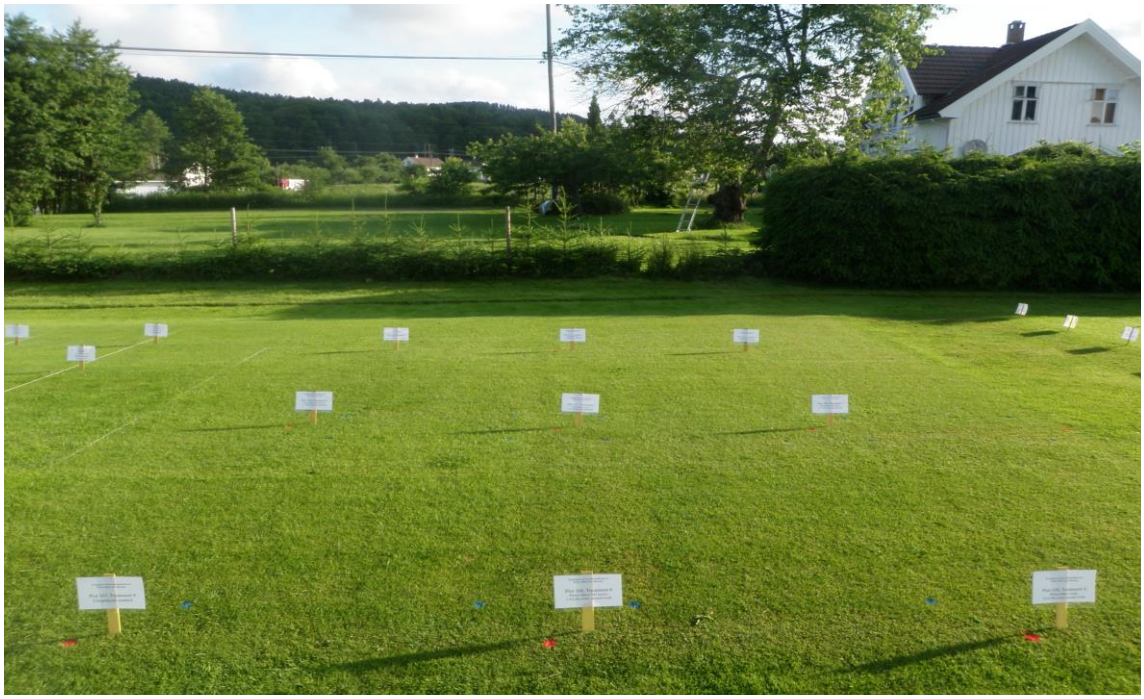
Bioforsk Rapport
Bioforsk Report
Vol. 8 Nr. 186 2013

Current and new formulations of the plant growth regulator Primo MAXX® (trinexapac-ethyl) for turfgrass

Comparison of PRIMO MAXX® (A11825A) and Primo MAXX® NG (A19238C) on golf course fairways and greens

Ingunn M. Vågen[1], Oiva Niemeläinen[2], Tatsiana Espevig[1], Trond Olav Pettersen[1], Pentti Ruuttunen[2] and Trygve S. Aamlid[1]

[1)] The Norwegian Institute for Agricultural and Environmental Research, Bioforsk Øst Landvik
[2)] Agricultural Research Centre of Finland (MTT)



Hovedkontor/Head office
Frederik A. Dahls vei 20
N-1430 Ås
Tel.: (+47) 40 60 41 00
post@bioforsk.no

Bioforsk Landvik
Bioforsk Øst
Reddalsveien 215
4886 Grimstad
Tel.: (+47) 40 60 41 00
ingunn.vaagen@bioforsk.no

Tittel/Title:

Current and new formulations of the plant growth regulator Primo MAXX® (trinexapac-ethyl) for turfgrass

Forfatter(e)/Author(s):

Ingunn M. Vågen, Oiva Niemeläinen, Tatsiana Espevig, Trond Olav Pettersen, Pentti Ruuttunen and Trygve S. Aamlid,

Dato/Date:	*Tilgjengelighet/Availability:*	*Prosjekt nr./Project No.:*	*Saksnr./Archive No.:*
31.12.2013	Open	190044	-
Rapport nr./Report No.:	*ISBN-nr./ISBN-no:*	*Antall sider/Number of pages:*	*Antall vedlegg/Number of appendices:*
8(186)/2013	978-82-17-01199-6	42	0

Oppdragsgiver/Employer:	*Kontaktperson/Contact person:*
1. Scandinavian Turfgrass and Environment Research Foundation 2. Syngenta Lawn and Garden	1. Maria Strandberg 2. Simon Watson

Stikkord/Keywords:	*Fagområde/Field of work:*
Avklipp, fairway, formuleringer, golf, green. høydevekst, plengras, vekstregulering,	Frøavl og gras til grøntanlegg
Clipping yield, fairway, golf green, height growth, lawn, turf quality	Turfgrass and seed production

Sammendrag:

Denne rapporten gir resultater og anbefalinger basert på til sammen fire forsøk med økende doser av to ulike formuleringer av vekstreguleringsmidlet Primo MAXX® (trinexapac-ethyl) på green og fairway i Norge og Finland i 2013.

Summary:

This report presents results and recommendations based on based on four field trials with increasing rates of two different formulations of the plant growth regulator Primo MAXX® (trinexapac-ethyl) on golf course greens and fairways in Norway and Finland in 2013.

Trygve S. Aamlid

Research leader,
Turfgrass and Seed Production

Ingunn Vågen

Project leader

Contents

1. Abstract

Syngenta's plant growth regulator for turf, Primo MAXX® (active ingredient trinexapac-ethyl, 121 g L^{-1}), was registered in Sweden in 2011 and has become widely used as a means to reduce mowing costs and improve turf quality on golf courses. In addition to or as potential substitute for the current formulation Primo MAXX® (A11825A), Syngenta recently also developed a new formulation, Primo MAXX® NG (A19238C) with approximately the same content of active ingredient (115.3 g L^{-1}) but with different additives / filling agents. The objective of the research reported here was to evaluate if:

- the new formulation provides comparable performance in terms of growth regulation on fairways and greens as the current formulation at comparable rates
- both formulations are safe to the turf at increasing rates

Field trials were conducted on fairways and greens at the Bioforsk Turfgrass Research Center Landvik, Norway, and at Loimijoki GC, Finland, from June through October 2013. The two formulations were compared with untreated control plots at rates 1.2, 1.6, 2.0 and 2.4 L ha^{-1} in the fairway trials and 0.2, 0.4 and 0.8 L ha^{-1} ha in the green trials. Registrations at regular intervals included turfgrass overall impression, turfgrass discoloration/color intensity, turfgrass darkness, turfgrass height growth, and turfgrass clipping yields. Measurements of turfgrass ball roll distance and root depth, and analyses of turfgrass freezing tolerance and concentration of water soluble carbohydrates (WSC) before winter were included in the green trial at Landvik. The results were analyzed by ANOVA including identification of the contrasts 'No Primo MAXX® vs. Primo MAXX®', 'Old vs. new formulation', 'Application rate' and 'Interaction formulation x rate'.

The four trials showed only minor differences in efficacy or safety of the two formulations. In some cases, the new formulation tended to have a slightly stronger growth regulating effect than the old formulation, but differences were not statistically significant. It is therefore concluded that the new formulation can replace the old one, or the two formulations can be used interchangeably at the same rates.

In the **fairway trials**, reductions is turfgrass overall appearance due to increasing rates of both formulations were quite apparent during the first part of the experimental period, and especially during a dry period in July and early August. Among the negative aspects of using too high rates were more red thread disease and increased competition from broadleaved weeds. These negative aspects were more conspicuous in the fescue/ colonial dominated fairway at Landvik than on the Kentucky bluegrass-dominated fairway on more fertile soil at Loimijoki. It is therefore concluded that both formulations should be labelled with 1.2 L ha^{-1} every second week as the standard rate on fairways. Like In most cases, this will enable Nordic greenkeepers to mow the fairways twice per week instead of three times per week without sacrificing much in turf visual appearance

As compared with the unsprayed control treatment, the retardation of plant growth in the **green trials** varied from 15-20 % at rates 0.2 and 0.4 L ha^{-1} to approximately 30 % at 0.8 L ha^{-1}. Turf treated with Primo MAXX® was always significantly darker than the untreated control. The first applications, especially of 0.8 L ha^{-1} caused reductions in overall appearance and color intensity, but creeping bentgrass greens needed less time than the fescue-dominated fairways to get customized to the growth regulators. On average for the experimental period, 0.4 L ha^{-1} led to slightly better overall appearance, freezing tolerance and higher carbohydrate content than either unsprayed control plots and plots receiving 0.8 L ha^{-1}. Although differences were not statistically significant, it is concluded that both Primo MAXX® and Primo MAXX® NG should be labelled with of 0.2 L ha^{-1} every week or 0.4 L ha^{-1} every second week as standard application rates for Nordic golf greens.

2. Introduction

The plant growth regulator Primo MAXX® (trinexapac-ethyl, 121 g a.i. L^{-1}) was registered for turfgrass use in Sweden in 2011 and in Finland in 2013. In addition to other documentation, the approval was based on trials in Norway and Finland in 2007 and 2008 showing reduced clipping yields, better playing quality and less damage from *Microdohium nivale* after use of Primo MAXX® (Aamlid et al. 2008, 2009).

The recommended rates on the Swedish label for Primo MAXX® are mostly higher than those recommended by Aamlid et al. (2009), although the Swedish label recognizes that discoloration can become a problem, especially in annual bluegrass (*Poa annua*) (Table 1). The Swedish label does not specify application intervals, but states that repeated applications are needed to maintain consistent growth regulation and that the total seasonal rate must not exceed 16 L ha^{-1}.

A survey among 90 Swedish golf courses using Primo MAXX® on greens in 2012 showed that 8 % applied Primo MAXX® weekly, 63 % every second week and 29 % at longer intervals. The application rate of 0.4 L ha^{-1} recommended on the Swedish label was followed by 47 % of the golf courses, whilst 37 and 16 % of the courses used lower and higher rates, respectively (P. Edman, Turfgrass Agronomist, Swedish Golf Federation, 2013).
The same survey also showed that for thirteen Swedish golf courses using Primo MAXX® on fairway in 2012, the medium application rate was 0.6 L ha^{-1} (range 0.3 – 2.0 L^{-1}), and the medium application interval 4 weeks (range 2-5 weeks).

Table 1. Application rates and/or intervals for Primo MAXX® on various types of turf recommended based on Nordic trials 2007-2008 (Aamlid et al. 2009) and on the Swedish product label.

Type of turf	Recommended by Aamlid et al. (2009)		Swedish label rate, L ha^{-1}**
	Rate, L ha^{-1}*	Application interval (weeks)	
Greens: Bentgrasses, red fescue, annual bluegrass	0.2–0.4	1-2	0.4
Fairways (<18 mm mowing height): Bentgrasses, red fescue, annual bluegrass	0.6–1.2	2-3	1.6
Sports turf, cemeteries, parks (>18 mm mowing height): Bluegrasses, red fescue, bentgrasses	1.0-2.0	3-4	2.4
Sports turf, cemeteries, parks (>18 mm mowing height): Perennial ryegrass	-	-	3.2

* Always use lowest rate for the first seasonal application (Aamlid et al. 2009)
** Cut rates by 50 % in case of discoloration in annual bluegrass (Swedish label)

Syngenta filed a dossier for registration of Primo MAXX® about the same time in Norway as in Sweden, but the application was rejected because the Norwegian Food Safety Authority did not find it sufficiently documented that one of the additives (filling agents) in the current formulation of Primo MAXX® was safe to human health. The safety of the active ingredient trinexapac-ethyl, which has been on the Norwegian market since 1998 in the form of the agricultural product Moddus, was not questioned.

In spring 2013, The Scandinavian Turfgrass and Environment Research Foundation (STERF) was asked by Syngenta to coordinate new Nordic trials with a new turfgrass formulation of trinexapac-ethyl, Primo MAXX® NG (A19238C), which does not contain the additive / filling agent questioned by the Norwegian Food Safety Authority.

The object of the trials was to clarify if:

- the new formulation A19238C provides comparable performance in terms of growth regulation on fairways and greens as the current formulation A11825A at comparable rates
- both formulations are safe to the turf at increasing rates

Two fairway trials and two green trials were carried in from May to October 2013 under the industrial partnership agreement between Syngenta and STERF. The trials were conducted by authorized GEP (Good Experimental Practice) teams in Norway and Finland and coordinated by Bioforsk.

Photo 1. Representatives from STERF, Syngenta and Bioforsk inspecting green trial at Bioforsk Landvik on 29 Aug. 2013. From left: Maria Strandberg, STERF, Simon Watson and Rod Burke, Syngenta, and Trond Pettersen and Ingunn Vågen, Bioforsk. Photo: Trygve S. Aamlid.

3. Fairway experiments

3.1 Materials & Methods

3.1.1 Protocol

The fairway trials followed a randomized complete block design with four blocks and nine treatments (Table 2). The amount of active ingredient trinexapac-ethyl applied in the two formulations was practically the same: The old formulation Primo MAXX® (A11825A) contained 121 g a.i. L^{-1}, and Primo MAXX® NG (A19238C/CGA163935SL) contained 115.3 g a.i. L^{-1}. The protocol prescribed eight applications at two week intervals (Table 2).

Experimental results were analyzed using the SAS procedure PROC GLM (SAS Institute 2002). Using the 'Contrast' statement in PRC GLM, we also determined *P*-values for the following sources of variation (degrees of freedom indicated in parenthesis):

- No Primo MAXX® vs. Primo MAXX® (1)
- Old vs. new formulation (1)
- Primo MAXX® rate, linear effect (1)
- Primo MAXX® rate, quadratic effect (1)
- Primo MAXX® rate, quadratic effect (1)
- Interaction formulation x rate, pooled (3)

Throughout this report, the term 'significant' always refers to $P \leq 0.05$. Effect with *P*-values in the range 0.05-0.10 are referred to as 'tendencies'.

Table 2: Treatments in fairway trials, Norway and Finland.

Treat-ment no.	Treatment	Expected number of applications	Application rate (L ha^{-1})
1	Untreated control	-	-
2	A11825A (Primo MAXX®)	8	1.2
3	A11825A (Primo MAXX®)	8	1.6
4	A11825A (Primo MAXX®)	8	2.0
5	A11825A (Primo MAXX®)	8	2.4
6	A19238C (Primo MAXX® NG)	8	1.2
7	A19238C (Primo MAXX® NG)	8	1.6
8	A19238C (Primo MAXX® NG)	8	2.0
9	A19238C (Primo MAXX® NG)	8	2.4

3.1.2 Norway

3.1.2.1 Experimental site and maintenance

The Norwegian fairway trial was established on 3 June 2013 at the Bioforsk Turfgrass Research Center Landvik, Grimstad (58°34'N, 8°52'E, 12 m a.s.l.). Because of ice damage during the winter 2012-13, the four blocks had to be placed at four different sites on the Research Center's fairway areas to ensure uniform plant cover within each block. The soil in blocks 2-4 was the original silt loam soil (64% sand, 29% silt, 7% clay), but the soil in block 1 contained more sand as it had been sand-capped before renovating that part of the fairway in 2011. Soil samples taken in July 2013 showed an ignition loss of 2.4, 3.1, 3.1 and 3.9 %, and a pH(H_2O) of 5.8, 5.6, 5.7 and 5.9 in the 0-20 cm rootzone in block 1, 2, 3 and 4, respectively.

The turf in all blocks was composed of varying proportions of colonial bentgrass (*Agrostis capillaris*), red fescue (*Festuca rubra*) and Kentucky bluegrass (*Poa pratensis*), and there were also traces of annual bluegrass. Block 2 was dominated by colonial bentgrass and had more than twice as high tiller density as the other blocks (Table 3).The amount of broadleaved weeds was low except in block 4 where there were some patches of white clover (*Trifolium repens*).

The size of the gross (treatment) plots was 1.5m x 2.5m = 3.75m^2.

Table 3. Botanical composition and fairway density of the four blocks in fairway trial at Landvik

Block number	Species, %					Tillers per m^2
	Agrostis capillaris	*Festuca rubra*	*Poa pratensis*	*Poa annua*	Broadleaved weeds	
1	32	33	35	0	0.1	43346
2	58	35	6	1	0.0	115589
3	33	55	10	3	0.1	50570
4	26	48	23	2	1.2	40938
Mean	37	43	18	1	0.4	62611

Except when weighing clippings, the fairway was mowed every Tuesday and Friday with a triplex fairway mower at 15 mm height and clippings returned. Granular fertilizers were mostly applied at four week intervals as shown in Table 4. The fairway plots were irrigated with 10 mm in weeks 26, 28 and 30, and with 20 mm in weeks 31 and 36, in total 70 mm.

Table 4. Fertilizer applications in fairway trial at Landvik.

Week	Fertilizer type	kg per 100 m^2			
		Product	N	P	K
8 May	Fullgjødsel 22-2-12	0.50	0.108	0.009	0.058
21 May	Scott Sportsmaster 12-0-9	1.20	0.144	0.000	0.090
18 Jun.	Scott Fairwaymaster 20-5-8	1.00	0.200	0.022	0.066
18 Jul.	Everris Proturf 12-5-20	1.50	0.180	0.033	0.249
14 Aug.	Scott Fairwaymaster 20-5-8	0.90	0.180	0.020	0.059
11 Sep.	Everris Proturf 12-5-20	1.10	0.132	0.024	0.183
08 Oct.	Scott Fairwaymaster 20-5-8	0.50	0.100	0.011	0.033
07 Nov.	Fullgjødsel 12-4-18 Micro	0.70	0.083	0.028	0.123
SUM			**1.127**	**0.147**	**0.861**

3.1.2.2 Implementation of protocol

Increasing rates of the two formulations of Primo MAXX® were applied a total of nine times from 4 June to 24 Sep. (Table 5) in accordance with the Norwegian 'Good Experimental Practise' Protocol (Tørresen 2007). We used an experimental backpack plot sprayer (Oxford / LTI) working at 150-200 kPa pressure. The spraying boom had three nozzles (Teejet 11002) spaced 50 cm apart. The boom provided full coverage of the central 1.0 m in each plot which was later used for all registrations. The spraying volume was 250 L ha^{-1}. Actual application rates were recorded by weighing the tank before and after spraying. Table 5 shows the deviations from the target values were mostly within the 10 % limit set by the GEP protocol.

Table 5. Application dates, weather conditions at application and actual application rates at all spraying events for the fairway trial at Landvik.

Appli-cation date	Time of day (hours)	Weather conditions at application			Treatment number / application rate (L Primo MAXX® ha^{-1})							
		Air temp °C	Rel. humi-dity, %	Wind Speed m s^{-1}	2 (target 1.2)	3 (target 1.6)	4 (target 2.0)	5 (target 2.4)	6 (target 1.2)	7 (target 1.6)	8 (target 2.0)	9 (target 2.4)
4 Jun.	07-09	14.7	48	1.0	1.2	1.5	2.0	2.5	1.1	1.6	1.9	2.4
18 Jun.	07-09	17.2	45	0.7	1.1	1.5	2.0	2.4	1.1	1.6	1.9	2.4
2 Jul.	08-10	15.1	56	2.3	1.2	1.6	2.1	2.9	1.4	1.8	2.3	2.5
16 Jul.	08-10	20.5	58	2.1	1.3	1.6	2.0	2.4	1.1	1.6	2.0	2.4
30 Jul.	08-09	18.4	83	1.2	1.2	1.6	2.1	2.5	1.2	1.6	1.9	2.5
13 Aug.	07-09	17.0	55	1.2	1.2	1.6	2.0	2.4	1.2	1.6	2.0	2.4
27 Aug.	07-09	13.2	97	0.0	1.2	1.6	2.0	2.4	1.2	1.6	2.0	2.4
11 Sep.	07-09	13.4	99	0.2	1.2	1.6	2.0	2.4	1.2	1.6	2.0	2.4
24 Sep.	07-09	10.5	63	0.7	1.2	1.6	2.0	2.4	1.2	1.6	2.0	2.4
Mean					1.2	1.6	2.0	2.5	1.2	1.6	2.0	2.4

Photo 1. Block 1 in the fairway trial at Landvik before the first application. Size of treatment plots was 1.5 m x 2.5 m. Photo: Trygve S. Aamlid

3.1.2.3 Weather data

On average for June to October, the growing season 2013 had 1.2 °C higher temperature than the 30 year normal value (Table 6). June had a lot of rain and little sunshine, but July, and to a lesser extent August, were warm and dry months with higher irradiance than the long term mean values.

Table 6. Weather data for Landvik meteorological station, about 200 m from the fairway experiment. Normal values for temperature and rainfall are 'official' values from the period 1961-90, while normal values for irradiance are calculated averages for the period 1994-2012.

	Mean temperature, °C		Precipitation, mm		Irradiance,MJ m^{-2} (305-2800 nm)	
	2013	30 yr normal	2013	30 yr normal	2013	19 yr average
June	14.3	14.7	159	71	582	613
July	17.7	16.2	12	92	686	608
Aug.	16.0	15.4	58	113	489	466
Sep.	12.7	11.8	176	136	259	265
Oct.	8.9	7.9	173	160	129	134
Mean / sum	13.9	12.7	578	654	2145	2086

3.1.2.4 Registrations

Turfgrass overall impression (1-9, 9 is best turf), turfgrass color intensity/freshness (1-9, 1 is completely brown/discolored, 9 is most intensely green), turfgrass color darkness (1-9, 9 is darkest turf) and per cent of plot area affected by disease were assessed by the same person every Monday morning. Turf height was measured using a Turf Check Prism device (Check Signature Inc., Shoreview, MN, USA) at five sites per plot every Monday morning after leaving the plots uncut since Friday. Turf height growth was expressed at daily height increments. Clippings from each plot were collected and weighed every fourth Monday (10 June, 8 July, 5 Aug., 2 Sep. and 30 Sep.) always six days after the last application of Primo MAXX®. Clippings were collected using a (single) walk-behind greens mower adjusted to a mowing height of 15 mm.

3.1.3 Finland

3.1.3.1 Experimental site and maintenance

The Finnish fairway trial was established on 4 June 2013 on fairway no 12 at Loimijoki Golf Course (www.loimijokigolf.fi), Ypäjä (60°49'N, 23°14'E, 86 m a.s.l.). The user intensity in 2013 was 18 000 rounds of golf. The season had started in the beginning of May and continued until the end of October, except for a one week closure in early October due to a cold spell. The fairway turf cover was composed of Kentucky bluegrass (90-92 %) with minor amounts of annual bluegrass (6-9 %). Broad leaved weeds amounted to less than 2 %.

The fairway had been seeded on agricultural land in 1992 and renovated in 2007 when the golf course was expanded to an 18 hole course.

Photo 2. Establishing fairway trial on fairway no. 12 at Loimijoki GC, 4 June 2013.
Photo: Oiva Niemeläinen.

Except when collecting clippings the trial was mowed twice a week with a John Deere 8700 fairway mower adjusted to 13-15 mm. The actual mowing height was often shorter because of thatch resulting in a soft surface.

The trial was fertilized with ammonium sulphate (21 % N; 24 % S) at rate of 1.13 kg N / 100 m^2 in early June. The fertilizer was placed to 1 cm depth into the thatch/topsoil with a Rapid turf sowing machine.

The trial was irrigated as needed with 3-4 mm of water at least every second night during periods of drought.

3.1.3.2 Implementation of protocol

Primo MAXX was applied eight times from 6 June to 12 Sep. The spraying treatments was carried out by MTT Agrifood' s GEP team using a portable, compressed air-powered "van der Weij" -type plot sprayer (Photo 3). Details about application volumes, nozzles etc. and weather conditons at application are given in Table 7. The size of the treatment plots was 2 m x 4 m (=8 m^2).

Photo 3. "van der Weij" -type plot sprayer used in trials at Loimijoki. Photo: Oiva Niemelainen.

Table 7. Spraying dates and weather conditions in Loimijoki fairway trial, 2013.

	Application date							
	6 June	**21 June**	**4 July**	**17 July**	**2 Aug.**	**16 Aug.**	**29 Aug.**	**12 Sep.**
Time of Day:	8:40	8:20	8:50	8:20	8:37	8:30	8:20	8:20
Application Method:	SPRAY	SPRAY	SPRAY	SPRAY	SPRAY	SPRAY	SPRAY	SPRAY
Application Placement:	BROFOL	BROFOL	BROFOL	BROFOL	BROFOL	BROFOL	BROFOL	BROFOL
Applied By:	PR,LR,JV	PR,LR,JV	PR,JV,AM	JV,ME,AM	VR,JKo,LR	JV,AM,LR	AM,JV,LR	AM,ME,LR
Air Temperature, Unit:	21.1 C	14.0 C	18.6 C	15.8 C	17.4 C	16.1 C	10.7 C	11.4 C
% Relative Humidity:	60	78	61	69	77	78	84	95
Wind Velocity, Unit:	1.5 MPS	0.5 MPS	0.5 MPS	3 MPS	2.5 MPS	2.5 MPS	0 MPS	0 MPS
Dew Presence (Y/N):	Y yes	Y yes	Y yes	Y yes	Y yes	Y yes	Y yes	Y yes
Soil Temperature, Unit:	17 C	15.4 C	17.6 C	16.5 C	17.6 C	15.2 C	14.7 C	14.3 C
Soil Moisture:	DAMP	DAMP	DAMP	DRY	DAMP	WET	DAMP	DAMP
% Cloud Cover:	0	70	1	1	98	75	30	100
Equipment Type:	SPRAYE	SPRAYE	SPRAYE	SPRAYE	SPRAYE	SPRAYE	SPRAYE	SPRAYE
Operation Pressure, Unit:	2.2 bar	2.2 bar	2.2 bar	2.2 bar	2.2 bar	2.2 bar	2.2 bar	2.2 bar
Nozzle Type:	Hardi 4110	Hardi 4110	Hardi 4110	Hard i4110	Hardi4110	Hardi4110	Hardi4110	Hardi4110
Nozzle Size:	16	16	16	16	16	16	16	16
Nozzle Spacing, Unit:	50 cm	50 cm	50 cm	50 cm	50 cm	50 cm	50 cm	50 cm
Nozzles/Row:	4	4	4	4	4	4	4	4
Boom ID:	KSU3	KSU3	KSU3	KSU3	KSU3	KSU3	KSU3	KSU3
Boom Length, Unit:	2 m	2 m	2 m	2 m	2 m	2 m	2 m	2 m
Boom Height, Unit:	50 cm	50 cm	50 cm	50 cm	50 cm	50 cm	50 cm	50 cm
Ground Speed, Unit:	1 mps	1 mps	1 mps	1 mps	1 mps	1 mps	1 mps	1 mps
Carrier:	WATER	WATER	WATER	WATER	WATER	WATER	WATER	WATER
Spray Volume, Unit:	300 l/ha	300 l/ha	300 l/ha	300 l/ha	300 l/ha	300 l/ha	300 l/ha	300 l/ha
Mix Size, Unit:	2.5 liters	2.5 liters	2.5 liters	2.5 liters	2.5 liters	2.5 liters	2.5 liters	2.5 liters
Propellant:	COMAIR	COMAIR	COMAIR	COMAIR	COMAIR	COMAIR	COMAIR	COMAIR

3.1.3.3 Weather data

The growing season 2013 at Loimijoki GC was warmer and the months July and September drier than the long term average (Table 8).

Table 8. Weather data from the Finnish Meteorological Institute's observatory in Jokioinen, about 13 km from the experimental field. Normal values for temperature, rainfall and irradiance are 'official' values from the period 1981-2000.

	Mean temperature, °C		Precipitation, mm		Irradiance, MJ m^{-2} (305-2800 nm)	
	2013	20 yr normal	2013	20 yr normal	2013	20 yr normal
June	16.6	14.0	57	63	587	577
July	16.4	16.7	56	75	599	582
Aug.	15.8	15.0	103	80	464	430
Sep.	10.8	9.9	23	58	264	252
Oct.	5.8	4.9	87	66	129	108
Mean / sum	13.1	12.1	326	342	2043	1949

3.1.3.4 Registrations

Registrations were carried out by MTT's field research team. The initial start-up registrations were made on 4 June, the day before the first application of Primo MAXX®. During the course of the trial, turf overall appearance (1-9, 9 is best turf) and color intensity (1-9, 1 is completely yellow / discolored, 9 is freshly green), were assessed and turf height measured at weekly intervals. Since turf height measurements were not always performed at a given number of days since the last mowing, turf height will be presented as absolute values rather than as daily height increments.

Clippings from each plot were collected and weighed at two to four weeks intervals using a 56 cm wide, John Deere 220 B single mower. Clippings were collected from 3.5 m length mowed both ways so that the registration area in the center of each plot was 3.92 m^2. On some occasions - particularly when the mowing schedule was changed for weather reasons - no clippings could be gathered because the course's mowing operation had taken place just prior to the anticipated clipping measurement. In those cases it was necessary to delay collection of clippings to the following week. On 26 June, the mower broke down, so there is only data from one trial block.

Photo 4. Collection of clippings in fairway trial at Loimijoki, 19 June 2013. Photo: Oiva Niemeläinen

3.2 Results

3.2.1 Norway

3.2.1.1 Turfgrass overall appearance

The initial assessment before the first application of Primo MAXX® confirmed that the turf was uniform within blocks. Reductions in turfgrass overall appearance due to use of Primo MAXX® showed up one to two weeks after the first application and were then significant until mid-September. After that the quality of the untreated control declined so that the differences were not significant any more. On most dates, the lowest scores for overall appearance were recorded on plots receiving the highest rate of the new formulation.

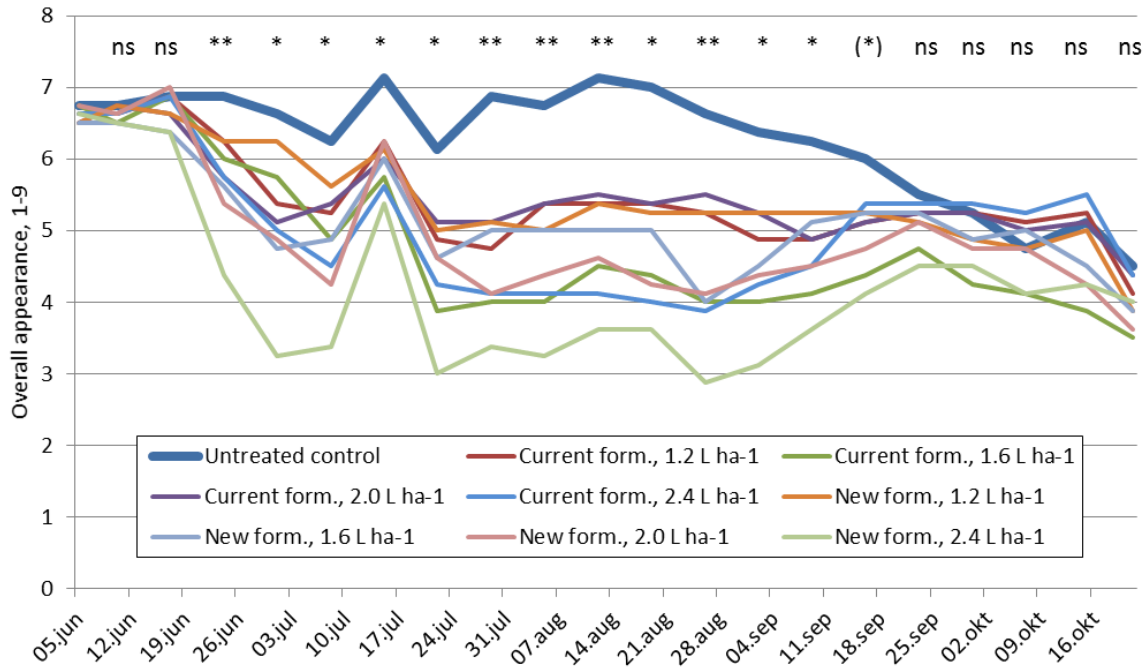


Figure 1. Turfgrass overall appearance (1-9, 9 is best) during the experimental period in fairway trial at Bioforsk Landvik. The significance symbols ***, **, * (*), and ns indicate probability levels $P \leq 0.001$, $P \leq 0.01$, $P \leq 0.05$, $P \leq 0.1$, and $P > 0.1$, respectively.

3.2.1.2 Turfgrass color intensity and turfgrass darkness

Although there was no pronounced discoloration, Primo MAXX® led to lower scores for color intensity / freshness throughout the course of the trial (Fig. 2). Plots receiving 2.4 L ha^{-1} of the new formulation usually had the lowest score for color intensity. At the same time, Primo MAXX® also resulted in significantly darker turf than in the unsprayed control treatment (Fig. 3). This can be seen also from Photos 5 and 6.

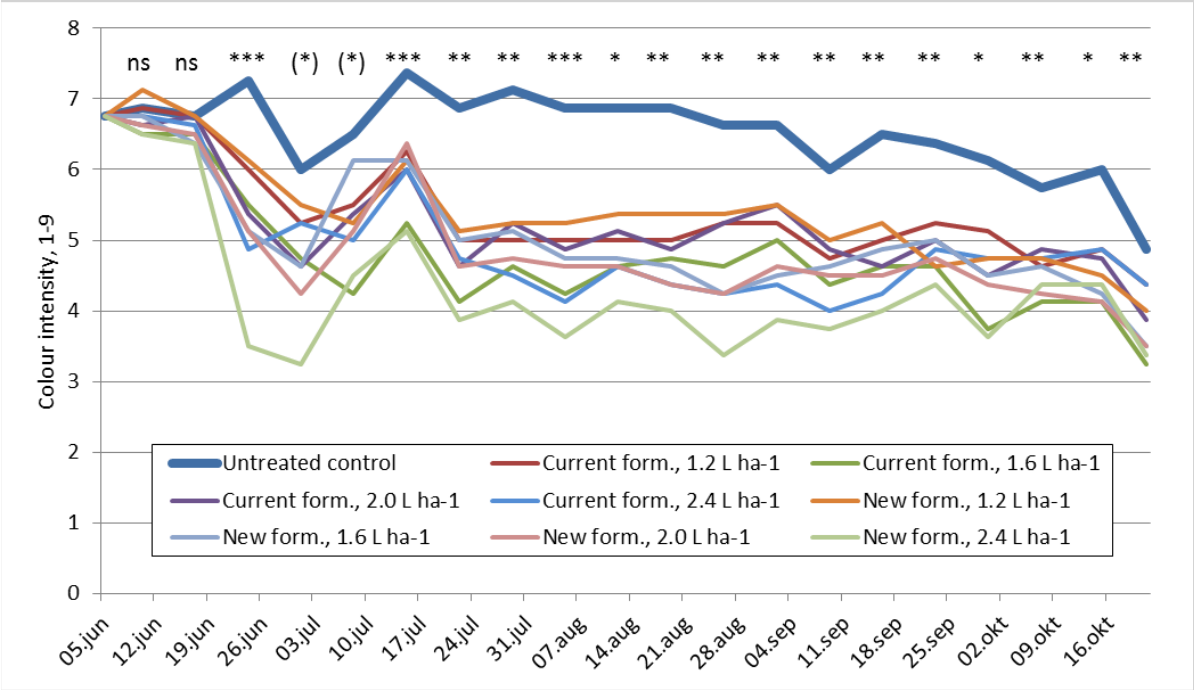


Figure 2. Turfgrass color intensity (1-9, 9 is most freshly green) during the experimental period in fairway trial at Bioforsk Landvik. Significance levels as in Fig. 1.

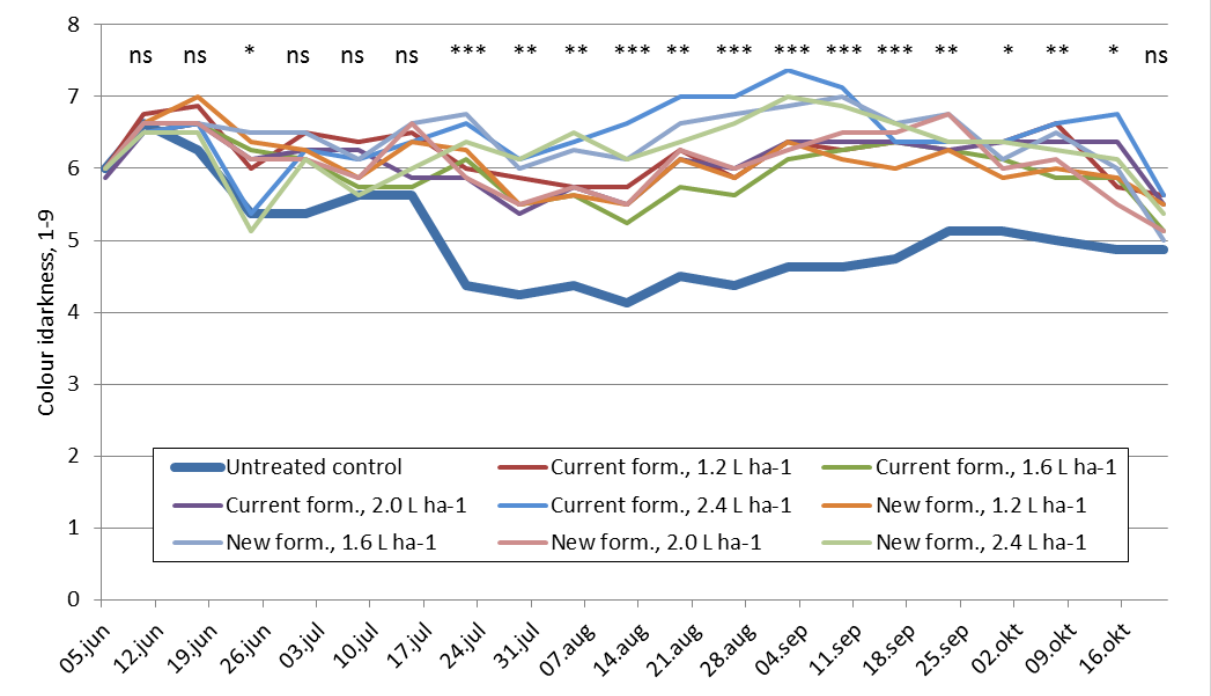


Figure 3. Turfgrass darkness (1-9, 9 is darkest turf) during the experimental period in fairway trial at Bioforsk Landvik. Significance levels as in Fig. 1.

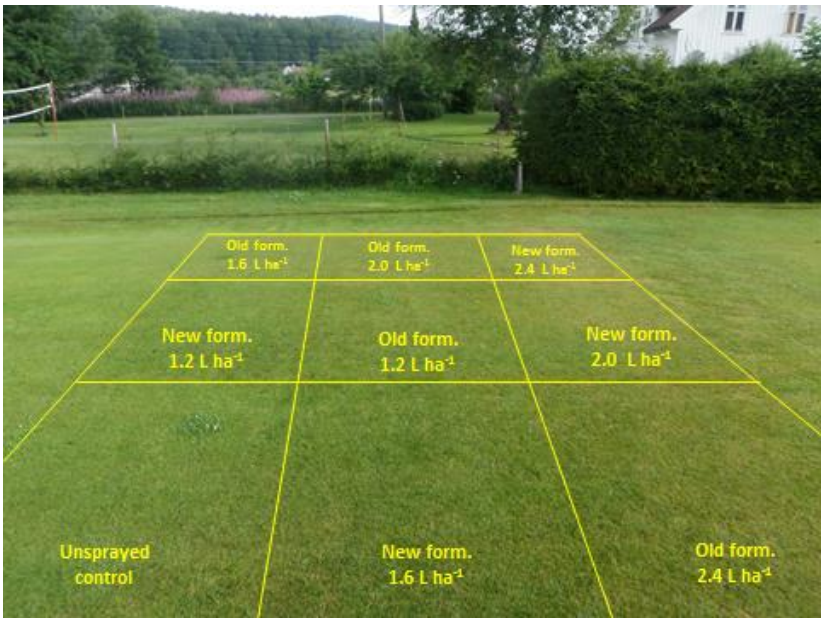


Photo 5. Block 1 in fairway trial at Landvik on 25 June 2013, after two applications. Photo: Trygve S. Aamlid.

Photo 6. From block 4 at Landvik on 11 Aug. 2013. Unsprayed control to the left of red dot and 2.4 L ha^{-1} of old formulation to the right of red dot. Treatment plots were labelled with red dots and observation plots with blue dots. Patches of white clover became more apparent after application of high rates of Primo MAXX® Photo: Trygve S. Aamlid.

3.2.1.3 Turfgrass diseases

The only disease observed in the trial was red thread (*Laetisaria fuciformis*). The symptoms were seen on red fescue from August to October and were more severe on plots sprayed with Primo MAXX® than on unsprayed control plots (data not shown in figure).

3.2.1.4 Turfgrass height growth and clipping yields

Applications of Primo MAXX® every second week led to significant reductions in daily height growth during the entire experiment (Fig. 4). On average for two formulations and four rates, the reduction in height growth compared with the unsprayed control treatment was more pronounced during the dry and warm period in July and early August than during the cooler and wetter period in September. On the other hand, within treatments sprayed with Primo MAXX®, differences in clipping yields due to increasing rates of the two formulations were more easily distinguished in September (Fig. 5).

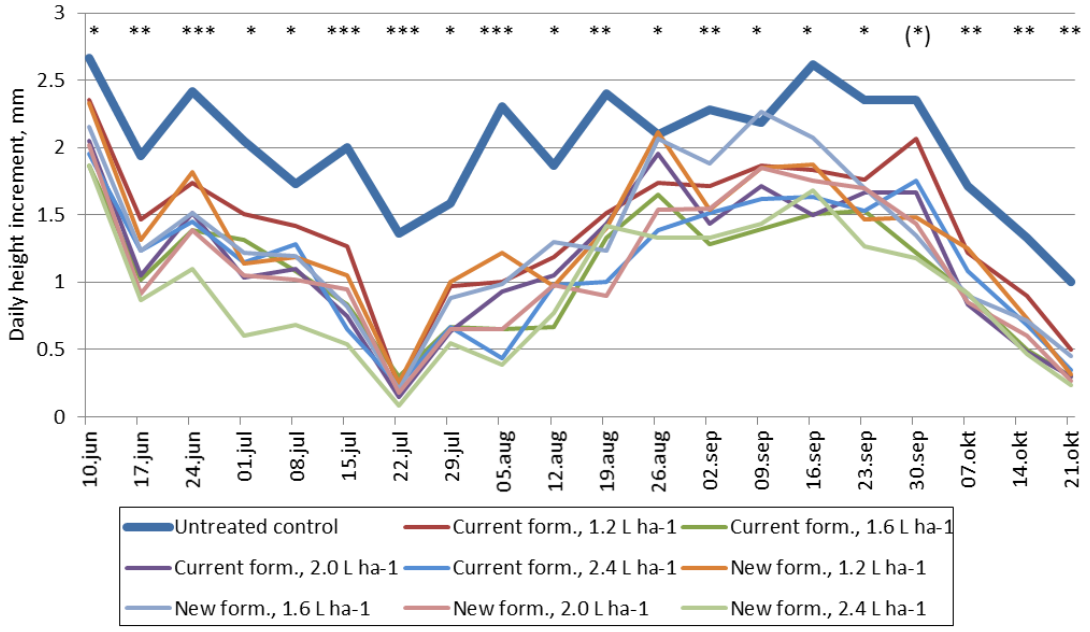


Figure 4. Daily height increment during the experimental period in fairway trial at Bioforsk Landvik. Significance levels as in Fig. 1.

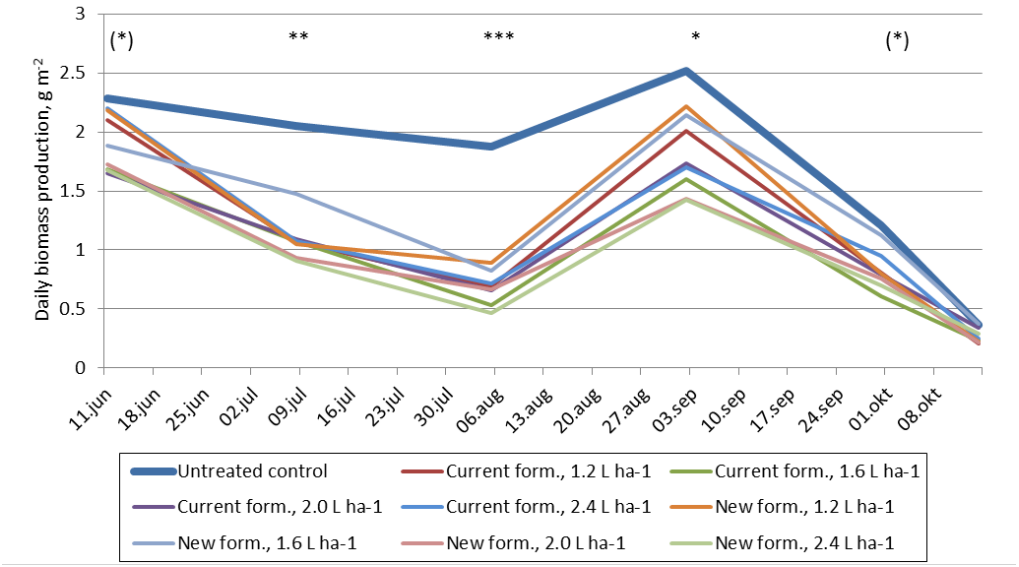


Figure 5. Daily production of clipping yields (g DM m^{-2}) on four dates during the experimental period in 2013. Significance levels as in Fig. 1.

Photo 7. Block 4 in the morning on 19 September 2013. Repeated application of Primo MAXX® during the growing season resulted in less formation of dew and/or guttation water. Photo: Agnar Kvalbein.

3.2.1.5 Contrasts

Results of contrast analyses for the fairway trial at Landvik are shown in Table 9. Except for diseases occurrence, most of the differences among treatments could be ascribed to the contrast 'No Primo MAXX® vs. Primo MAXX®'. In addition there were significant linear effects of increasing rate on turfgrass overall appearance, turfgrass color intensity, turfgrass darkness, and turfgrass height growth, and a similar tendency for clipping yields. Differences between the old and new formulation of Primo MAXX® were never significant, but for clipping yield there tended to be an interaction as the old formulation caused a stronger reduction at an application rate of 1.2 and 1.6 L ha^{-1} while it was the other was round at the higher rates 2.0 and 2.4 L ha^{-1} (Fig. 6).

Table 9. Results of contrast analyses on the effect of increasing rates of two Primo Maxx formulations on turfgrass overall apperance, turfgrass color intensity, darkness, occurrence of red thread diesease, daily height growth and daily dry matter production of turfgrass clippings in fairway trial at Landvik. Mean of all observations. Significance levels as in Fig. 1.

	Turfgrass overall appearance (1-9)	Turf colour intensity (1-9)	Turfgrass colour darkness (1-9)	Red thread, % of plot area	Daily height increment mm d^{-1}	Turf-grass clippings g DM m^{-2} d^{-1}
Contrast 1: No Primo MAXX vs. Primo MAXX®						
No Primo **MAXX®**	6.24	6.51	5.00	0.11	2.02	1.60
Primo **MAXX®**	4.97	4.91	6.20	0.28	1.18	0.93
Sign.	***	***	***	(*)	***	***
Contrast 2: Old vs. new formulation						
Primo **MAXX®**	5.10	5.00	6.19	0.26	1.19	0.91
Primo **MAXX®** NG	4.84	4.83	6.20	0.30	1.17	0.95
Sign.	ns	ns	ns	ns	ns	ns
Contrasts 3-5: Application rate						
1.2 L ha^{-1}	5.39	5.33	6.14	0.13	1.36	1.00
1.6 L ha^{-1}	4.87	4.83	6.18	0.33	1.19	1.00
2.0 L ha^{-1}	5.11	4.97	6.10	0.27	1.14	0.86
2.4 L ha^{-1}	4.50	4.54	6.37	0.42	1.03	0.85
Sign. Linear	*	**	ns	*	**	(*)
Sign. Quadratic	ns	ns	ns	ns	ns	ns
Sign. Cubic	ns	(*)	ns	ns	ns	ns
Contrast 6-8: Interaction formulation x rate (pooled)						
Sign.	ns	ns	ns	ns	ns	(*)
|						
Overall ANOVA	**	***	***	(*)	***	***

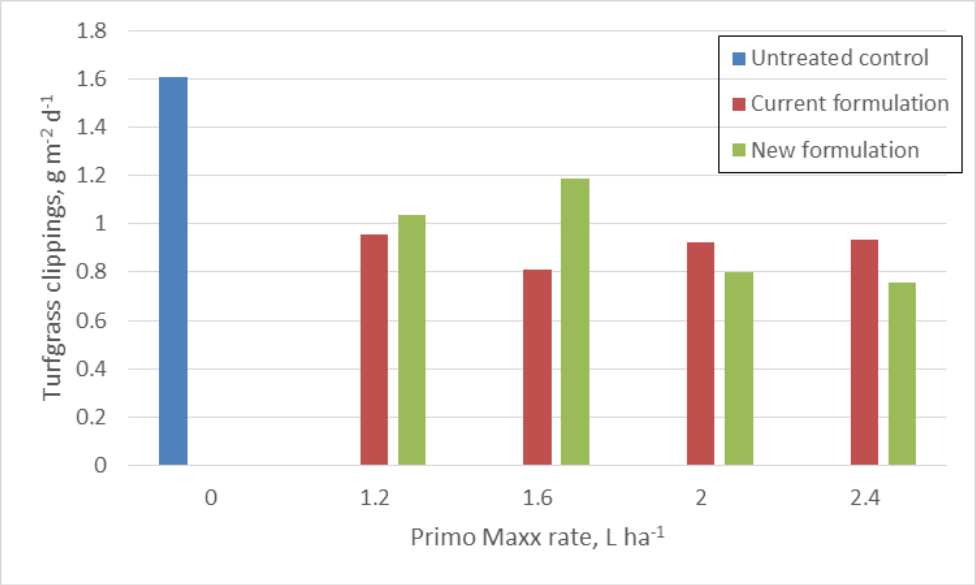


Figure 6: Tendency ($P \leq 0.10$) to interaction between formulations and rates of Primo MAXX® on daily production of dry matter in clippings in fairway trial at Bioforsk Landvik. Means of five weighings during the growing season.

3.2.2 Finland

3.2.2.1 Turfgrass overall appearance

Differences in turfgrass overall appearance in the fairway trial at Loimijoki were significant only on two dates (Fig. 7). In both cases, the untreated control plots had higher quality scores than plots sprayed with Primo MAXX®. On one occasion in late August, there was a tendency to a lower score in the treatment receiving the highest rate of the new formulation than in the treatment receiving the highest rate of the old formulation, but at the last but one assessment in late September the ranking of the two formulations was opposite when both were given at a rate of 2.0 L ha^{-1}.

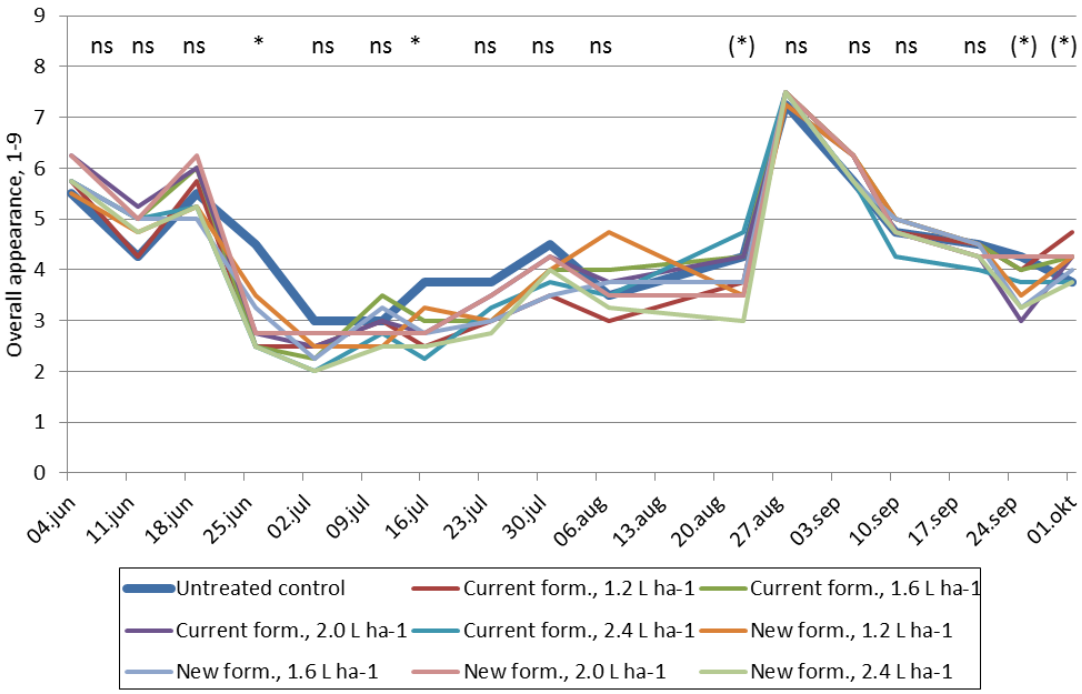


Figure 7. Overall appearance (1-9, 9 is best) during the experimental period in the fairway trial at Loimijoki GC. Significance levels as in Fig. 1.

3.2.2.2 Turfgrass color intensity

Before 27 August, differences in color intensity were not significantly except on 25 June when the unsprayed control plots were more freshly green than all plots sprayed with Primo MAXX® (Fig. 8). In contrast, the observations in September mostly showed better color after application of Primo MAXX® than on unsprayed plots.

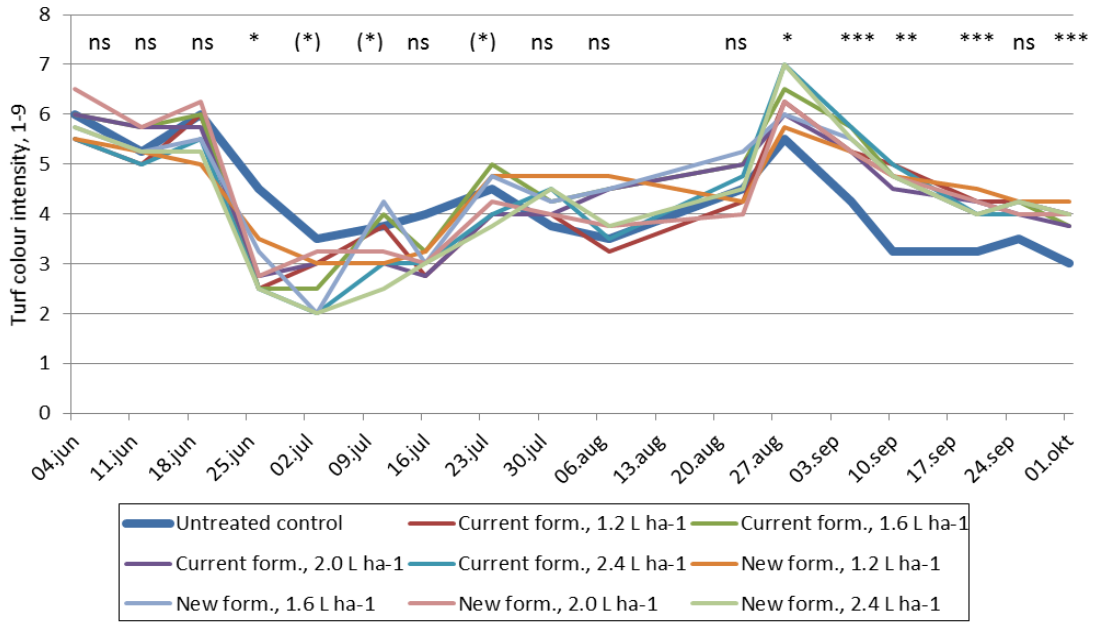


Figure 8. Turfgrass color intensity (1-9, 9 is most intensely green) during the experimental period in fairway trial at Loimijoki GC. Significance levels as in Fig. 1.

3.2.2.3 Height of turf at mowing

On average for 16 observations, the turf height measurements showed lower values than expected from the 13-15 mm bench setting of the fairway mower. This was partly because the realized mowing height was lower due to softness of the thatch layer, and partly because the observers did not always ensure that the prism was sitting on the soil surface and not only on the top of the thatch (Photo 8). Regardless of this, turf height was mostly higher on plots sprayed with Primo MAXX® than on unsprayed control plots (Fig. 9).

Photo 8. Initial measurement of turf height before the first application of Primo MAXX®. Photo: Oiva Niemeläinen.

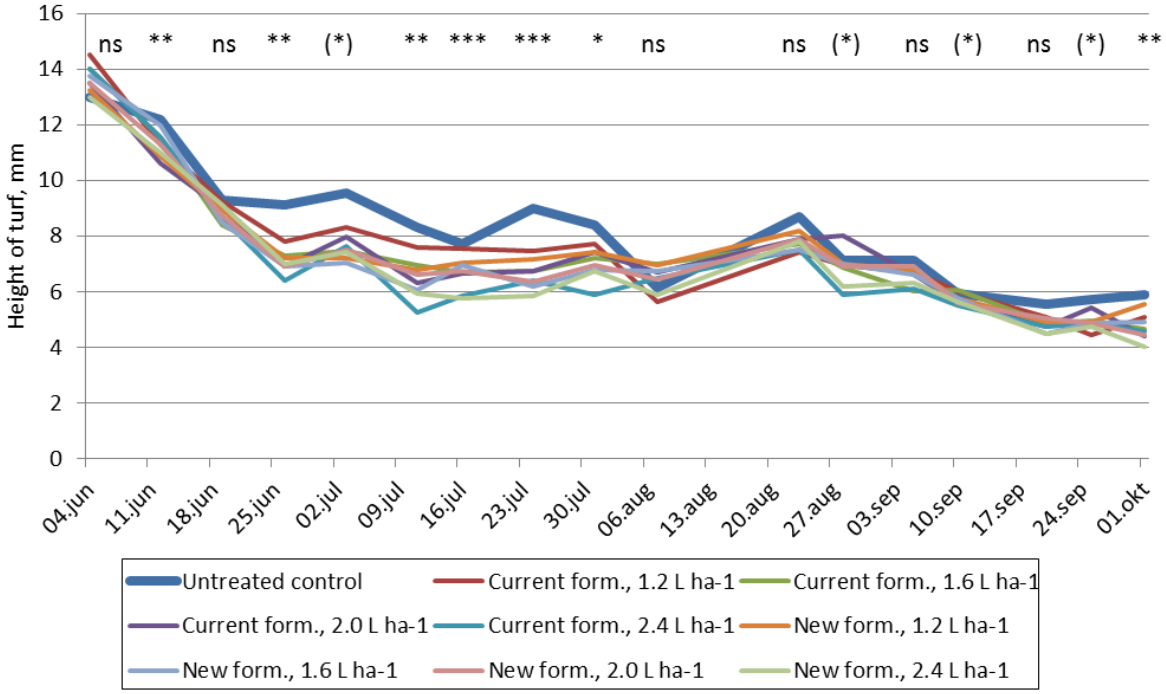


Figure 9. Height of turf at mowing, measured throughout the experimental period in fairway trial at Loimijoki GC. Significance levels as in Fig. 1.

3.2.2.4 Clipping yields

Clipping yield were significantly higher in the unsprayed control treatment than in the treatments sprayed with Primo MAXX® on five out of six observation dates (Fig. 10). The strongest relative reductions in clipping yield were recorded in July. A significant effect of increasing application rates was seen only in late August.

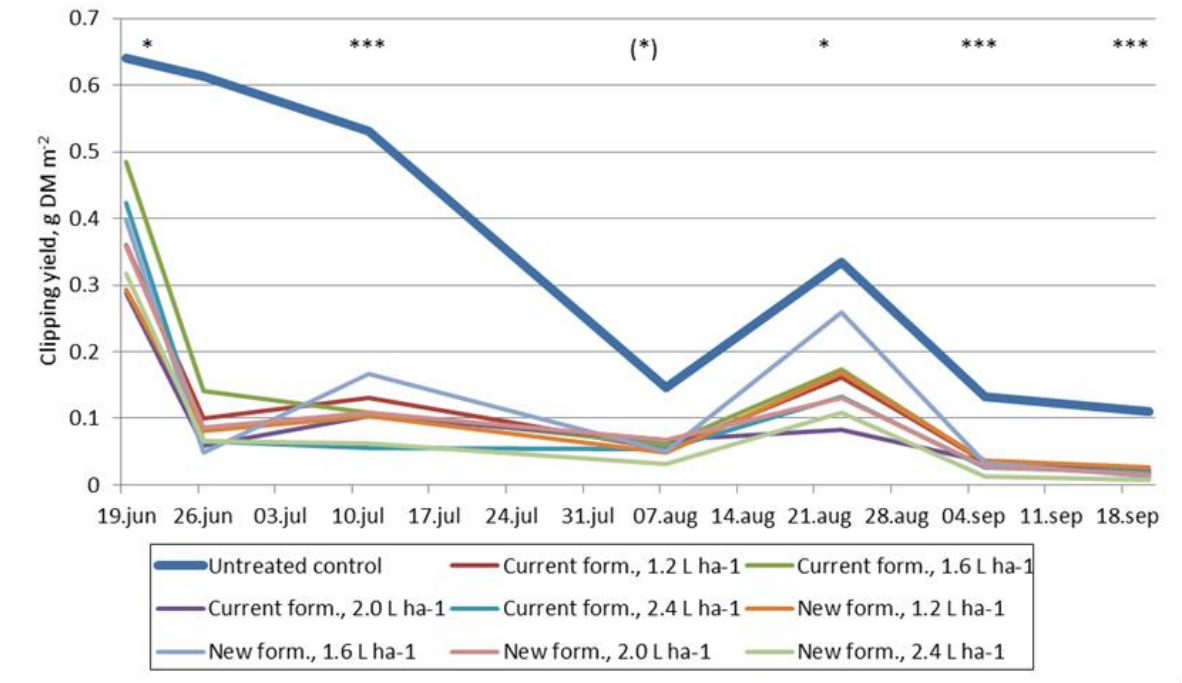


Figure 10. Clipping yields (g DM m^{-2}) sampled during the experimental period in fairway trial at Loimijoki GC. Significance levels as in Fig. 1.

3.2.2.5 Contrasts

As suggested by Figures 7-10, the contrast 'No Primo MAXX® vs. Primo MAXX®' accounted for most of the variation among treatments (Table 10). On average for all observations, turfgrass height at mowing was 12 % lower and clipping yields 61 % lower on plots sprayed with Primo MAXX® than on unsprayed plots. There were also tendencies to lower overall appearance and higher color intensity on plots receiving Primo MAXX®.

The contrast 'Old vs. new formulation' was not significant for any character, but the linear effect of increasing application rates was highly significant for turf height at mowing. Like turf quality, turfgrass height showed a pronounced drop as the application rate increased from 2.0 to 2.4 L ha^{-1}. For turfgrass color intensity there tended to be a quadratic effect as the highest score was obtained at 1.6 L ha^{-1}.

Table 10. Results of contrast analysis on overall appearance, turfgrass color intensity, height of turf at mowing and dry weight of clippings in fairway trial at Loimijoki GC. Mean of all observations. Significance levels as in Fig. 1.

	Turfgrass overall appearance (1-9)	Turfgrass colour intensity (1-9)	Height of turf mm	Turfgrass clippings g DM m^{-2}
Contrast 1: No Primo MAXX® vs. Primo MAXX®				
No Primo Maxx	4.39	4.13	8.16	0.33
Primo Maxx	4.14	4.30	7.22	0.12
Sign.	(*)	(*)	***	***
Contrast 2: Old vs. new formulation				
Primo **MAXX®**	4.16	4.30	7.25	0.12
Primo **MAXX®** NG	4.11	4.31	7.17	0.11
Sign.	ns	ns	ns	ns
Contrast 3: Application rate				
1.2 L ha^{-1}	4.16	4.30	7.49	0.12
1.6 L ha^{-1}	4.20	4.45	7.25	0.14
2.0 L ha^{-1}	4.25	4.28	7.27	0.11
2.4 L ha^{-1}	3.93	4.19	6.89	0.10
Sign. Linear	ns	(*)	***	ns
Sign. Quadratic	(*)	(*)	ns	ns
Sign. Cubic	ns	ns	(*)	ns
Contrast 4: Interaction formulation x rate (pooled)				
Sign.	ns	ns	ns	ns
Overall ANOVA	ns	ns	***	***

4. Green experiments

4.1 Materials & Methods

4.1.1 Protocol

The protocol for the green trials prescribed a randomized complete block design with four blocks, seven treatments and approximately ten applications at two week intervals (Table 10).

The trials were conducted at the same sites as the fairway trials, i.e. Bioforsk Landvik, Norway and Loimijoki GC, Finland. In addition to the original protocol implemented at both sites, the protocol for Landvik prescribed recording of root development, plant carbohydrate status and freezing tolerance before winter.

The experimental results were analyzed by PROC GLM including contrasts as in the fairway trial (SAS Institute 2002). However, since the application rates increased geometrically and not arithmetically, the effect of increasing rates of Primo MAXX® could not be split into linear and quadratic effects.

Table 10: Treatments in green trials

Treatment No.	Treatment	Expected number of applications	Application Rate
1	Untreated	-	-
2	A11825A (Primo MAXX®)	10	0.2 L ha^{-1}
3	A11825A (Primo MAXX®)	10	0.4 L ha^{-1}
4	A11825A (Primo MAXX®)	10	0.8 L ha^{-1}
5	A19238C (Primo MAXX® NG)	10	0.2 L ha^{-1}
6	A19238C (Primo MAXX® NG)	10	0.4 L ha^{-1}
7	A19238C (Primo MAXX® NG)	10	0.8 L ha^{-1}

4.1.2 Norway

4.1.2.1 Experimental site and maintenance

Because of winter damage, Bioforsk Landvik had no green available for this trial in spring 2013. The trial was laid out on 15 July after complete grow-in of a USGA-green that had been renovated in spring and reseeded on 24 May 2013 with a seed blend consisting of 25% of each of the creeping bentgrass (*Agrostis stolonifera*) cultivars 'Penn A-1', 'Penn A-4', 'Penn G-6' and 'Declaration', seeding rate 8 g m^{-2}. Soil samples taken at establishment in July 2013 indicated an ignition loss of 0.76 % and a pH(H_2O) of 5.7. Plot size was 1.5m x 2.5m (=3.75m^2).

The green was mowed with a single, walk-behind mower every Monday, Wednesday and Friday. The mowing height was 4.0 from the start of the trial until 14 Aug., 3.5 mm from 16 Aug. until 23 Oct. and 4 mm at the final mowing on 4 Nov.

Fertilizer applications are shown in Table 11. All fertilizer inputs during the experimental phase were in liquid formulations (Table 11).

Table 11. Fertilizer applications in green trial at Landvik.

		Per 100 m^2			
Date	**Fertilizer type**	**fertilizer**	**kg N**	**kg P**	**kg K**
Grow-in phase:					
24 May	Marihøne Plus - preseeding	6.25	0.500	0.250	0.313
07 Jun.	Andersson 13-2-13	1.50	0.195	0.013	0.162
13 Jun.	Arena Crystal	1.10	0.209	0.021	0.165
19 Jun.	Andersson 13-2-13	1.50	0.195	0.013	0.162
25 Jun.	Greenmaster liquid NK 10-0-10	2.00	0.200	0.000	0.166
02 Jul.	Wallco flytende	3.00	0.153	0.030	0.129
10 Jul.	Wallco flytende	3.00	0.153	0.030	0.129
Total grow-in phase			**1.605**	**0.357**	**1.226**
Experimental phase					
18 Jul.	Wallco flytende	2.50	0.128	0.025	0.108
24 Jul.	Wallco flytende	2.50	0.128	0.025	0.108
31 Jul.	Greenmaster liquid NK 10-0-10	1.20	0.120	0.000	0.100
06 Aug.	Wallco flytende	2.00	0.102	0.020	0.086
14 Aug.	Wallco flytende	2.00	0.102	0.020	0.086
20 Aug.	Greenmaster liquid NK 10-0-10	1.00	0.100	0.000	0.083
29 Aug.	Wallco flytende	2.00	0.102	0.020	0.086
13 Sep.	Greenmaster liquid NK 10-0-10	1.00	0.100	0.000	0.083
25 Sep.	Wallco flytende	1.00	0.051	0.010	0.043
08 Oct.	Arena Crystal	0.20	0.038	0.004	0.030
23 Oct.	Wallco flytende	0.70	0.036	0.007	0.030
08 Nov.	Wallco flytende	0.70	0.036	0.007	0.030
Total experimental phase			**1.041**	**0.138**	**0.872**

During the experimental phase 15 July – 15 Nov. the green was verticut once (18 Sep.) and topdressed 6 times with a total of 2.5 mm sand. Topdressing was carried out at least one week before determination of clipping weight.

The green was irrigated frequently during grown-in in late May and June. During the experimental phase, 5 mm of irrigation water was given after each input of fertilizer or topdressing and otherwise 20 mm, i.e. to 80 % of field capacity, each time the soil water content was down to 9 % (v/v) as measured with a TDR instrument with 20 cm long probes. In addition to this irrigation, the green was also syringed with 2 mm of water on warm days in late July. The total amount of irrigation water given during the experimental period was c. 250 mm.

From 14 Aug. 18 Oct. the trial area was subjected to 23 passages with a friction wear drum with golf spikes. This amount of wear corresponded to 7500 rounds of golf.

4.1.2.2 Implementation of protocol

Primo MAXX® was applied six times at two week intervals using the same equipment and application volume (250 L ha^{-1}) as in the fairway trial (see previous chapter). Details about application dates, weather conditions at application and actual application rates are given in Table 12. Deviations from the target rate were always less than 10 %.

Table 12. Application dates, weather conditions at application and actual application rates at all spraying events for the green trial at Landvik.

Appli-cation date	Time of day (hours)	Weather conditions at application			Treatment number / application rate (mL Primo MAXX® per ha)					
		Air temp °C	Rel. humi-dity, %	Wind speed m s^{-1}	2 (target 200)	3 (target 400)	4 (target 800)	5 (target 200)	6 (target 400)	7 (target 800)
16 Jul.	08-10	20.5	58	2.1	205	409	819	196	392	819
30 Jul.	08-09	18.4	83	1.2	188	409	802	205	409	819
13 Aug.	07-09	17.0	55	1.2	205	406	791	200	401	810
27 Aug.	07-09	13.2	97	0.0	198	409	790	203	403	815
11 Sep.	07-09	13.4	99	0.2	196	407	793	201	404	812
24 Sep.	07-09	10.5	63	0.7	197	395	793	203	396	790
Mean					198	406	798	201	401	811

4.1.2.3 Registrations in the field

Registrations were performed in the central 1.0 x 1.5 m plot area that received full coverage of Primo MAXX® and followed the same protocol as in the fairway trial except that clippings were collected and weighed at two week instead of four week interval. An additional registration in the green trial was golf ball roll distance every second week using a short stimpmeter modified for research plots (Gaussion et al. 1995). Measurements were taken in two directions 24-30 hours after mowing.

By the end of the growing season, on 12 Nov. root depth was measured using a root sampler, 30 cm long and 56 mm in diameter. One core was extracted per plot, and the length of the intact hanging cylinder taken as an indication of root depth.

4.1.2.4 Determination of carbohydrates and freezing tolerance

On 14 Nov. one core sample, 56 mm in diameter and 3 cm deep, for analyses of water soluble carbohydrates (WSC) and one core sample, 100 mm diameter and 5-7 cm deep, for determination of freezing tolerance (LT_{50}) were taken from each of the unsprayed plots and the plots that had received the old and new formulation of Primo MAXX® at rates 0.4 and 0.8 L ha^{-1} (treatments 1, 3, 4, 6 and 7). The samples were placed in a freezing chamber at -2 °C for four days in darkness to ensure optimal hardening status of the plant material (Tronsmo et al. 2013).

After thawing at 4 °C for two days, the samples to be analyzed for WSC were dried at 60 °C for 48 hours. Bentgrass crowns were separated from sand and cut 0.5 cm above and 0.5 cm below the apex before analysis for glucose, fructose, sucrose and fructans in the Animal

Photo 9. Tiller groups in plastic tray filled with moist sand. The tiller groups were completely covered with sand before transfer to the freezing chamber. Photo: Trond O. Pettersen.

Nutrition Laboratory, Swedish University of Agricultural Sciences according to the protocol by Boehringer (1984). WSC were expressed as per cent of plant dry weight.

The short-term freezing tests were conducted according to Espevig et al. (2014). Briefly, 10 tiller groups, each consisting of 3-5 tillers, were washed free from soil in cold water, dried between paper towels and wrapped into slightly moist paper. Roots were truncated to 2-3 cm. Plant material wrapped in paper towels was placed in the middle of plastic trays of 17 x 17 x 6 = 1734 cm^3, filled with slightly moist sand and kept at 4°C until the start of the freezing treatments (Photo 9). The trays were then placed in the middle of a programmable freezing chamber. After the temperature had been lowered from 2 °C to -2 °C at a rate of 2 °C h^{-1}, the plants were kept at -2 °C overnight to ensure ice nucleation. Then, the temperature was lowered from -2 °C to -12 °C at a rate of 2 °C h^{-1} and from -12 °C to -36 °C at a rate of 3 °C h^{-1}. Plants were removed from the freezer at -21, -24, -27, -30, -33 and -36 °C and allowed to thaw for 4 °C overnight. These predetermined test temperatures were based on expected freezing tolerance.

After thawing, the tiller groups were planted into nursery trays filled with standard potting compost (Photo 10). Separated, non-frozen plants were included to ensure that damage was not due to separation of the tiller groups. The survival of the plants was recorded as 'dead' or 'alive' after 3-wk regrowth in a growth chamber at 18 °C (day) and 12 °C (night) and 16-h photoperiod with an average PPDF of 144 µmol m^{-2} s^{-1} (Photo 11). Freezing tolerance was calculated as the lethal temperature for 50 % of the tiller groups (LT_{50}), using the logistic distribution PROC PROBIT (SAS Institute 2002).

Photo 10. Potting of tiller groups in nursery trays. Photo: Trond O. Pettersen.

Photo 11 . Assessment of survival after regrowth in growing chamber. Photo: Tatsiana Espevig

4.1.3 Finland

4.1.3.1 Experimental site and maintenance

All greens at Loimijoki GC suffered severe winter damage during the winter 2012/2013 because of ice encasement. The trial was located on a practice green which also suffered nearly total damage. The practice green was originally established with creeping bentgrass. It was reseeded with velvet bentgrass (*Agrostis canina*) eight times from early May to the end of July 2013. Sand dressing was carried out in May, June and September. The condition of the green improved during the summer and reached a good level in August and early September. Botanical assessment by the end of the trial on 1 Oct. showed 50-60 % annual bluegrass and 40-50 % *Agrostis* sp.

Except for weighing of clippings, the green was mowed to 3 mm height every day with a John Deere 2500A triplex mower. The green was fertilized weekly with an ammonium sulphate & urea mixture (50 % of each). The total nitrogen application during the growing season was 290 kg N ha^{-1}. In addition 1200 kg ha^{-1} ordinary horticultural lime was applied.

Photo 12. Experimental green Loimijoki on 26 June 2013, shortly after the first experimental treatment. Photo: Oiva Niemeläinen.

4.1.3.2 Implementation of protocol

The first application of Primo MAXX® was carried out on 21 June when the turf was considered sufficiently uniform for experimentation (Photo 12). Over the next 15 weeks, applications were conducted a total of seven times using the same equipment as in the fairway trial at the same site. Weather conditions at each spraying event are given in Table 13. The size of the treatment plots was 3.0 m x 2.0 m.

Table 13. Spraying dates and weather conditions in the green trial at Loimijoki Golf in 2013.

	A	B	C	D	E	F	G
Application Date:	21/6/2013	4/7/2013	17/7/2013	2/8/2013	16/8/2013	29/8/2013	12/9/2013
Time of Day:	9:10	9:40	9:20	9:50	9:30	9:10	8:50
Application Method:	SPRAY	SPRAY	SPRAY	SPRAY	SPRAY	SPRAY	SPRAY
Application Placement:	BROFOL	BROFOL	BROFOL	BROFOL	BROFOL	BROFOL	BROFOL
Applied By:	PR,LR,JV	PR,JV,AM	ME,JV,AM	VR,JKo,LR	AM,JV,LR	AM,JV,LR	AM,ME,LR
Air Temperature, Unit:	15.8 °C	19.2 °C C	17.3 °C	17.6 °C	16.1 °C	12.1 °C	11.7 °C
% Relative Humidity:	74	59	58	76	77	82	95
Wind Velocity, Unit:	1 MPS	0.5 MPS	2 MPS	0 MPS	0.4 MPS	0 MPS	0 MPS
Dew Presence (Y/N):	yes	yes	no	no	yes	yes	yes
Soil Temperature, Unit:	15.1 °C	17.6 °C	17.1 °C	17.7 °C	14.6 °C	14.9 °C	14.7 °C
Soil Moisture:	DRY	DRY	DRY	DAMP	WET	DAMP	DAMP
% Cloud Cover:	30	30	5	70	40	40	100

4.1.3.3 Registrations

Registrations were the same as in the fairway trial on the same site except that clipping yields were determined every two weeks. As in the fairway trial, turf heights and clipping yields were expressed in absolute terms as it could be ascertained how many days had elapsed since the last mowing.

4.2 Results

4.2.1 Norway

4.2.1.1 Turfgrass overall appearance

On 22 July, i.e. six days after the first application, the unsprayed control plots and plots receiving the highest rates of Primo MAXX® had, in turn, the highest and lowest scores for turfgrass overall appearance (Fig. 11). This tendency was also observed on 29 July, but it changed on 5 Aug. when the unsprayed control plots were surpassed by plots receiving the lowest rate of either formulation of Primo MAXX®. During the next weeks, difference were not significant until 16 September after which all treatments sprayed with Primo MAXX® started to be ranked significantly above the untreated control, with 0.4 L ha^{-1} on the very top.

4.2.1.2 Turfgrass color intensity

Differences in turf color intensity during the growing season were mostly inconsistent except in the late fall when plots sprayed with Primo MAXX® had a more freshly green color than unsprayed control plots. During the first part of the experimental period, it is noteworthy that plots receiving the highest rate of the new formulation mostly had a lower scores on day no 13 than on day no 6 after last application, while it was the other way round for the two lower rates of both formulations and even for the highest rate of the old formulation. The difference in color intensity between the old and new formulation on 29 July (13 days after the first application of Primo MAXX®) is shown in Photo 13.

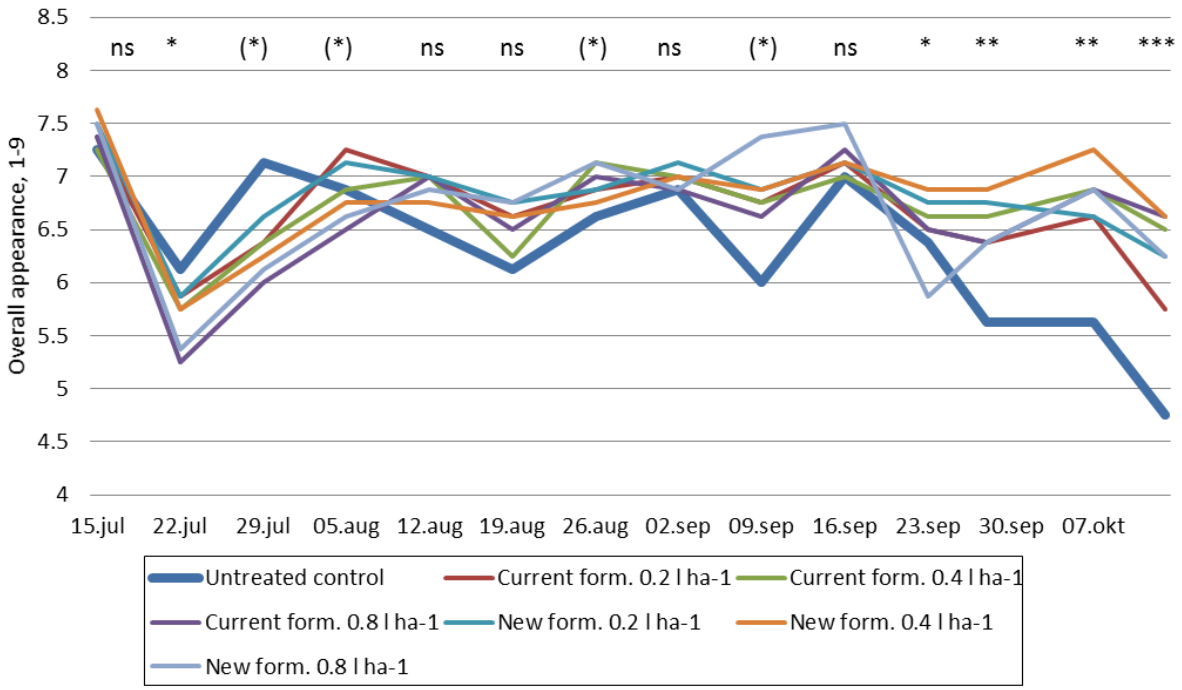


Figure 11. Overall appearance (1-9, 9 is best) during the experimental period in the green trial at Bioforsk Landvik. Significance levels as in Fig. 1.

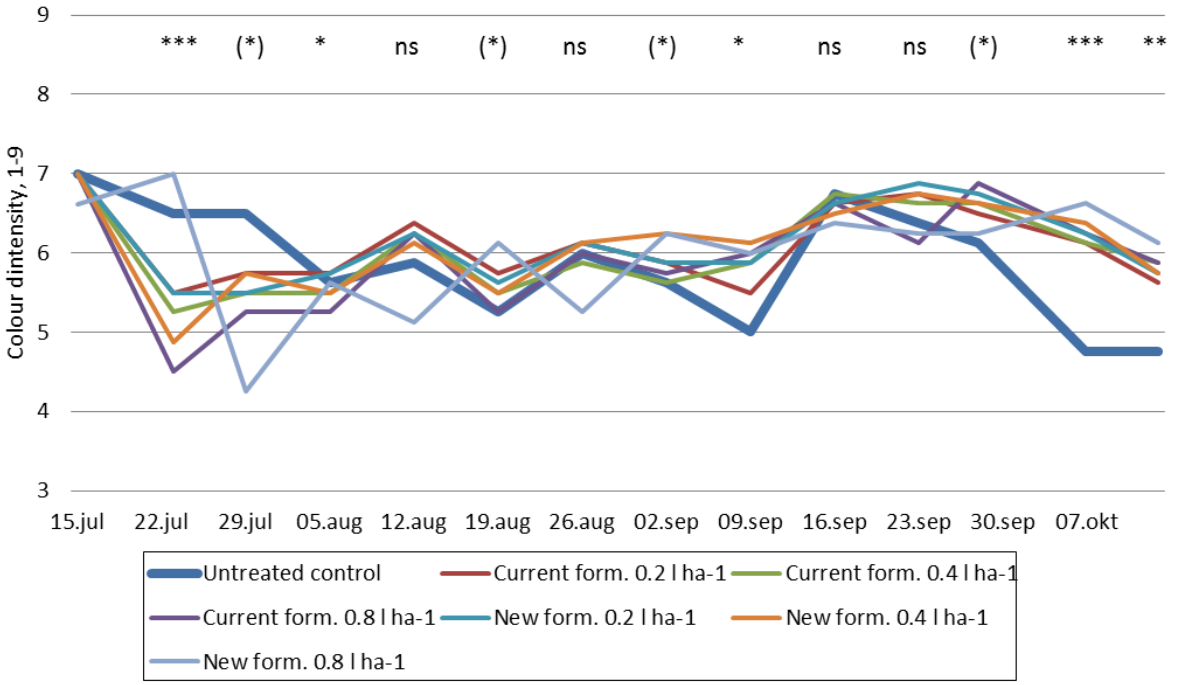


Figure 12. Turfgrass color intensity (1-9, 9 is most freshly green) during the experimental period in the green trial at Bioforsk Landvik. Significance levels as in Fig. 1.

Photo 13: Difference in greenness / color intensity of plots that had received 0.8 l ha^{-1} of either the old formulation (left) or the new formulation (right). Treatment plots were marked with red dots and registration plots with blue dots. Photo taken on 29 July 2013 by Trygve S. Aamlid.

4.2.1.3 Turfgrass darkness

Differences in turfgrass darkness were significant except for one observation. Unsprayed control plots had lighter color than plots sprayed with 0.2 or 0.4 L ha^{-1}, which, in turn, were lighter than plots sprayed with 0.8 L ha^{-1} (Fig. 13).

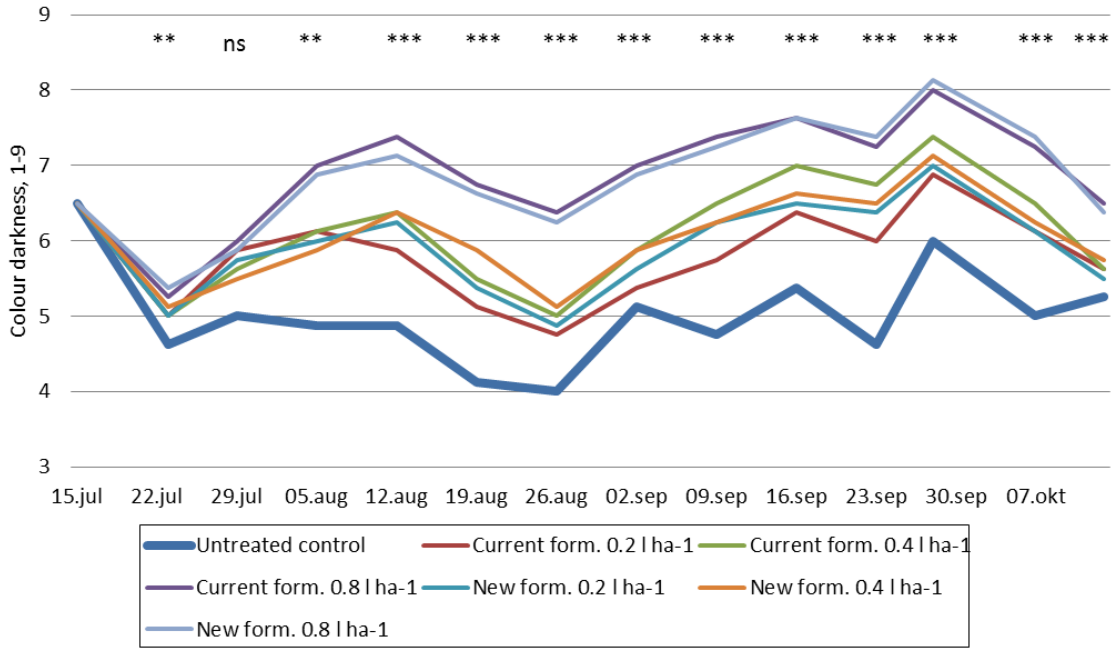


Figure 13. Turfgrass darkness (1-9, 9 is darkest turf) during the experimental period in the green trial at Bioforsk Landvik. Significance levels as in Fig. 1.

4.2.1.4 Ball roll

Green speed 24 hours after mowing mostly showed significant differences with the shortest and longest ball roll on unsprayed control plots and plots receiving the highest rate of Primo MAXX®, respectively (Fig. 14).

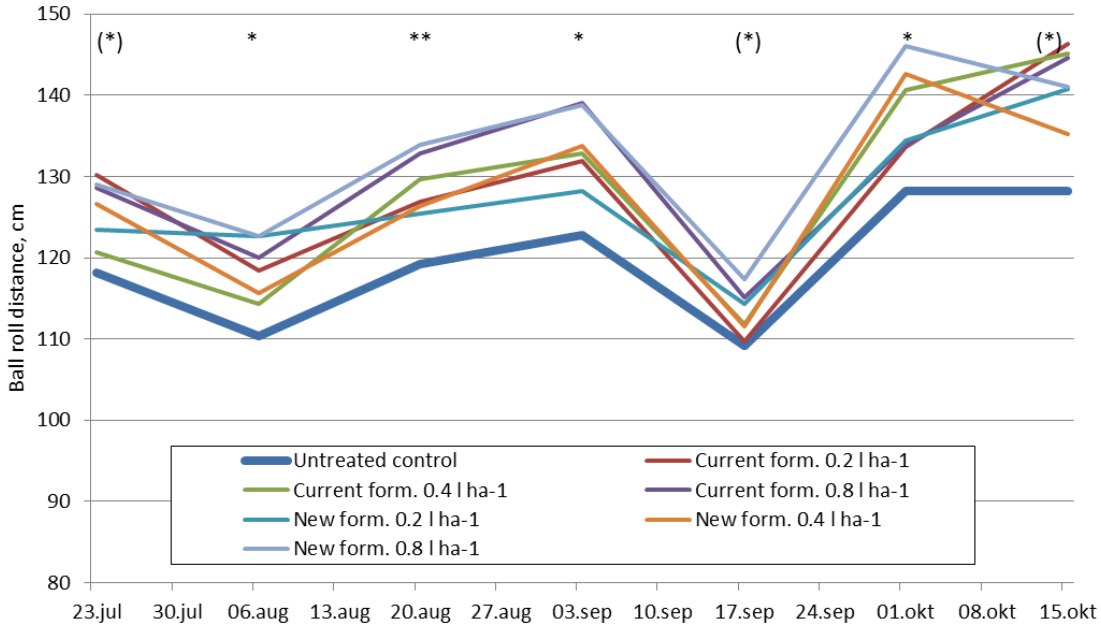


Figure 14. Ball roll distance as measured with a short (1/2 length) stimpmeter during the experimental period in the green trial at Bioforsk Landvik. Significance levels as in Fig. 1.

4.2.1.5 Turfgrass height growth

Turfgrass height growth peaked in early August and followed a steady decline after that (Fig. 15). Differences in height growth mostly reflected the rates of Primo MAXX®, with minor effect of the two formulations.

4.2.1.6 Clipping yields

Clipping yields were highest on unsprayed control plots and lowest on plots sprayed with 0.8 L ha^{-1} of Primo MAXX® (Fig. 16).

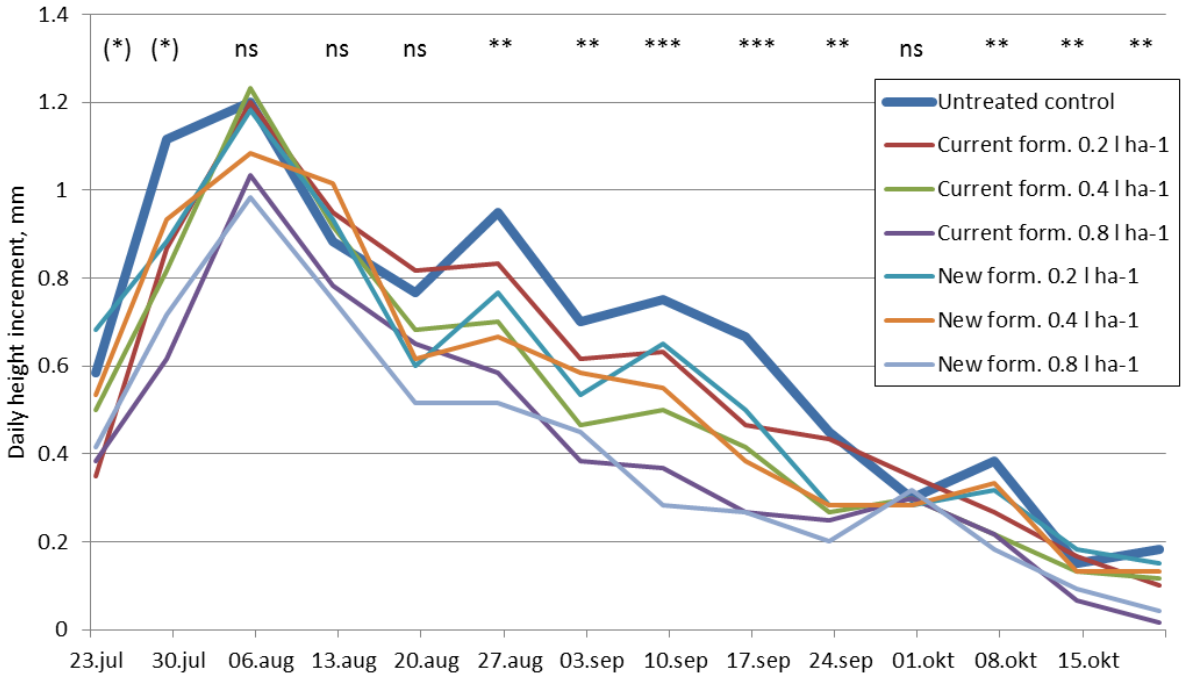


Figure 15. Height increment, mm day^{-1}, during the experimental period in the green trial at Bioforsk Landvik. Significance levels as in Fig. 1.

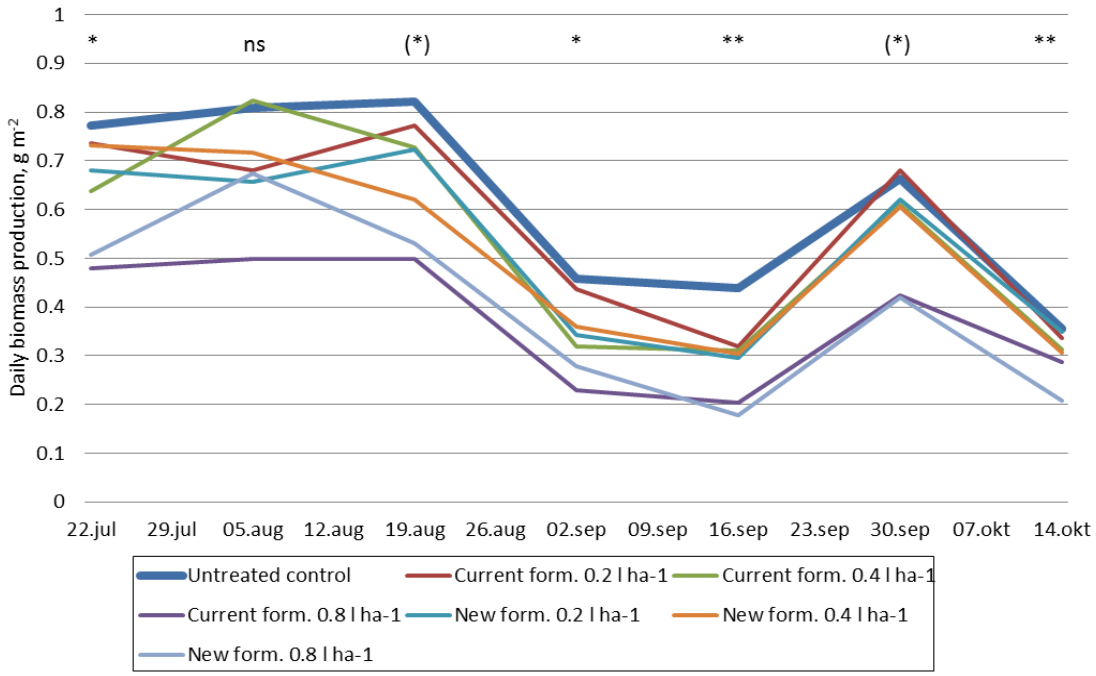


Figure 16. Dry matter production in clippings (g DM m^{-2} d^{-1}) during the experimental period in the green trial at Bioforsk Landvik. Significance levels as in Fig. 1.

4.2.1.7 Contrasts

Differences among treatments were mostly due to the contrast 'No Primo Primo MAXX®, vs. Primo MAXX®', but for most characters there was also an effect of increasing rates (Table 14). While the differences between 0.2 and 0.4 L ha^{-1} were mostly small, the turf became notably darker, golf ball roll distance increased, and daily height increments and clipping yield decreased significantly as the application rate was doubled from 0.4 to 0.8 L ha^{-1}. The mean values for the two formulations were, never significantly different, and there was also no significant interaction 'Formulation x rate'.

Table 14. Results of contrast analysis of turfgrass overall apperance, turfgrass color intensity, turfgrass color darkness, ball roll distance, daily height increment and daily dry weight production of turfgrass clippings in green trial at Landvik in 2013. Mean of all observations. Significance levels as in Fig. 1.

	Turfgrass overall appearance (1-9)	Turf colour intensity (1-9)	Turfgrass colour darkness (1-9)	Ball roll distance cm	Daily height increment mm d^{-1}	Turf-grass clippings g m^{-2} d^{-1}
Contrast 1: No Primo MAXX® vs. Primo MAXX®						
No Primo MAXX®	6.28	5.78	4.89	119.4	0.86	0.62
Primo MAXX®	6.66	5.95	6.25	128.9	0.72	0.50
Sign.	**	(*)	***	***	***	*
Contrast 2: Old vs. new formulation						
Primo MAXX®	6.62	5.94	6.25	128.9	0.72	0.51
Primo MAXX®NG	6.76	5.97	6.26	129.0	0.72	0.48
Sign.	ns	ns	ns	ns	ns	ns
Contrast 3: Application rate						
0.2 L ha^{-1}	6.69	6.04	5.83	127.6	0.79	0.55
0.4 L ha^{-1}	6.70	5.99	6.06	127.6	0.74	0.56
0.8 L ha^{-1}	6.59	5.84	6.88	131.6	0.63	0.39
Sign.	ns	(*)	***	**	***	**
Contrast 4: Interaction formulation x rate						
Sign.	ns	ns	ns	ns	ns	ns
Overall ANOVA	(*)	ns	***	***	***	*

4.2.1.8 Turfgrass root depth

On average for two formulations, the root depth on 12 Nov. 2013 was 24.2 cm on unsprayed control plots and 23.4 cm, 25.2 cm and 23.2 cm on plots sprayed with 0.2, 0.4 and 0.8 L ha^{-1}, respectively (data not shown in table or figure) None of these differences were statistically significant (data not shown). As for formulations there was almost a tendency (*P*=0.11) to deeper rots on plots receiving the old formulation than on plots receiving the new formulation of Primo MAXX® (mean values 24.7 and 23.1 cm, respectively.

4.2.1.9 Water soluble carbohydrates and freezing tolerance

On average for two formulations, the concentration of WSC in turfgrass crowns before winter was numerically higher on plots sprayed with 0.4 L ha^{-1} (14.8 % of DM) than on unsprayed plots (13.6 %) or plots sprayed with 0.8 L ha^{-1} (14.0 %). Correspondingly, the mean value for LT_{50} was also numerically lower on plots sprayed with 0.4 L ha^{-1} (-31.1 °C) than on unsprayed plots (-30.1 °C) and plots sprayed with 0.8 L ha^{-1} (-30.2 °C). On average for two rates, the old and new formulation of Primo MAXX® gave practically the same content of WSC (14.3 vs. 14.5 % of DM), but LT_{50} was slightly lower for the old than for the new formulation (-31.2 vs -30.1 °C). However, none of these differences in WSC or freezing tolerance were statistically significant. On average for treatments, the WSC in turfgrass crowns was composed of 4 % glucose, 6 % fructose, 31 % sucrose and 59 % fructans (data not shown in table or figure).

4.2.2 Finland

4.2.2.1 Turfgrass overall appearance

As a result of winter damage and several reseeding operations, turfgrass overall appearance in the green trial at Loimijoki increased until late August (Fig. 17). The intermediate rates of either formulation produced good results, but the differences among treatments were not significant except for one assessment in September when the quality of unsprayed plots was inferior to that of sprayed plots.

4.2.2.2 Turfgrass color intensity

After the start of the trial in late June there were three assessments when the unsprayed control treatment tended to give better color than most treatments sprayed with Primo MAXX® (Fig. 18). In August and September this trend was mostly reversed, and on two dates in September the unsprayed control was significantly behind the other treatments.

4.2.2.3 Turfgrass height

Turfgrass height growth showed considerable variation, but there were peaks in late June and early August (Fig. 19). Unsprayed control plots mostly gained more height than the plots sprayed with the highest rates of Primo MAXX®, but differences were not significant.

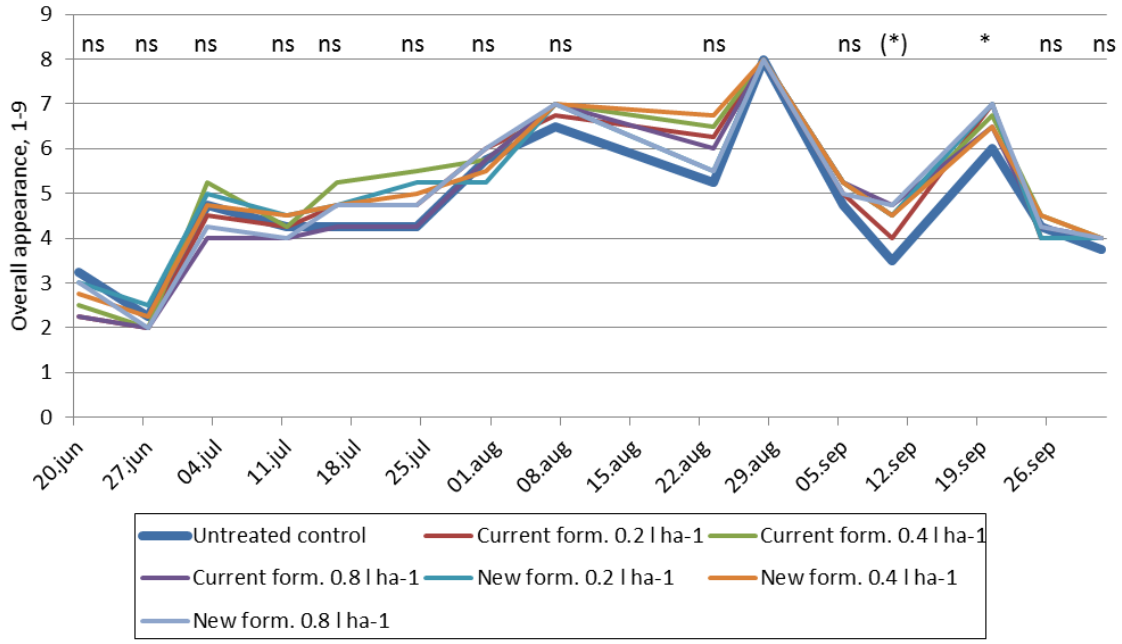


Figure 17. Overall appearance (1-9, 9 is best) during the experimental period in the green trial at Loimijoki GC. Significance levels as in Fig. 1

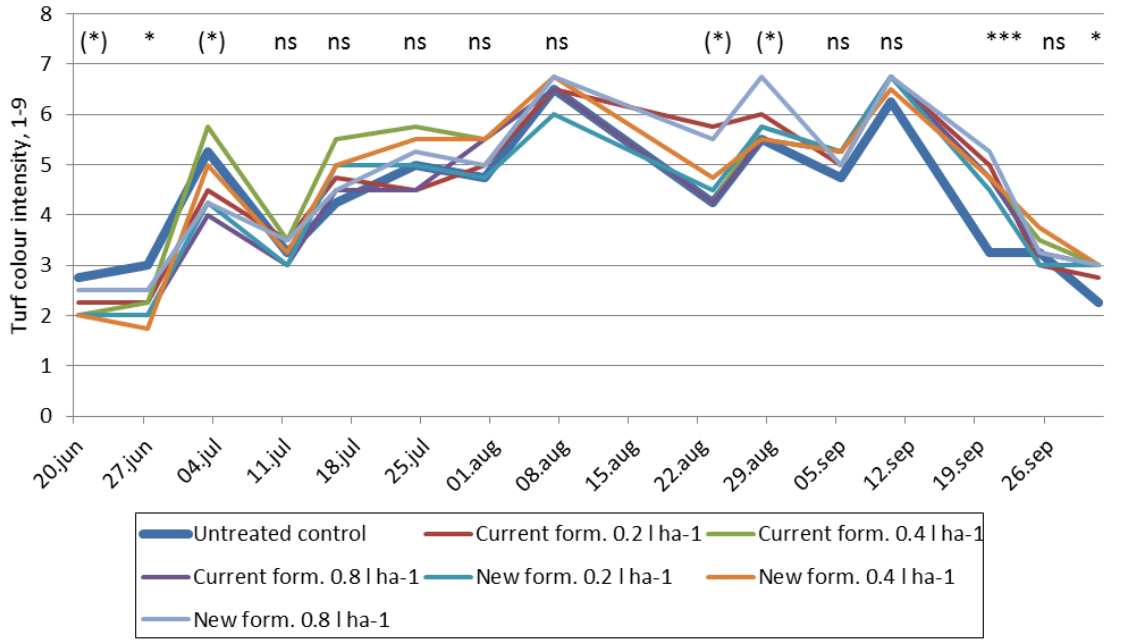


Figure 18. Turfgrass color intensity (1-9, 9 is most intensely green) during the experimental period in the green trial at Loimijoki GC. Significance levels as in Fig. 1

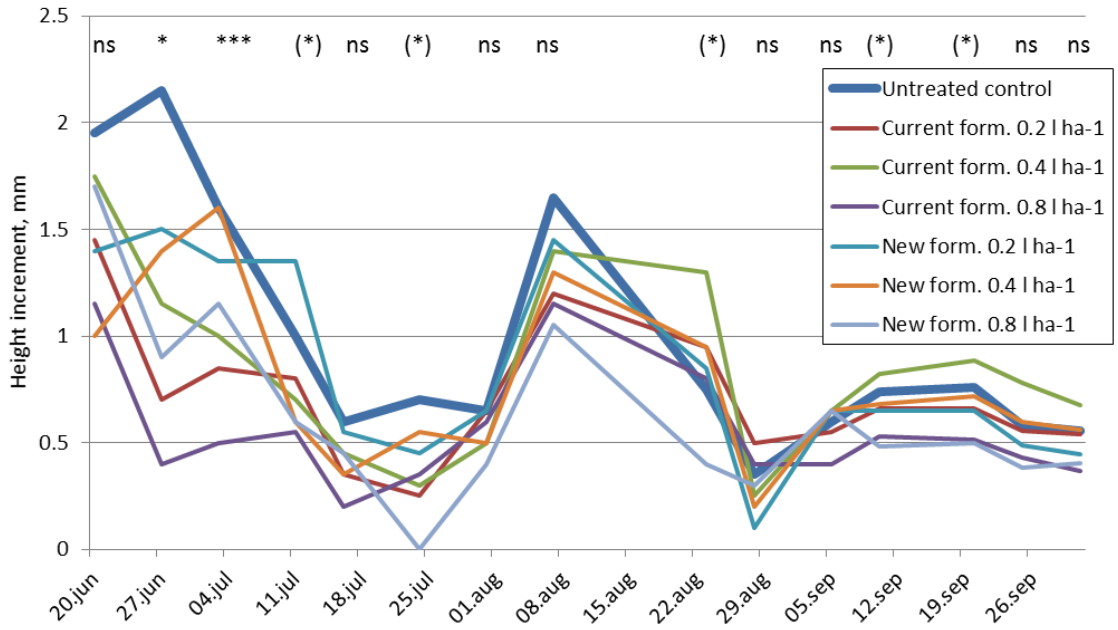


Figure 19. Height increment (mm) since last mowing, measured throughout the growing period in the green trial at Loimijoki GC. Significance levels as in Fig. 1.

4.2.2.4 Clipping yields

Except at the first observation in early July, the highest clipping yields were produced on unsprayed control plots and the lowest yields on plots sprayed with the highest rate of Primo MAXX®, new formulation (Fig. 20). Differences were either significant or there were clear tendencies. The high absolute figures for clipping yields indicate that more than one day had elapes since the last mowing.

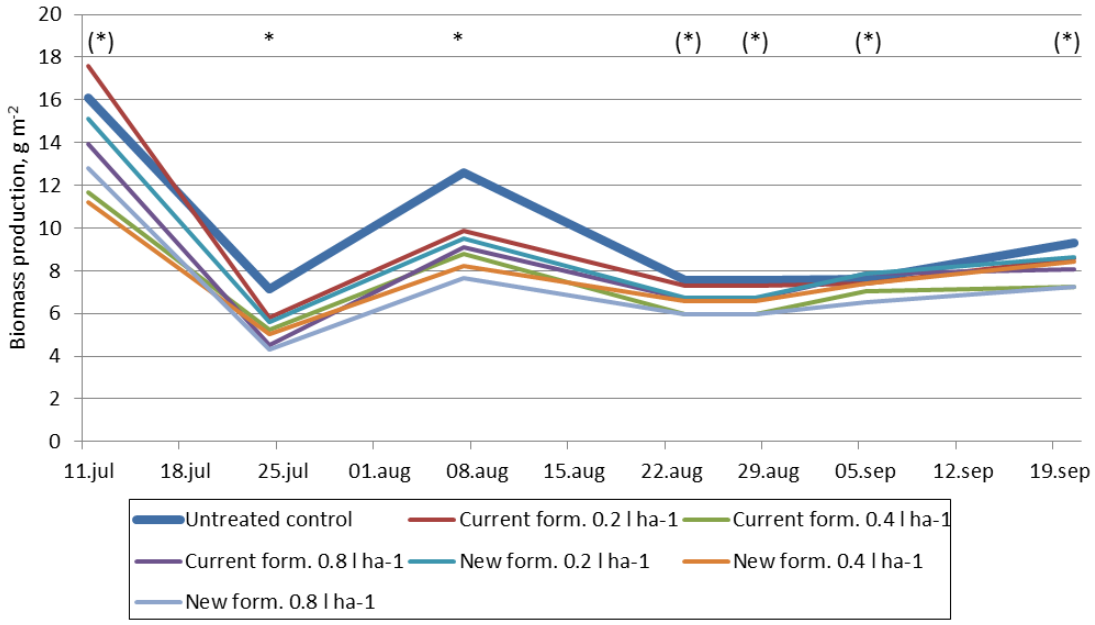


Figure 20. Biomass production since last mowing (g DM m^{-2}) sampled throughout the growing period in green trial at Loimijoki GC. Significance levels as in Fig. 1.

4.2.2.5 Contrasts

As in the other trials, most of the variation in overall appearance, color intensity, height growth and clipping yield could be ascribed to the contrast 'No Primo MAXX vs. Primo MAXX' (Table 15). For daily height growth and clipping yields there were, however, differences also among the different rates. Turfgrass height growth showed an increasing response up to the highest rate, 0.8 L ha^{-1}, but for clipping yields there was no reduction as the rate was doubled from 0.2 to 0.4 L ha^{-1}.

Differences between the two formulations were not significant, but for clipping yield there was almost a tendency (*P*=0.12) lower values with the new than with the old formulation.

Table 15. Results of contrast analysis on turfgrass overall apperance, turfgrass color intensity, height increase of turf since last mowing and dry weight of turfgrass clippings since last mowing in green trial at Loimijoki GC in 2013. Mean of all observations. Significance levels as in Fig. 1.

	Turfgrass overall appearance (1-9)	Turfgrass color intensity (1-9)	Height increment mm	Turfgrass clippings g DM m^{-2}
Contrast 1: No Primo MAXX® vs. Primo MAXX®				
No Primo MAXX®	4.82	4.39	0.98	9.68
Primo MAXX®	5.15	4.67	0.72	8.02
Sign.	(*)	*	*	***
Contrast 2: Old vs. new formulation				
Primo MAXX®	5.14	4.67	0.70	8.22
Primo MAXX® NG	5.17	4.67	0.75	7.81
Sign.	ns	ns	ns	ns
Contrast 3: Application rate				
0.2 L ha^{-1}	5.13	4.57	0.77	8.86
0.4 L ha^{-1}	5.28	4.79	0.81	7.53
0.8 L ha^{-1}	5.04	4.64	0.59	7.66
Sign.	ns	ns	(*)	***
Contrast 4: Interaction formulation x rate				
Sign.	ns	ns	ns	ns
Overall ANOVA	ns	(*)	(*)	***

5. Discussion and recommendations

5.1 Old versus new formulation

Despite a 5 % lower concentration of the active ingredient trinexapac-ethyl, some of the results presented in this report suggest a slightly stronger effect of the new than of the old formulation of Primo MAXX® on turfgrass visual characters and clipping yields. This is visualized in Photo 13 and also reflected by the fact that, on average for two sites and three rates, the old and new formulation reduced clipping yields in the green trials by 16 and 21 %, respectively, compared with the unsprayed control treatment. In the fairway trial at Landvik, there were, however, also indications that the stronger and perhaps more persistent effect of the new formulation will only occur at higher application rates, while it in fact may be the other way round in at the lower and more commonly used application rates (Fig. 6). Since not only tiller elongation, but also root elongation is mediated by bioactive gibberellins (Taiz & Zeiger 2010) the fact that creeping bentgrass in the green trial at Landvik tended to get deeper roots after treatment with the old than with the new formulation, may also be taken as an indication of a stronger suppression of gibberellins with the new formulation. However, since none of these differences could be verified statistically, **our overall conclusion is that the two formulations had comparable efficacy and safety on the turf, and that there, from an agronomic perspective, is no objection against replacing the old formulation with the new one on the commercial market.**

5.2 Optimal rates on fairways

On average for two trials, two formulations, and relative figures for both turf height and clipping yields, application of 1.2, 1.6, 2.0 and 2.4 L ha^{-1} at two week intervals resulted in 36, 37, 42 and 46 % growth reduction compared with the unsprayed control treatment. While these reductions are mostly stronger than those reported from earlier trials on fairways in Norway and Finland (Aamlid et al. 2008, 2009), the relatively small differences between them confirm that the contrast 'No Primo MAXX® vs. Primo MAXX®' accounted for most of the variation in the fairway trials. It appears that the Swedish greenkeepers who have started using Primo MAXX® on fairways realize this as the rates reported from practice are mostly lower than the current label's recommendation for 1.6 L ha^{-1} (Swedish Golf federation Questionnaire 2012; see Introduction chapter). On the other hand, it also shows the need for turf managers more experience with the growth regulator.

One of the arguments against applying too high rates of Prim MAXX® on fairways is that weeds will become more apparent and interfere with ball lie and thus playing quality. During the dry period in July and early August, this was quite conspicuous for white clover in one of the fairway blocks at Landvik (Photo 6). Higher rates of Primo MAXX® also resulted in more red thread disease which, however, is more of a cosmetic problem.

As in earlier projects (Aamlid et al. 2008, 2009, 2011) reductions in turfgrass overall appearance due to use of Primo MAXX® were more apparent on the red fescue/colonial bentgrass dominated fairway at Landvik than Kentucky-bluegrass dominated fairway at Loimijoki. However, since the quality reductions were most apparent during the dry period in July and early August 2013, this may not only be due to species composition, but also to the heavier soil and more frequent irrigation in the Finnish trial. For practice, the implication is that lower rates of Primo MAXX® should be applied on fescue/bentgrass fairways (typically links courses) than on parkland courses with more fertile and drought-

tolerant soils and a turf cover dominated by Kentucky bluegrass and perhaps even perennial ryegrass (*Lolium perenne*).

Most fairways on Nordic golf courses are mowed three times per week. A realistic goal for Primo MAXX® on Nordic golf courses would then be to reduce the frequency by 1/3, i.e. to two mowings per week. Using the 1/3 rule, i.e. mowing a mixed stand of Kentucky bluegrass and perennial ryegrass at 12 mm every time turf height had reached 18 mm, Stier (2004) reported from Wisconsin that 0.8 L ha^{-1} every second week reduced the number of mowings per season by 23 %, i.e. not quite fulfilling the goal. In contrast, **the 36 % reduction achieved by applications of 1.2 L ha^{-1} every second week in the present trials may well be considered a standard rate for application of Primo MAXX® and Primo MAXX® NG on Nordic fairways. As already mentioned, the rate will have to be adjusted depending on turfgrass species, soil fertility and how vigorously the turf is growing. To avoid severe loss in turfgrass overall appearance, the first seasonal application should always be reduced by 50 %, and the need for mixing small amount of nitrogen in to the spraying liquid is just as high for the new as for the old formulation.**

5.3 Optimal rates on putting greens

Most of the differences among treatments in the green trials could be ascribed to the contrast 'No Primo MAXX® vs. Primo MAXX®', but there were also significant effects on most response variables of doubling the rate from today's Swedish recommendation of 0.4 L ha^{-1} to 0.8 L ha^{-1}. On the other hand there was little difference between 0.2 and 0.4 L ha^{-1}. This in agreement with one of our earlier trials on a creeping bentgrass green showing the contrast 'No Primo MAXX® vs. Primo MAXX®' to be the main source of variation and that there was no significant differences in clipping yields between the rates 0.15, 0.30 and 0.45 L ha^{-1} sprayed at either one or two week intervals (Aamlid et al. 2009).

On average for the two green trials presented in this report and two earlier trials (Aamlid et al. 2009, 2012), application of Primo MAXX® at 0.2-0.4 L ha^{-1} at one to two week interval can be expected to result in 15-20 % reduction in turfgrass height growth and clipping yields on Nordic putting greens. Even without tank-mixing with fertilizer, such a light and frequent application regime is not likely to result in severe reduction in turfgrass overall appearance or color intensity. On the contrary, in both of the present trials, visual scores tended to be higher scores on plots sprayed with 0.2-0.4 L ha^{-1} than on unsprayed control plots and plots sprayed with 0.8 L ha^{-1}.

Our data suggest that a doubling of the application rate from 0.4 to 0.8 L ha^{-1} is likely to reduce turfgrass height growth and clipping yields from 80-85 % to about 70 % of that on untreated greens. At the same time, the green speed is likely to increase not only by 6-7 %, but by 10 % compared to untreated greens. Such a doubling of the application rate is, however, likely to result in not only lower scores for visual quality parameters, but also less freezing tolerance and a lower concentration of reserve carbohydrates in turfgrass crowns compared with 0.4 L ha^{-1}. **For use on greens, we therefore recommend that both Primo MAXX® and Primo MAXX® NG be labelled with a standard rate of 0.2- 0.4 L ha^{-1}, the lowest rate to be used in combination with weekly applications.** As on fairways, we also suggest that the product label include a warning that the first seasonal application of Primo MAXX® should not exceed 0.2 L ha^{-1}. These recommendations are not only based on Nordic experience, but they are also in agreement American studies showing more consistent quality on creeping bentgrass greens receiving 0.14 L ha^{-1} every week than on greens receiving 0.26 or 0.42 L ha^{-1} at two or three week intervals, respectively (McCullogh et al. 2005).

6. References

Aamlid, T.S., O. Niemelainen, M. Rannikko, T. Haugen, S. Junnila, T. Espevig & Å. Susort 2008. Evaluation of the plant growth regulator Primo MAXX® (trinexapac-ethyl) on Nordic golf courses. Bioforsk Report 3(1): 1-30.

Aamlid, T.S., O. Niemelainen, M. Rannikko, O. Noteng, M. Waldner, T. Haugen, S. Junnila, T. Pettersen & T. Espevig 2009. Evaluation of the plant growth regulator Primo MAXX® (trinexapac-ethyl) on Nordic golf courses. Results from the second evaluation year 2008 and recommendations. Bioforsk Report 4 (4): 1-28.

Aamlid, T.S., O. Niemelainen, M. Barth, T. Pettersen, P. Persson, M. Jalli & S. Junnila 2011. Impact of Primo MAXX® and fungicides on turfgrass quality and winter survival on Nordic golf greens, July 2010 – June 2011. Bioforsk rapport 6(70): 1-30.

Aamlid, T.S., T. Pettersen, M. Niskanen & L. Wiik 2012. Impact of Primo MAXX® and fungicides on turfgrass winter survival on Nordic golf courses. Results from the second experimental year, July 2011 – May 2012. Bioforsk Fokus 7(77): 1-30.

Boehringer, S.A. 1984. Methods of enzymatic food analysis using single reagents. Boehringer Mannheim GmbH, Mannheim, Germany, 79 p.

Espevig, T., M. Höglind & T. S. Aamlid. 2014. Dehardening resistance of six turfgrasses used on golf greens. Environmental and Experimental Botany (Accepted, in press).

Gaussoin, R., Nus, J. & Leuthold, L. 1995. A modifield stimpmeter for small-plot turfgrass research. HortScience 30: 547-548.

McCullough, P.E., H. Liu & L.B. McCarty 2005. Trinexapac-ethyl application regimens influence creeping bentgrass putting green performance. HortScience 40: 2167-2169.

SAS Institute 2002. SAS/STAT user's guide. Version 9.1. Cary, NC, USA.

Stier, J. 2004. Plant growth regulation and mowing reduction. The Grass Roots 33 (1): 5 and 7.

Taiz, L. & E. Zeiger 2010. Plant physiology. Fifth Edition. Sinauer Associates. 782 pp.

Tronsmo A., T. Espevig, L. Hjeljord & T.S. Aamlid 2013. Evaluation of freezing tolerance and susceptibility to *Microdochium nivale* of velvet bentgrass cultivars in controlled environments. International Turfgrass Society Research Journal 12: 69-80.

Tørresen, K.S. 2007. Kvalitetshåndbok for gjennomføring av godkjenningsforsøk med plantevernmidler. Utgave VI. (In Norwegian).