clegg Soil Impact Tester with a 2.25 kg hammer being released from a height of 0.46 m above the surface (Lafayette Instrument Co., Lafayette, Indiana, USA).
- *Infiltration rate* was measured on each plot on 11 November using a double ring infiltrometer with an outer ring diameter of 12.8 cm and an inner ring diameter of 4.5 cm. The infiltrometer was inserted 2 cm into the turf after a long period with heavy rainfall. Water levels in the inner ring were measured after three minutes of infiltration.

- *Root depth and weight of roots and verdure:* Root depth was measured using a root auger, 30 cm long and 5.6 cm in diameter on 4 April and 18 October. One core was extracted per plot, and the length of the intact hanging core taken as an indication of root depth. Each core was then divided into three sections; above ground material (verdure after mowing), roots at 0-5 cm soil depth and roots under 5 cm soil depth; which were all washed and dried at 60°C for 48 hours before weighing.
- *Mycorrhizal colonization*: On 5 June and 18 October, two soil cores, 2.1 cm in diameter, were taken to 20 cm depth from each plot. At the first sampling, colonization was studied independently in annual bluegrass and red fescue. Due to disappearance of annual bluegrass in late summer, sampling on 18 October only included red fescue. Mycorrhizal colonization was determined used the same method as in 2011.
- *Clipping yield and nutrient removal in clippings*: Clippings from a net plot area of 0.56 m x 2m = 1.12 m^2 were collected and weighed every other Monday from 26 March to 22 October. Dry weight was determined after drying at 60°C for 48 hours. Clippings were pooled for the periods 26 March – 21 May (spring), 4 June – 2 July (early summer), 16 July - 27 August (late summer) and 10 Sep – 22 Oct. (autumn) and analyzed for total content of N, P and K by the Eurofins Food & Agro Laboratory (Moss, Norway).
- *Nutrient content in roots and verdure:* After weighing on 18 October, one pooled sample of verdure and roots from various depths in each plot was analyzed for N, P and K by the Eurofins Food & Agro Laboratory (Moss, Norway).
- *Soil mineral nitrogen content* (NH_4-N plus NO_3-N) was determined in samples from the 20 cm topsoil layer in each plot on 5 June. The samples were frozen and analyzed in the soil laboratory at Bioforsk Apelsvoll, Kapp, Norway.
- *Nutrient leakage:* The drainage water from all lysimeters was collected throughout the growing season. Volume-proportional water samples were pooled for the periods 20 March – 29 May (spring), 30 May – 10 July (early summer), 10 July – 5 Sep. (late summer) and 5 Sep – 13 Nov. (autumn) and analyzed for total N, NO_3-N, total P and total K by the Eurofins Food & Agro Laboratory (Moss, Norway).

3.5 Statistical analyses

The experimental data were analyzed using the ANOVA procedure of the SAS software package, version 9.2 (SAS institute, Cary, NC, USA). Significant differences among treatments were identified by Fisher's protected LSD test at the 0.05 probability level. Effects within the 0.05 – 0.15 probability level were expressed as 'tendencies' 'or trends'.

4. Results

4.1 Results from the grow-in period August - November 2011

4.1.1 Turf coverage

The development of turf coverage during grow-in is shown in Figure 1. Two weeks after sowing, before the effects of different fertilizer levels had started to show up, turf coverage was significantly better on Green Mix rootzones than on rootzones amended with peat (Photo 3). Two months after sowing this effect had been reversed as rootzones amended with peat had slightly, although not significantly, better coverage than Green Mix rootzones. At the same time, plots with peat were more uneven due to distinct spots of bare soil and distinct spots with high color intensity (Photo 4). At the last assessment before winter turf, turf coverage on individual plots varied from 75 to 98 %.

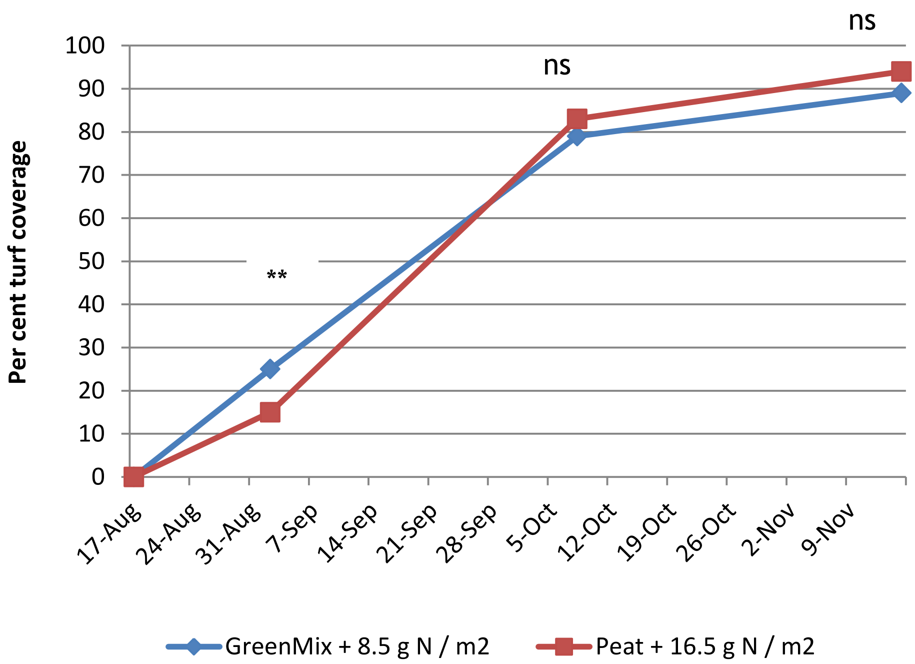

*Figure 1: Development of turf coverage from seeding on 17 August to the end of the growing season on two rootzones receiving different amounts of fertilizer. In this and following figures and tables, significance levels are indicated as follows: ***: P<0.001, **: 0.001<P<0.01, *: 0.01<P<0.05, (*):0.05<P<0.15 ('tendency or 'trend'); ns: not significant.*

Photo 3: Field emergence on 1 September 2011, two weeks after seeding. The turf on Green Mix rootzones had significantly better coverage and more intensely green color than on plots amended with peat. Photo: Trygve S. Aamlid.

Photo 4: On 10 October 2011, the turf on rootzones amended with peat had a more intensely green color than the turf on Green Mix rootzones, but they were also more uneven. Photo: Trygve S. Aamlid.

4.1.2 Tiller numbers and botanical composition

On 22 November, the tiller numbers of red fescue were significantly higher on peat-amended rootzones that had received 16.5 g N/m^2 than on compost-amended rootzones that had received 8.6 g N/m^2 (Figure 2). Annual bluegrass contributed a significant percentage of the total tiller population on all plots (Photo 5) and showed a tendency to develop more tillers on peat-amended rootzones receiving the higher fertilizer rate. On average for all plots, the total tiller density by the end of the grow-in year was 28537 tillers/m^2 on Green Mix rootzones, and 43262 tillers/m^2 on peat-amended rootzones (Figure 2).

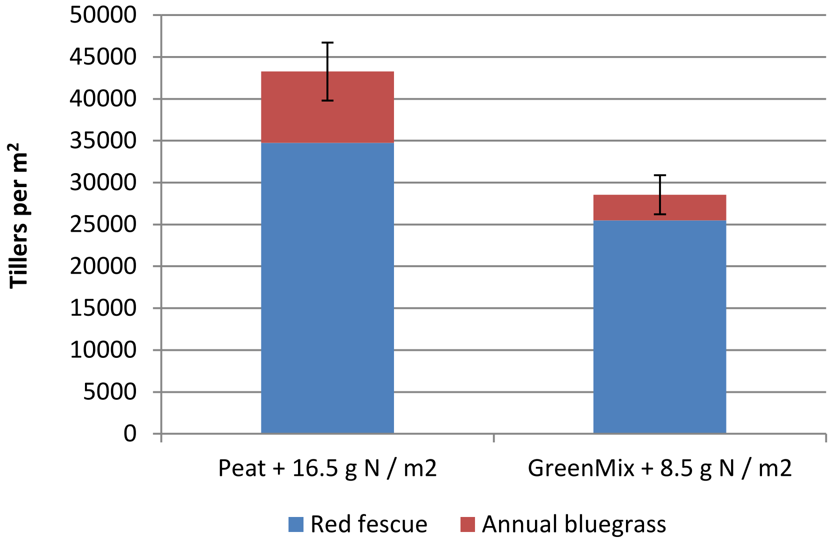

Figure 2: Tiller density and botanical composition by the end of grow-in year on two rootzones that had received different amounts of fertilizer. Annual bluegrass made up 11 % of total tiller number of Green Mix plots and 20% of total tiller number on peat-amended plots. Bars indicate ± 1 SE for total tiller number (n=2).

⊥

Photo 5: Close-up on 10 October 2011. Annual bluegrass constituted a significant part of the sward on all plots during grow-in. Photo: Trygve S. Aamlid.

4.1.3 Mycorrhiza

Mycorrhizal colonization two months after seeding was very limited, and there was no significant difference in colonization levels between rootzones or turfgrass species (Table 6).

Table 6: Effects of root zone and turfgrass species on mycorrhizal colonization on 18 October 2011

		% of roots colonized	ANOVA
Rootzone	**Peat**	2.1	ns
	Green Mix	1.9	
Species	**Red fescue**	1.8	ns
	Annual bluegrass	2.2	

4.1.4 Leaching losses

The total amount of drainage water did not differ significantly between the two rootzones but there was a tendency to more drainage water from Green Mix rootzones than from peat-amended rootzones during the first collection period from 6 to 13 September (Table 7). In spite of 50 % lower fertilizer inputs, the concentrations, and thus losses, of total N, NO_3-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 during the first period can mostly be explained by higher precipitation, but also by the fact that turf coverage in early September was only 30-40 % as opposed to 75-85 % in mid-October

Table 7: Total amount of drainage water (leachate), concentration of total N, nitrogen in nitrate, 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.

		6-13 September			11-26 October		
		Green Mix	**Peat**	**ANOVA**	**Green Mix**	**Peat**	**ANOVA**
Total leachate	**L/m^2**	86	81	(*)	16	13	ns
Total N	**Concentration mg/L**	18.9	7.4	***	7.5	1.7	***
NO_3-N		16.5	7.2	***	6.3	1.4	***
Total P		2.4	0.7	***	2.0	0.6	***
Total K		295.0	13.3	***	121.3	8.4	***
Total N	**Nutrient losses g/m^2**	1.63	0.58	***	0.12	0.02	***
Total P		0.21	0.06	***	0.03	0.01	***
Total K		25.43	1.07	***	1.91	0.11	***

4.2 Recordings from March to November 2012

4.2.1 Turf coverage and visual assessment of botanical composition

Turf coverage and botanical composition throughout the experimental season 2012 is shown in Figure 3. In spring and early summer, a certain percentage of plot area was still bare soil (Photo 6) and annual bluegrass constituted a significant part of the stand. At the assessments in June and July plots with Green Mix in the rootzone had significantly less bare soil and significantly less red fescue, but significantly more annual bluegrass than plots with peat in the rootzone. However, regardless of rootzone, red fescue outcompeted annual bluegrass from 6 July to 7 August (Photo 7a,b), and in August, it covered almost 100 % on both rootzones. A certain invasion of creeping bentgrass occurred in autumn; significantly more on Green Mix rootzones than on peat-amended rootzones (Figure 3).

Type of topdressing material had no effect on per cent bare soil, red fescue or annual bluegrass on any of the observation dates, but encroachment of creeping bentgrass in autumn was significantly stronger on plots receiving Green Mix topdress than on plots receiving straight sand topdress. This effect peaked on 7 September when, on average for rootzones, creeping bentgrass covered 3.9 and 2.4 % of plot area, respectively (data not shown in table or figure).

Interactions between rootzone and topdressing were not significant except in June and July when replacement of straight sand topdress with Green Mix topdress resulted in more annual bluegrass on peat-amended rootzones (mean values for two observations 7.6 and 9.9 %, respectively), but less annual bluegrass on Green Mix rootzones (mean values 16.5 and 15.0 %, respectively; data not shown in table og figure).

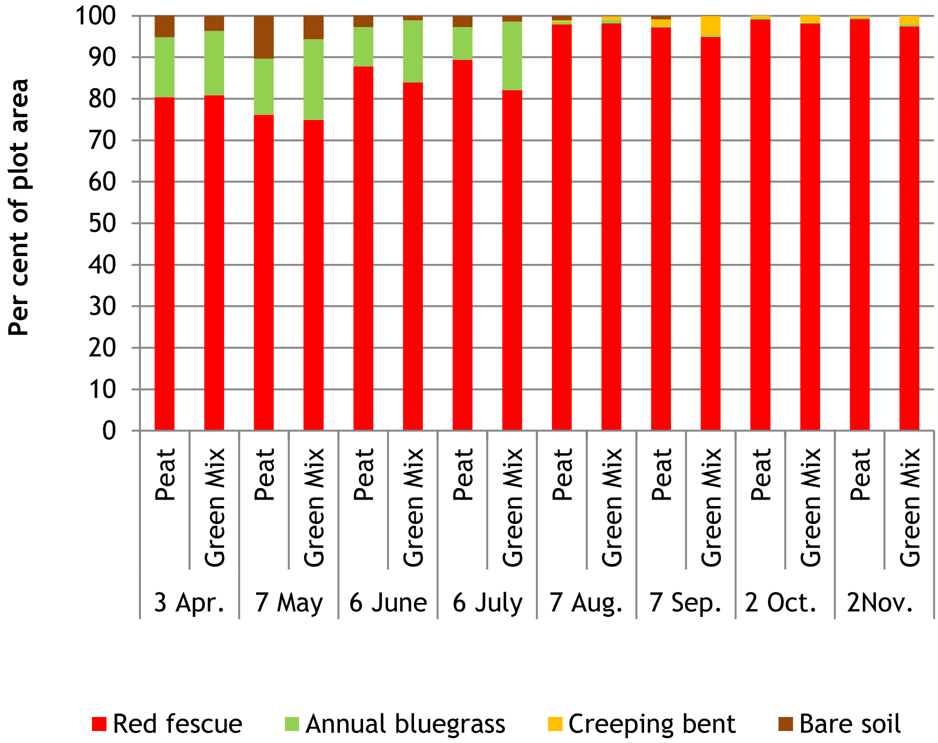

Figure 3: Development of turf coverage and botanical composition on peat-amended rootzones and Green Mix rootzones during 2012. Means of two topdressing treatments.

Photo 6. Experimental field on 25 April 2012. Treatments have been labeled in two of the four blocks. The central border section was used for a different trial. Photo: Trygve S. Aamlid.

Photo 7a,b. Annual bluegrass disappeared and turf coverage of red fescue improved significantly from early July onwards. Photos: Trygve S. Aamlid.

4.2.2 Turfgrass general appearance, density and color

Mean values for visual assessments of turf general appearance, density and color are shown in Table 8. Green Mix significantly increased the scores for all parameters, both when used in the rootzone and as topdressing. An interaction between rootzone and topdressing was seen in autumn as the positive effect of Green Mix topdressing on color intensity was more pronounced on rootzones amended with peat than on Green Mix rootzones (Photo 8, Figure 4).

Table 8: Effects of rootzone and topdressing on turf density, color and general appearance.

Factor		General appearance (8 obs.)	Turf density (7 obs.)	Color intensity (3 obs.)
		1-9, 9 is highest score		
Rootzone	Peat	3.8	4.3	3.5
	Green Mix	5.5	5.9	6.6
Topdressing	Straight sand	4.3	4.7	4.5
	Green Mix	5.0	5.5	5.7
		ANOVA		
	Rootzone	***	***	***
	Topdressing	***	***	***
	Rootzone x topdressing	ns	ns	**

Photo 8: Significant effects of rootzone and topdressing on turfgrass color intensity in autumn. Different topdressing materials had the strongest effect on rootzones amended with peat.
Photo: Trygve S. Aamlid.

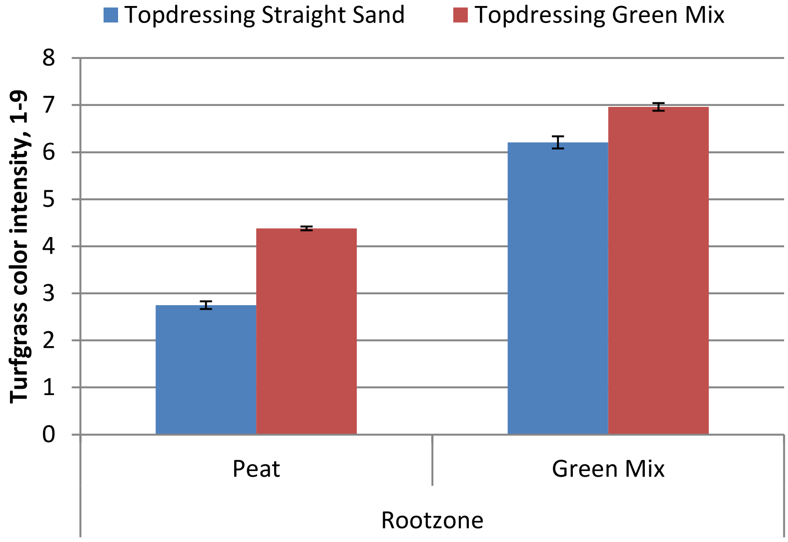

Figure 4: Interaction between rootzone amendment and topdressing material on color intensity (scale 1-9, where 9 is the most intensely green turf). Mean of assessments of on 4 Sep., 8. Oct, and 2 Nov. 2012. Bars indicate ± 1 SE (n=12).

The effects of rootzone and topdressing combinations on general appearance during 2012 are shown in more detail in Figure 5. The lowest scores for visual turf quality were recorded in early May (see also Photo 6) and the highest scores in August (Photo 7b). The effect of different rootzones was evident from the start of the growing season. The effect of Green Mix topdress became evident about one months after the first dressing on Green Mix rootzones and about two months after the first dressing on peat-amended rootzones (Figure 5).

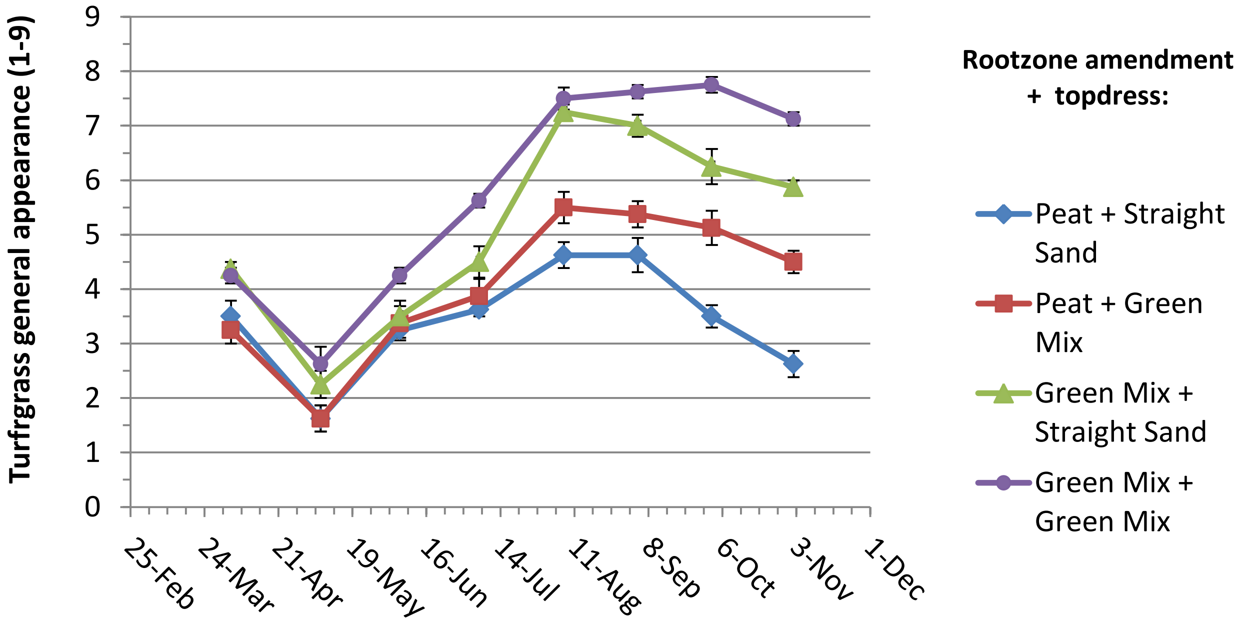

Figure 5: General appearance on a scale from 1-9 of the different rootzone/topdressing combinations during the growing season 2012. Bars indicate ± 1 SE (n=4).

4.2.3 Turfgrass diseases

The only disease identified in the experiment was red thread (*Laetisaria fuciformis*). This was first seen in September and by the last assessment on 2 November it had expanded to 6-11 % of plot area. The main effects of rootzone and topdressing materials were both significant and there also tended to be an interaction in that peat-amended rootzones dressed with straight sand had significantly more red thread than the other treatment combinations (Figure 6)

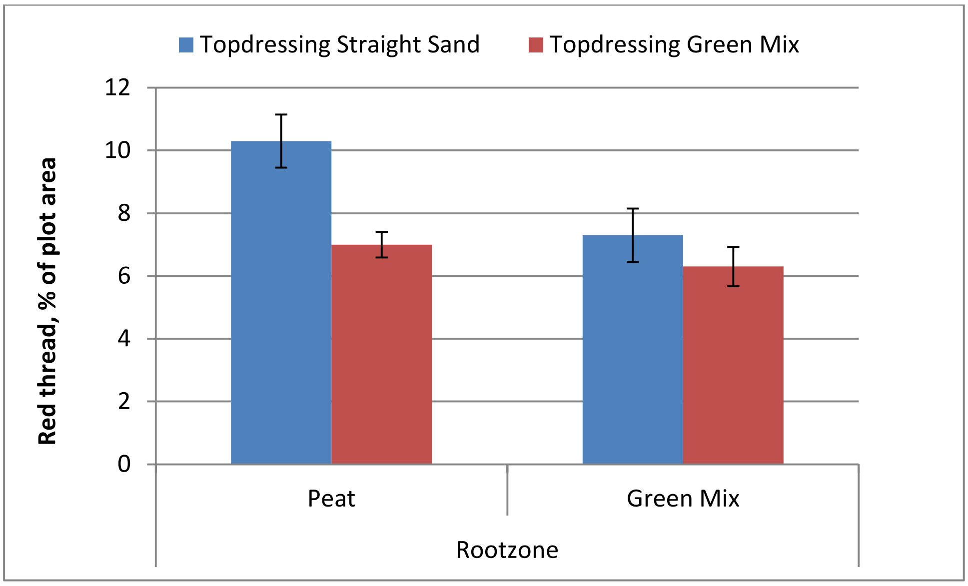

Figure 6. Combined effect of rootzone and topdressing material on red thread infection on 2 November 2012. Bars indicate ± 1 SE (n=4).

4.2.4 Tiller numbers and botanical composition

Tiller countings on 2 May 2012 showed a drop in tiller density from the previous fall. The effect of last year's higher fertilizer applications to peat-amended rootzones was no longer evident as the mean values were similar; 10003 tillers m^{-2} on Green Mix rootzones vs. 9864 tillers m^{-2} on peat-amended rootzones. At this point in time annual bluegrass made up 11 % of the total tiller number on Green Mix rootzones and 7 % on peat-amended rootzones (data not shown in table or figure)

New tiller countings on 3 October showed an eightfold increase in tiller density during the growing season 2012. On 3 October, the mean values were 80874 tillers m^{-2} on Green Mix rootzones vs. 76096 tillers m^{-2} on peat-amended rootzones. Neither this difference nor the much smaller difference in tiller number due to different topdressing materials was statistically significant.

4.2.5 Per cent ignition loss

In October 2012, fourteen months after establishment, per cent ignition loss in the upper 2 cm (mat) layer of the green was not influenced by rootzone composition but it was significantly higher after dressing with Green Mix than after dressing with straight sand (Table 9). By contrast, ignition loss at 2-4 cm depth was significantly higher on Green Mix rootzones than on than on peat-amended rootzones. At 2-4 cm depth there was also a significant interaction as Green Mix rootzones had a higher ignition loss after dressing with straight sand than with Green Mix, while the opposite was true for rootzones amended with peat (Figure 7).

Table 9: Effects of organic amendment in root zone and topdressing on ignition loss in thatch/mat layer 14 months after establishment.

		Ignition loss, %	
		0-2 cm	2-4 cm
Rootzone	Peat	5.5	3.5
	Green Mix	5.5	3.9
Topdressing	Straight sand	5.1	3.7
	Green Mix	5.9	3.7
		ANOVA	
	Rootzone	ns	*
	Topdressing	*	ns
	Root zone x topdressing	ns	*

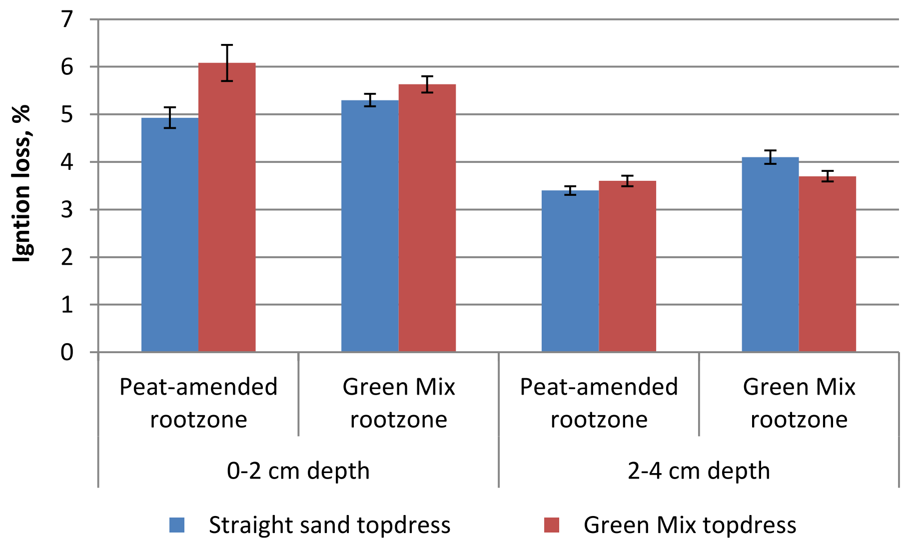

Figure 7: Combined effects of rootzone and topdressing on per cent ignition loss at 0-2 and 2-4 cm depth in October 2011. Bars indicate ± 1 SE (n=4).

4.2.6 Green speed and surface hardness

Turfgrass ball roll distance increased from July to October 2012 and was consistently higher on rootzones amended with peat than on Green Mix rootzones (Figure 8). The difference between of Green Mix topdress and straight sand topdress was also significant (P=0.02) with means values 109 and 107 cm, respectively (data not shown in table or figure). Interactions were not significant.

Because of lack of play, the green surfaces were generally rather soft, but nonetheless significantly harder on Green Mix rootzones than on peat-amended rootzones (Figure 8). Type of topdress had no effect on surface hardness, and interactions were not significant for this character.

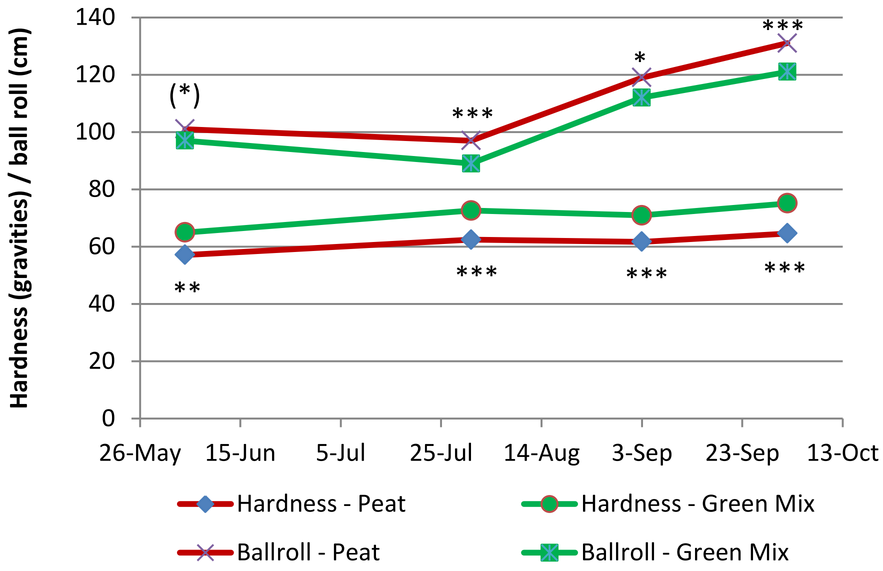

Figure 8: Effects of rootzone composition on green speed and hardness.

4.2.7 Infiltration

Infiltration rates measured in November 2012 were high for all treatments, but nonetheless significantly higher on Green Mix rootzones than on rootzones amended with peat. The mean values were 386 and 258 mm water per hour, respectively (data not shown in table or figure). Topdressing materials had no influence on this character and interactions were not significant.

4.2.8 Root depth and weight of roots and verdure

The average root depth determined as length of intact hanging cylinder samples on 18 April 2012 was 22.4 cm for both rootzones (data not shown in table or figure). On the same date the total root weight was 179 and 173 g/m^2 in peat-amended and Green Mix rootzones, respectively. The difference was not significant, but there was a tendency to more roots in deeper than 5 cm in Green Mix rootzones that had received 8.6 g N/m^2 in 2011 than in peat-amended rootzones that had received 16.5 g N/m^2 in 2011 (Table 10).

At the next sampling on 18 October, root depths varied from 21.0 to 24.8 cm, again with no significant difference between either rootzone og topdressing treatments (data not shown in table of figure). The total root weight in the upper 5 cm was about four times higher than in April, and for this layer there was also a tendency that root weight had increased more in rootzones amended with peat than in Green Mix rootzones (Table 10). Below 5 cm the relative increase in root weight since April was less than in the upper layer, and there was no longer a tendency to more roots in Green Mix rootzones than in peat-amended rootzone.

Topdressing materials had no effect on root weight in any layer in October. The weight of verdure was not affected by either rootzone or topdressing material, and interactions were not significant for any character.

Table 10: Weight of roots at two depths in April and October 2012 and weight of verdure in October 2012 as affected by rootzone and topdressing material

		Dry weight, g/m^2							
		18 April			18 October				
		Roots 0-5 cm depth	**Roots deeper than 5 cm**	**Total roots**	**Roots 0-5 cm depth**	**Roots deeper than 5 cm**	**Total roots**	**Ver-dure**	**Verdure + roots**
Root-zone	Peat	130	49	179	555	136	691	273	964
	Green Mix	115	58	173	442	138	580	251	831
Top-dressing	Straight sand				516	141	657	267	923
	Green Mix				481	134	615	257	872
		ANOVA							
Rootzone		ns	(*)	ns	(*)	ns	(*)	ns	(*)
Topdress					ns	ns	ns	ns	ns
Root zone x topdressing					ns	ns	ns	ns	ns

4.2.9 Mycorrhiza

On 5 June 2012, mycorrhizal colonization was even more limited than in October 2011, and there was no effect of either rootzone or topdressing (Table 11). However, on this date, significantly ($P = 0.013$) more colonization was found on annual bluegrass (1.3 %) than on red fescue roots (0.8 %, data not shown in table or figure). In October 2012 colonization had increased significantly to an average of 40 % and there was a significant effect as almost three times more mycorrhiza was found in Green Mix rootzones than in peat-amended rootzones. Some of the mycorrhizal structures are shown in Photo 9.

Table 11. Effects of root zone and topdressing on mycorrhizal colonization at two sampling dates. Figures from 5 June are means of red fescue and annual bluegrass.

		5 June	**18 October**
		% of roots colonized	
Root zone	Peat	0.9	21.6
	Green Mix	1.2	58.7
Topdressing	Straight sand	1.0	40.3
	Green Mix	1.1	40.0
		ANOVA	
	Root zone	ns	***
	Topdressing	ns	ns
	Root zone x topdressing	ns	ns

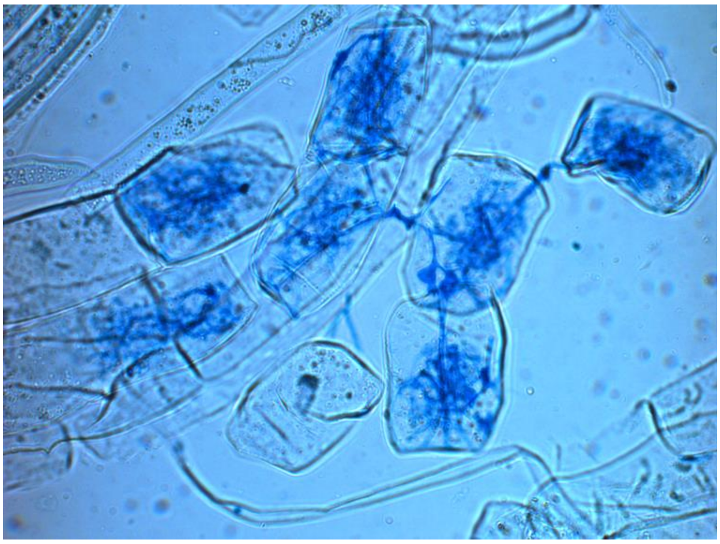

Photo 9: Root cells with arbuscules, i.e. structures made of heavily branched hyphae that function as a site for nutrient exchange between the plant and the fungus. Photo: Theo Ruissen.

4.2.10 Clipping yields

Clipping yields in early spring showed an odd pattern (Figure 9). Part of the reason for this might have been that bright and sunny weather during the observation period in week 16 (mean irradiance per hour 184 W m^{-2}) was followed by dull and rainy weather during the observation period in week 17 (mean irradiance per hour 85 W m^{-2}). Except for this anomaly, red fescue showed a bimodal growth pattern with a first maximum in late May and a second and lower maximum in late August.

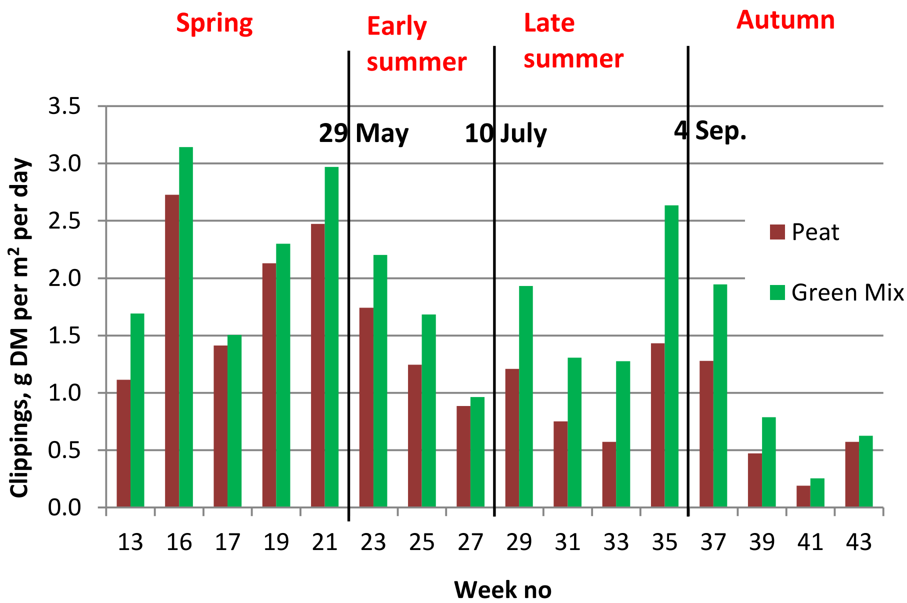

Figure 9: Daily production of clippings on peat-amended ad Green Mix rootzones during 2012.

Turfgrass clippings yields were always higher on Green Mix rootzones than on peat-amended rootzones Figure 9 and Table 12). The difference was most pronounced in late July and August. On average for 16 recordings throughout the growing season and two topdressing materials, clipping yield was 35 % higher on Green Mix rootzones than on peat-amended rootzones (Table 12).

Different topdressing materials had no effect on clipping yields during spring, early summer, late summer or on average for the whole season, but the Green Mix topdress tended (*P*=0.10) to produce more clippings the straight sand topdress in autumn (Table 12). Interactions between rootzone material and topdressing material were not significant.

Table 12: Mean values for clipping yields, nitrogen concentration in clippings and total nitrogen removal during various periods as affected by rootzone composition and topdressing material

	Clippings per day, g DM/m^2			Nitrogen (N), % of clipping dry weight			Nitrogen (N), Removal in clippings, g N/m^2		
Main effect, rootzone composition									
	Green Mix	Peat	ANOVA	Green Mix	Peat	ANOVA	Green Mix	Peat	ANOVA
Spring	2.37	2.03	*	3.07	2.72	**	5.10	3.87	**
Early summer	1.62	1.29	**	3.26	2.94	**	2.21	1.58	***
Late summer	1.79	0.99	***	3.56	3.02	**	3.56	1.68	***
Autumn	0.82	0.59	***	3.55	2.95	***	2.04	1.22	***
Whole season	1.70[1]	1.26[1]	***				12.91	8.35	***
Main effect, topdressing material:									
	Green Mix	Straight sand		Green Mix	Straight sand		Green Mix	Straight sand	
Spring	2.19	2.21	ns	2.95	2.83	ns	4.52	4.45	ns
Early summer	1.45	1.46	ns	3.18	3.03	(*)	1.95	1.85	ns
Late summer	1.40	1.38	ns	3.32	3.26	(*)	2.66	2.58	(*)
Autumn	0.73	0.69	(*)	3.26	3.23	ns	1.68	1.58	(*)
Whole season	1.48[1]	1.49[1]	ns				10.81	10.46	ns

[1] Average of 16 clippings. Values are not the arithmetic means of period means because there are different number of clippings behind the seasonal means.

4.2.11 Nitrogen concentration in clippings and nitrogen removal

On average for rootzones and topdressing material, the nitrogen (N) concentration in clipping dry matter increased from 2.9 % in spring to 3.1 % in early summer and 3.3 % in late summer (Table 12). The effect of rootzone composition on N concentration was significant during all periods, the greatest relative difference between Green Mix rootzones and peat-amended rootzones being recorded in late summer and autumn (Table 12). In relative terms, the effect of rootzone on N concentration was, however, much smaller than for clipping yields.

As a result of higher clipping yields and higher nitrogen concentration in clippings, the total N removal over the whole season was 50 % higher on Green Mix than on peat-amended rootzones (Table 12).

Replacing straight sand topdress with Green Mix topdress had no effect on the N concentration or total N removal in clippings in spring. During the rest of the season there were tendencies to higher N concentrations and/or N removal after dressing with Green Mix than after dressing with straight sand. In total for the growing season and on average for two rootzones, N removal in clippings was, however, only 3 % higher from plots topdressed with Green Mix than from plots topdressed with straight sand (Table 12).

No significant interactions between rootzone material and topdressing material were observed for N concentration or N removal in clippings.

4.2.12 Phosphorus concentration in clippings and phosphorus removal

The concentration of phosphorus (P) in turfgrass clippings increased from spring to autumn. The increase was most conspicuous on Green Mix rootzones where the P concentration in clippings was significantly higher than on peat-amended rootzones during all periods except spring (Table 13). In total for the growing season and topdressing materials, P removal in clippings was 73 % higher on Green Mix rootzones than on peat-amended rootzones.

Type of topdress also had a significant effect on the concentration of P in clipping yields. On average for rootzones, the total P removal was 8 % higher from plots dressed with Green Mix than from plots dressed with straight sand.

During the early summer period there was a significant interaction in that Green Mix topdress increased the total P removal in clippings more on Green Mix than on peat-amended rootzones (data not shown). Otherwise, interactions for P concentration or P removal were not significant.

Table 13: Mean values for phosphorus and potassium concentration in clippings and total phosphorus and potassium removal during various periods as affected by rootzone composition and topdressing material

	Phosphorus (P)						Potassium (K)					
	% of dry weight			Removal, g/m^2			% of dry weight			Removal, g/m^2		
Main effect, rootzone composition												
	Green Mix	**Peat**	**ANOVA**	**Green Mix**	**Peat**	**ANOVA**	**Green Mix**	**Peat**	**ANOVA**	**Green Mix**	**Peat**	**ANOVA**
Spring	0.38	0.35	ns	0.63	0.50	*	1.70	1.64	ns	2.85	2.34	(*)
Early summer	0.45	0.35	***	0.30	0.19	***	1.91	1.80	(*)	1.30	0.96	***
Late summer	0.59	0.40	***	0.59	0.22	***	2.46	2.09	(*)	2.47	1.16	***
Autumn	0.60	0.42	***	0.35	0.17	***	2.25	1.89	***	1.29	0.78	***
Whole season				1.87	1.08	***				7.91	5.24	***
Main effect, topdressing material												
	Green Mix	**Straight sand**		**Green Mix**	**Straight sand**		**Green Mix**	**Straight sand**		**Green Mix**	**Straight sand**	
Spring	0.38	0.35	ns	0.58	0.55	ns	1.73	1.62	ns	2.63	2.56	NS
Early summer	0.43	0.37	**	0.27	0.23	***	2.00	1.71	**	1.22	1.04	**
Late summer	0.51	0.48	**	0.42	0.40	**	2.33	2.22	**	1.85	1.77	**
Autumn	0.52	0.51	**	0.27	0.25	*	2.04	2.10	*	1.05	1.02	*
Whole season				1.54	1.42	(*)				6.76	6.40	(*)

4.2.13 Potassium (K) concentration in clippings and phosphorus removal

The K concentration in clippings increased from spring to late summer, but unlike the pattern for N and P there was a drop from late summer to autumn on both rootzones (Table 13). The relative effect of rootzone composition on K concentration was rather weak in spring and early summer but increased to approximately the same level as for N in late summer and autumn. In total for the growing season, 51 % more K was removed in clippings from Green Mix rootzones than from peat-amended rootzones.

The effect of Green Mix topdress on K concentration in clippings was of same the magnitude as for P in spring, early summer and late summer, but in autumn, there was a significant interaction as the K concentration was the same regardless of topdressing material on Green Mix rootzones but decreased if straight sand was replaced by Green Mix topdress on peat-amended rootzones. Opposite tendencies i.e. a stronger positive effect of Green Mix topdress on per cent K in clippings on peat-amended rootzones than on Green Mix rootzones, were recorded during the spring, early summer and late summer periods (Figure 10).
In total for the growing season and on average for the two rootzones, K removal in clippings was 6 % higher on plots dressed with Green Mix than on plots dressed with straight sand.

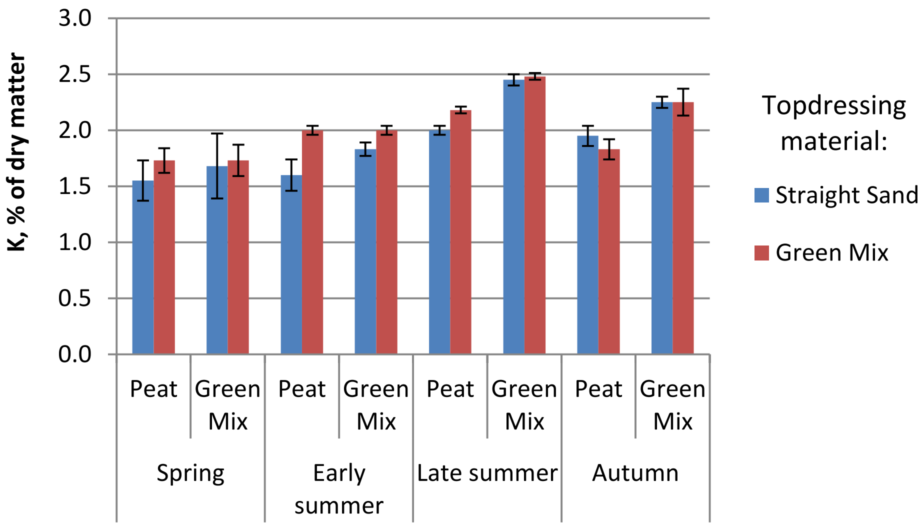

Figure 10. Effect of straight sand vs. Green Mix topdress on per cent K in clippings from two rootzones in spring, early summer, late summer and autumn. Bars indicate ± 1 SE (n=4).

4.2.14 Nutrient content in roots and verdure

On 18 October 2012, the concentration of N, P and K in dry matter of roots and verdure from Green Mix rootzones were, in turn, 30, 55 and 16 % higher than in roots and verdure from peat-amended rootzones (Table 14). On average for rootzones, the use of Green Mix topdress also gave a significantly higher concentration of P and K but had no significant effect on the concentration of N. Furthermore, there tended to be an interaction between rootzone and topdressing in that replacement of straight sand topdress with Green Mix topdress had a much stronger effect on the concentration of potassium in roots and verdure on Green Mix rootzones than on peat-amended rootzones (Figure 11).

Table 14: Concentration and total content of N, P and K in roots and verdure sampled on 18 October

		Concentration, % of DM			Total content in roots and verdure, g/m^2		
		N	P	K	N	P	K
Root-zone	Peat	1.04	0.16	0.64	10.0	1.45	6.1
	Green Mix	1.35	0.23	0.74	11.2	1.93	6.2
Top-dressing	Straight sand	1.15	0.17	0.66	10.5	1.52	6.0
	Green Mix	1.24	0.22	0.73	10.7	1.85	6.3
				ANOVA			
Rootzone		**	**	**	ns	*	ns
Topdress		ns	*	*	ns	(*)	ns
Rootzone x topdressing		ns	ns	(*)	ns	ns	(*)

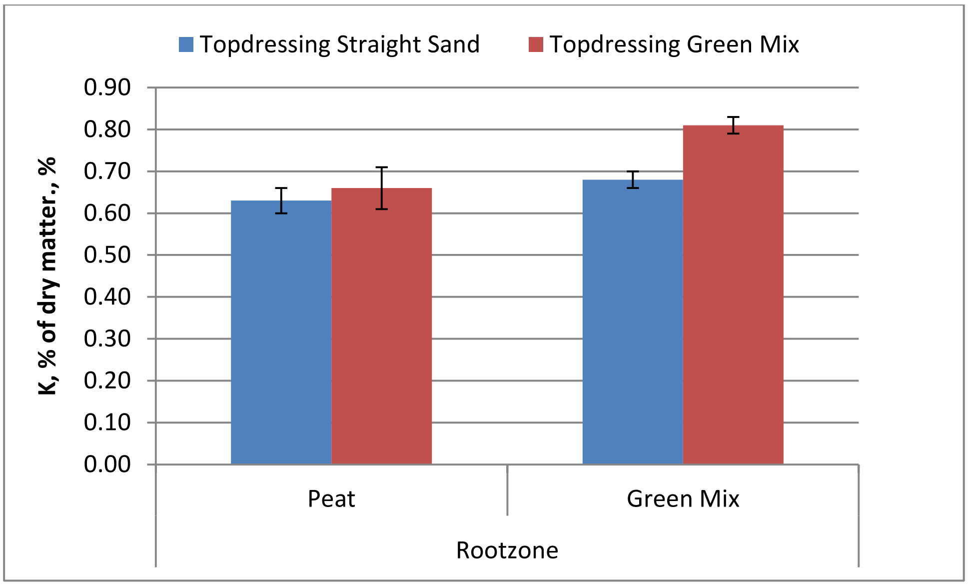

Figure 11. Combined effect of rootzone and topdressing material on concentration of potassium in roots and verdure on 18 October 2012. Bars indicate ± 1 SE (n=4).

The total content of N and K in roots and verdure was not significantly affected by rootzone or topdressing material, although for K there tended to be an interaction mostly reflecting the same pattern as in Figure 11. The total P-content in roots and verdue was significantly higher on Green Mix root zones than on peat-amended rootzones, and there was also a tendency towards a higher content with Green Mix topdress instead of straight sand topdress (Table 14).

4.2.15 Soil mineral nitrogen

On 5 June 2012, there was no significant effect of rootzone or topdressing on N available as nitrate, but Green Mix rootzones contained significantly more ammonium (Table 15). A significant rootzone x topdressing interaction showed that the content of NH_4-N in peat rootzones was unaffected by type of topdress, whilst it decreased if straight sand topdress was replaced with Green Mix topdress on Green Mix rootzones (Figure 12).

Table 15. Effects of root zone and topdressing on N-min content in the soil on 5 June 2012.

		NO_3-N	NH_4-N	Tot. N-min
			g/m^2	
Root zone	Peat	0.049	0.186	0.234
	Green Mix	0.045	0.413	0.459
Topdressing	Straight sand	0.050	0.306	0.356
	Green Mix	0.044	0.293	0.336
			ANOVA	
	Root zone	ns	***	***
	Topdressing	ns	(*)	(*)
	Root zone x topdr.	ns	*	ns

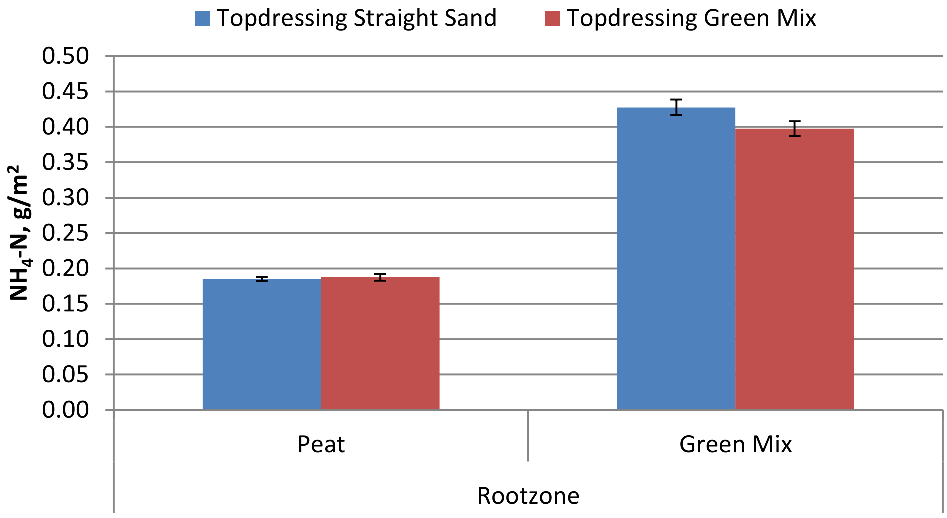

Figure 12. Combined effect of rootzone and topdressing material on plant available NH_4-N in June 2012. Bars indicate ± 1 SE (n=4).

4.2.16 Nutrient leaching

The total amount of drainage water collected during the growing season 20 March – 13 November 2012 was 995 mm from Green Mix rootzones and 965 mm from peat-amended rootzones. This difference, as the even smaller difference between plots receiving straight sand or Green Mix topdress, was not significant.

Throughout the year, losses of total N, NO_3-N, total P and total K in drainage water were significantly higher from Green Mix rootzones than from rootzones amended with peat (Table 16). In total for the growing season, the difference was almost three times for total N, twenty times for NO_3-N, more than two times for P and more than three times for K.

Table 16: Leaching losses of total N, NO_3-N, total P and total K from rootzones with different organic amendment during various periods and in total for the growing season 2012. Means of two topdressing materials.

	Total-N, g/m²			NO_3-N, g/m²			Total-P, g/m²			Total-K, g/m²		
	Peat	**Green Mix**	**ANOVA**	**Peat**	**Green Mix**	**ANOVA**	**Peat**	**Green Mix**	**ANOVA**	**Peat**	**Green Mix**	**ANOVA**
Spring	0.17	1.06	**	0.04	0.95	***	0.18	0.44	**	1.16	5.32	***
Early summer	0.13	0.32	***	0.01	0.03	(*)	0.11	0.29	**	0.94	4.09	***
Late summer	0.19	0.37	***	0.00	0.01	***	0.14	0.35	***	1.86	5.81	***
Autumn	0.33	0.48	***	0.00	0.02	***	0.50	0.84	***	2.71	6.19	***
Total	0.82	2.23	***	0.05	1.01	***	0.93	1.92	***	6.67	21.41	***

Leaching of NO_3-N was virtually limited to the spring period when the maximum concentration measured in leachate from one Green Mix plot was 8.7 mg/L. After turf coverage was close to 100 % in late May, N leaching mainly occurred in other forms than nitrate, probably mostly ammonium and organic forms. Leaching of P showed a distinct peak in autumn, while leaching of K was more evenly distributed throughout the growing season (Table 16).

On average for rootzones, replacing straight sand topdress with Green mix topdress had no effect on the leaching losses of P, but lead to increased losses of total N, NO_3-N, and K corresponding to 8, 7 and 7 %, respectively (data not shown). However, neither these differences nor the interactions between rootzone and topdressing materials were statistically significant.

5. Discussion

5.1 Implications of compost for fertilization during establishment

Faster grow-in of putting greens on Green Mix rootzones than on rootzones amended with Sphagnum peat was demonstrated by Aamlid (2005). That trial was conducted with creeping bentgrass (*Agrostis stolonifera*) but the present results confirm that the same enhancement occurs in red fescue. In agreement with soil analyses showing higher values for plant-available nutrients, the fact that turf coverage already two weeks after seeding was better on Green Mix than on peat-amended rootzones indicates that some of the nutrients in the compost were directly available at the seedling stage.

Unlike in the trial with creeping bentgrass (Aamlid 2005), the higher nutrient content in Green Mix rootzones was offset by the application of 50 % less fertilizer than on peat-amended rootzones during grow-in. However, the development of turf coverage and the lower tiller density on Green Mix than on peat-amended rootzones by the end of the grow-in year suggest that a lower reduction, perhaps 20-30 %, would have been more appropriate. The fact that nitrogen (N) losses during one rainy week in September 2011 was almost of the same magnitude as during the entire growing season 2012 confirms that the grow-in phase is the most risky phase for N leaching from turfgrass areas (Carrow et al. 2001, Petrovic nd Easton 2005), but within reasonable limits, this risk will not be reduced by lowering fertilizer inputs. On the contrary, Aamlid (2005) found that the leaching losses from both peat-amended and Green Mix rootzones increased if the grow-in phase was prolonged by cutting fertilizer applications by one third.

5.2 Implications of compost for fertilization of established turf

The advantage of Green Mix as a slow-release source of plant nutrients showed up as soon as we started to give equal fertilizer inputs to both rootzones in spring 2012. Significant differences between the two rootzones in general appearance were observed already in April and significant differences in coverage in May. However, the strongest effect of Green Mix on turfgrass clipping yield and N concentration was not seen until late summer, reflecting the importance of temperature for mineralization of soil organic matter. Jones (1980, cited by Carrow et al. 2001) indicated sufficiency ranges of 2.75-3.50 % N, 0.30-0.55 % P and 1.00 – 2.50 % K in turfgrass clippings, and Ericsson et al. (2012a,b) recommended that fertilizer inputs should be aimed at maintaining a stable N concentration of 3.1-3.5 %. Based on these recommendation and our data presented in Tables 12 and 13, it seems that late summer and early autumn is the time of year facilitating the greatest savings in fertilizer applications due to use of compost in the rootzone.

One of the major premises for demand-driven fertilization is that the proportion among nutrients in plant tissue is constant for various species and under various growing conditions and that the ideal fertilizer should have a N:P:K ratio of 100:14:65 (Ericsson et al. 2013). Because K is liable to leaching and important for turfgrass stress tolerance (Carrow et al. 2001) it is often recommended to increase the supply of this nutrient; hence the fertilizer given for grow-in in 2011 had a N:P:K ratio of 100:13:86. In 2012, we reduced the amount of P corresponding to a ratio of 100:5:81, partly because of the high content of P in Green Mix and partly because we expected that this would enhance root colonization by mycorrhiza. However, in spite of this reduction, the ratio between nutrients removed in clippings in 2012 was N:P:K = 100:14:61 on Green Mix rootzones and 100:13:63 on peat-amended rootzones, i.e. very close to the predictions by Ericsson et al. (2013). The nutrient concentrations in turfgrass roots and verdure were generally lower than in the clippings, and N:P:K ratios of 100:17:55 on Green Mix rootzones and 100:15:61 on peat-amended rootzones suggest that slightly more P, but slightly less K was retained in these underground and lower part of the plant compared with the clippings.

The leaching losses of N reported in this study were mostly low in relation to rootzone N content and the amount of N applied in fertilizer. EU's maximum allowable concentration for drinking water of 50 mg NO_3 corresponding to 11 mg NO_3-N per liter (Council of European Union 1998) was exceeded only from Green Mix rootzones during the early grow-in phase in September 2011. Moreover, the total loss of 2.2 g N/m^2 from Green Mix rootzones during the growing season 2012 was less than one half of the average annual loss from Norwegian agriculture from 1992 to 2007 (Bechman et al. 2008). Our findings are in general agreement with the review by Petrovic & Easton (2005) who concluded that N concentrations in surface water from managed turfgrass sites is usually much lower than in surface water from agricultural sites and that leaching of P should be a much greater concern for turfgrass managers. In our study, this is well illustrated by the fact that the total leakage of P during 2012, on average for rootzones, was almost as high as for N (1.5 and 1.4 g/m^2, respectively), despite the 20 fold difference in fertilization rates. Another calculation is that the total output of P in clippings and leachate, even on peat-amended rootzones receiving straight sand topdressing, was about three times higher than the input of P in fertilizer. All in all, our data show that P was available in excess of turfgrass requirements in all treatments, and there is no doubt that fertilization with this element can be totally omitted if compost is added to the rootzone or topdress on putting greens.

While most of the N and P in the Green Mix rootzone were in organic form and thus protected from leakage, the loss of 25 g K/m^2 from the newly constructed green during one week in September 2011 is a clear indication of the redundancy of this element in the Green Mix rootzone. The fact that leaching of K was two to three times higher than K removal in clippings during all periods in 2012 further suggests that fertilization with this element can be omitted for at least two years after establishing greens on Green Mix rootzones. If Green Mix is applied in the topdress at the rates used in this experiment, there will be an annual input of K of 3.15 kg K/m^2, also reducing the need for this element in fertilizer. Except for the tendency to higher concentration of K in root and verdure on Green Mix rootzones that also received Green Mix topdress, our data showed no tendency to increeased uptake of K regardless of how much K was available in the rootzone. On the other hand, the tendency for soil mineral N to decrease on Green Mix rootzones when straight sand topdress was replaced with Green Mix topdress may well be taken as an indication that excessive inputs of K replaced NH_4 at the cation exchange sites.

5.3 Mycorrhiza and competition against annual bluegrass

Based on the assumption that mycorrhiza plays a stronger role for plants growing under natural conditions than in cultivated systems with high inputs of P (e.g. Gange et al. 1999, Joner 2012) a surprising result was the almost three times higher colonization level in Green Mix than in peat-amended rootzones in autumn 2012. Possible explanations are that the more vigorously growing turf on Green Mix rootzones provided more assimilates for the symbiotic component, and/or that organic forms of N and P in compost do not inhibit mycorrhiza to the same extent as readily available nutrients in mineral fertilizers. A higher initial content of mycorrhiza in Green Mix rootzones at construction is not likely as propagules will be killed by temperatures around 70 ^{o}C during the composting process; this is also confirmed by the very low proportion of roots colonized in autumn 2011 and spring 2012. Higher colonization rates in Green Mix rootzones must therefore be due to more conducive conditions for mycorrhiza during the summer 2012, but our data does not say anything about the actual contribution of mycorrhiza to the higher uptake of P or other nutrients on Green Mix rootzone.

Earlier studies have indicated that the fertilizer requirements for N (e.g. Ericsson et al. 2013) and P (e.g. Raley et al. 2013) are higher for annual bluegrass than for red fescue. Thus, the higher proportion of annual bluegrass tillers on peat-amended than on Green Mix rootzones in 2011 was probably due to the higher fertilizer inputs to the peat-amended rootzones during grow-in. Conversely, the lower contribution of annual bluegrass to turf coverage on peat-amended rootzones in spring and early summer 2012 can probably be explained by the fact that the lower nutrient content compared with Green Mix rootzones was no longer compensated by higher fertilizer applications. Although it is a common observation that the annual bluegrass population on golf greens decline with increasing temperature and decreasing rainfall from spring to summer (e.g. Cline et al. 1993), the sudden and almost complete disappearance of annual bluegrass from July to August in our trial probably mostly reflects that is was an annual biotype (weed-type) of annual bluegrass, and not a greens type with better persistence and adaptation to low mowing heights (Vargas & Turgeon 2004). The observation that a higher percentage of annual bluegrass roots than of red fescue roots was colonized by mycorrhiza in spring 2012 has later been substantiated by pot trials (Andersen 2013), but it is in conflict with the traditional opinion that annual bluegrass develops less mycorrhiza than other turfgrass species.

5.4 Effect of Green Mix topdress

As would be expected on young and immature greens, the effects of different topdressing materials on clipping yields and the N, P and K balances were altogether small compared with the effects of rootzone compositions. Despite this, inclusion of compost in the topdress had a strong effect of turfgrass general appearance and intensity of green color already 1-2 months after the first application. Some of this effect could be an artefact due to the much darker color of the topdressing sand after amendment with compost, but there were other positive aspects of using green mix topdress, e.g. on disease occurrence and playing quality, that are likely to become more prevalent as the green becomes older. Greenkeepers managing red fescue apply an average of 7 mm topdressing per year, and according to the Danish supplier of Green Mix topdress, this corresponds to 3-4 g plant available nitrogen per m^2 or about 50 % of the nitrogen requirement on established red fescue greens (Kvalbein et al. 2012).

5.5 Implications for soil physical conditions

The implications of using compost in the rootzone or topdress on soil physical conditions require studies over a longer time period. Many greenkeepers are afraid that greens amended with compost will lose macroporosity and infiltation rate over time, but he data presented in this report and those presented by Aamlid (2008) over a three year period suggest otherwise, i.e. that Green Mix compost is more stable and resistant to deterioration than sphagnum peat. A major reason for this, and also for the harder surfaces of Green Mix rootzones than of peat-amended rootzones in this study, is probably that compost not only contains organics, but also a certain amount of mineral matter. Thus, if the compost retains its structure over time, it may perhaps be accepted that the organic matter content in the thatch/mat layer stabilizes at a somewhat higher level than on greens constructed on peat-amended rootzones and receiving straight sand topdress. A special consideration in the ongoing experiment is that that the compost in the rootzone had been composted in heaps over a long period of time, whereas the compost in the topdress was a so-called mattress-compost that contained more plant-available nutrients per unit organic matter but was perhaps less stable and mature.

5.6 Conclusion and fertilizer recommendation

If funding permits, this project will continue for another four to five years to clarify the long-term effect of compost on aging red fescue greens. Based on the results available so far, our preliminary conclusion is that the use of Green Mix rootzones and Green Mix topdress has many advantages and should be preferred to peat-amended rootzones and straight sand topdress, respectively.

The implications for turfgrass nutrition of using of Green Mix rootzones and Green Mix topdress on young greens can be expressed as follows:

- Replacement of peat-amended rootzones with Green Mix rootzones will reduce the N requirement for grow-in by 20-30 %. N will still have to be applied at weekly intervals to ensure rapid grow-in.
- Once turf coverage is complete, Green Mix rootzones will reduce the N requirement for nitrogen by 20-50 % compared with peat-amended rootzones. The largest savings in N fertilization can be expected in late summer when the soil temperature is conducive to N mineralization, and especially on greens that also receive regular applications on Green Mix topdress.
- There is no need for application of P on Green Mix rootzones.
- Fertilization with K on Green Mix rootzones can be omitted at least for the first two years after establishment, but the K concentration in the soil, or preferably in plant tissue, should be monitored regularly as large losses of K through the drainage system can be expected. Regular application of Green Mix topdress will cover 60-100 % for the potassium requirement on established red fescue greens.
- Because of the high pH, ammonium sulfate is an ideal fertilizer source for compost-amended putting greens. For the same reason, compost-amended greens should also receive regular inputs of micronutrients, especially iron (Fe) and manganese (Mn).

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