NIBIO OPPDRAGSRAPPORT | NIBIO COMMISSIONED REPORT **Archive: 17/01893**

SUSTAINABLE FAIRWAY MANAGEMENT:

EVALUATION OF SYNGENTA'S SOIL SURFACTANT 'QUALIBRA' AND PLANT GROWTH REGULATOR 'PRIMO MAXX II' ON IRRIGATED AND UNIRRIGATED TURFGRASS MAINTAINED AS GOLF COURSE FAIRWAY

Trygve S. Aamlid & Trond Pettersen, NIBIO

TRYGVE S. AAMLID[1] AND TROND PETTERSEN[2]

[1]NIBIO, Department for Urban Greening and Environmental Engineering,
[2]NIBIO Landvik Research Center, Grimstad, Norway

TITTEL/TITLE

SUSTAINABLE FAIRWAY MANAGEMENT: EVALUATION OF SYNGENTA'S SOIL SURFACTANT 'QUALIBRA' AND PLANT GROWTH REGULATOR 'PRIMO MAXX II' ON IRRIGATED AND UNIRRIGATED TURFGRASS MAINTAINED AS GOLF COURSE FAIRWAY

FORFATTER(E)/AUTHOR(S)

Trygve S. Aamlid and Trond Pettersen

Dato/Date:	Tilgjengelighet/Availability:	Prosjekt nr./Project	Saksnr./Archive No.:
29.05.2017	Confidential	190062	17/01893
Rapport nr. /Report No.:		Antall sider/ Number of pages: 30	Antall vedlegg/ Number of appendices: 0
Oppdragsgiver/Employer: STERF / Syngenta Lawn & Garden		Kontaktperson/Contact person: Maria Strandberg / Marcela Munoz	

Stikkord/Keywords:	Fagområde/Field of work:
Norsk: fairway, golf, spillekvalitet, vanning, vekstregulering, trineksapak-etyl vætemiddel	Division for miljø og naturressurser Avdeling for grøntanlegg og miljøteknologi
English: fairway, golf, plant growth regulator, playing quality, soil surfactant, trinexapac-ethyl	Division for Environment and Natural Resources, Department for Urban Greening and Environmental Engineering

GODKJENT / APPROVED, 29 May 2017

Avdelingsleder / Department leader

Prosjektleder / Project leader

CONTENT

SUMMARY

Syngenta's soil surfactant Qualibra and plant growth regulator Primo Maxx II were evaluated from 15 April 2016 to 15 April 2017 on 9 months old fairway turf dominated by *Festuca rubra* and *Poa pratensis* on a sandy soil at the Norwegian Institute of Economy's Turfgrass Research Centre Landvik, Grimstad Norway (58°34'N, 8°52'E, 12 m a.s.l.). Qualibra was applied at four week intervals at a rate of 20 L in 800 L water per ha, and Primo Maxx II was applied at three week intervals at a rate of 1.0 L in 400 L water per ha, both in factorial combination with either no irrigation or irrigation to field capacity once a week. Registrations included soil water content at 0-12 cm depth and turfgrass height twice a week (before each mowing to 15 mm); turfgrass quality, tiller density, chlorophyll concentration, golf ball lie and clipping yield at three week intervals; thatch thickness and potential soil water repellency by the end of the growing season 2016 and turfgrass diseases and color in spring 2017.

The growing season 2016 had higher-than-normal precipitation from April to August, hence, the turf was exposed to drought only for short periods in May and June. However, even during these periods, Qualibra did not result in an increased or more uniform soil water content or better turfgrass quality. In contrast, the soil water content tended to be lower on Qualibra –treated plots, thus suggesting that this surfactant act more like a draining penetrant than as a water-retaining polymer. As a results, the total amount of water needed for weekly replenishment of field capacity was slightly higher on Qualibra-treated than on untreated plots. Without irrigation there were also indications of reduced growth rates and less uniform color on Qualibra-treated plots. It is, however, possible that benefits of Qualibra would have been more appareant under prolonged drought situations as the water drop penetration test showed less potential soil water repellency than in the untreated control. On the positive side, application of Qulalibra in 2016 also eliminated fairy rings in spring 2017.

On average for all observation during the growing season, Primo Maxx II reduced turfgrass growth in height and clipping yields by 13 and 24 %, respectively. A stronger reduction in clipping yields than in height growth suggests that the reduction in vertical growth was not compensated by more tillering; this was also confirmed by the visual observations of tiller density and by the fact that the golf ball was sitting significantly closer to the soil surface on Primo-treated than on untreated plots. In contrast, the thatch layer after one season with reguar application of Primo Maxx II was significantly thicker than on untreated plots, perhaps suggesting that the turf allocatated more of its resourecs to rhizomes and roots in the uppermost soil layer than to the tillers. Most likely as result of less above-ground growth, the soil water content was also slightly higher and more uniform after application of Primo Maxx II to unirrigated plots, although this was not reflected in more uniform cholophyll content or better turfgrass quality.

Given the relatively high rainfall on 2016, we conclude that neither Qualibra nor Primo Maxx II showed any obvious potential to contribute to more sustainable fairway management without reducing turfgrass visual quality or playing quality. We therefore think that the experiment ought be repeated with with better control of water inputs, preferabily under a mobile rainout shelter.

INTRODUCTION

Reduced inputs of energy and labor for turfgrass irrigation, mowing are fertilizing are important for more sustainable golf course management. Among the different types of turf on a golf course, the fairways usually make up the largest area that is mowed several times a week. Economic and environmental savings in fairway management is therefore important for the golf industry.

Among Syngenta products, the newly formulated plant growth regulator Primo Maxx II (trinexapac-ethyl) and the soil surfactant Qualibra have special prospects in reducing maintenance costs and improving turf quality. An earlier Scandinavian project showed Primo Maxx II to be equally effective as as the old formulation in reducing turfgrass growth. On average for height increments and clipping yields, the growth reduction of Primo Maxx II was 36-37 % when applied to fairways at 1.2 L/ha at two week intervals (Vågen et al. 2013).

Earlier Scandinavian trial with Qualibra showed improved turf quality when applied on sand-based greens in combination with a very restrictive irrigation regime but not when applied in combination with excessive irrigation (Aamlid et al. 2016). The effect of Qualibra on fairways has not been evaluated earlier under Nordic climate conditions.

The objective of this project was to quantify the the effect of Primo Maxx II and/or Qualibra on turfgrass quality, playability, water use, growth rate and nitrogen uptake on a soil-based fairway.

MATERIAL AND METHODS

Experimental site: Soil and botanical compostion

The experiment was laid out in April 2016 on a fairway established on a sandy loam soil (94% sand, 4% silt, 2% clay, 4.5 % OM) at NIBIO Landvik Turfgrass Research Center, Grimstad, South East Norway (58°34'N, 8°52'E, 12 m a.s.l.).

Soil samples taken on 31 May 2016 (Photo 1) showed pH (H2O) = 6.3, P-AL = 390 mg/kg dry soil, K-AL = 62 mg/kg dry soil, Mg-AL = 94 mg/kg dry soil and Ca-AL = 860 mg/kg dry soil.

Photo 1. Soil sampling for chemical analyses on 31 May 2016. Photo: Trygve S. Aamlid

Soil cylinders taken to 16 cm depth one hour after abundant irrigation in April 2016 and dried for 48 h at 103°C showed that the soil contained 25 vol% plant available water at field capacity (FC). This was also confirmed by water retention curves (pF) developed earlier from the same soil type (Ekeberg & Njøs 1970). Assuming 16 cm effective root depth, 25 vol% corresponds to a total reservoir of 40 mm plant available water at FC.

The average length of intact hanging cylinders extracted from the fairway with a 5 cm diameter core at the start of the trial in April 2016 was 12 cm. We assumed that fine roots would develop for another 4 cm, giving an effective root depth of 16 cm.

The fairway had been seeded in July 2015 using a standard Scandinavian fairway seed mixture containing 55 % red fescue (20 % *Festuca rubra* spp. *commutata* 'Raisa', 15 % *Festuca rubra* spp. *commutata* 'Barswing' and 20 % *Festuca rubra* spp. *rubra* 'Frigg') and 45 % Kentucky bluegrass (*Poa pratensis*; 25 % 'Miracle', 10 % 'Yvette' and 10 % 'Limousine'). Tiller countings in 19 mm diameter core samples taken in April 2016 showed 52 % red fescue (43,632 tillers /m2) 42 % Kentucky bluegrass (34,207 tillers/m2) and 6 % annual bluegrass (*Poa annua*) (c. 4,654 tillers/m2).

Experimental treatments and design

The experiment was laid out according to a randomized complete block design with four replicates and three experimental factors:

Factor 1: Irrigation

A. No irrigation (except for 4 mm to all plots after application of fertilizer or Qualibra).
B. Irrigation to FC = 25 % SWC once a week.

Factor 2: Soil surfactant

1. Untreated
2. Qualibra 20 l/ha every four weeks

Factor 3: Plant growth regulator

i. Untreated
ii. Primo MAXX II, 1.0 l/ha every third week

Each treatment plot was 3 m x 3 m, and the entire experimental area 24 m x 12 m. Plots were irrigated accurately using an irrigation boom with flat fan nozzles spaced 5 cm apart and a gauge showing the volume of water applied (Photo 2). At each irrigation event, the volume of water was determined individually for each plot based on measurements of SWC. Five measurements per plot were taken with a TDR instrument (Field Scout 300, Spectrum Technologies, Aurora, IL, USA) with 12 cm long probes and the mean value calculated. The amount of water (mm) in the irrigated treatment was calculated as:

Photo 2. Irrigation boom used for plot irrigation. Photo: Trygve S. Aamlid

40 – (mean SWC x 1.6) (because of an anticipated 16 cm root depth).

For application of Qualibra and Primo Maxx II, we used an experimental backpack plot sprayer (Oxford / LTI) working at 150-200 kPa pressure (Photo 3). The 2.0 m wide spraying boom had five nozzles (Teejet 11004) spaced 50 cm apart. The boom provided full coverage of the central 2.0 m in each plot which was later used for all observations. The application volume for Primo Maxx II was 400 l/ha. When spraying Qualibra, we went over each plot twice, thus giving an application volume of 800 l/ha. The actual application rates were recorded by weighing the tank of the sprayer before and after spraying. Tables 1 and 2 show that the deviations from the target values were always less then 10 %, i.e. within the limits set by the Norwegian Standard for Good Experimental Practice.

Photo 3. Experimental plot backpack sprayer used for application of Qualibra and Primo Maxx. Photo: Trygve S. Aamlid

Table 1 and 2 also show weather conditions at application. Primo Maxx II is supposed to be taken up by the leaves, and Table 2 shows that there was always a minimum of 5 h from application to rainfall. Since the effect of Qualibra is supposed to be enhanced by high soil moisture contents and/or rainfall immediately before or after application, the protocol prescribed 4 mm irrigation to the entire experiment (including the unirrigated treatments) after application. Despite this, Table 1 suggests that the unirrigated plots may have bee too dry for optimal effect of Qualibra at the first two applications on 20 April and 18 May. The third application on 15 June was made after a dry period, but rainfall had started 3-4 hours before application, and there was ample rainfall during the following 48 h.

Table 1. Relevant weather data, soil water content and realized application rates at the six applications of Qualibra.

Date	Time of day, hours	At application			Rainfall last 48 h before applica-tion, mm	Soil water content on unirrigated plots at application, vol %	Rainfall + irrigation first 48 h after applica-tion, mm	Qualibra, actual application rate, l/ha (target: 20 l/ha) [1]	
		Air temp., °C	Relative humidity, %	Wind speed m/s				Block 1 & 2	Block 3 & 4
20 Apr.	09.15-09.45	11.4	35	1.5	2	not measured	4	18.0	19.7
18 May	17.30-18.15	12.6	77	2.8	0	3.3	4	20.3	20.9
15 June.	13.00-14.00	14.9	92	1.2	10	0.7 (on 14 June)	22	19.5	20.0
12 July	12.45-13.30	20.8	63	3.0	4	10.5	22	19.8	20.1
10 Aug.	08.30-09.00	13.3	61	0.6	7	18.2 (on 9 Aug.)	4	18.9	19.1
6 Sep.	12.30- 13.00	17.4	86	.1	0	13.6	4	19.3	20.0

[1]Actual application rates were reported separately for block 1&2 and block 3&4 because of the limited volume of the spraying tank.

Table 2. Relevant weather data and realized application rate at the eight applications of Primo Maxx II.

Date	Time of day, hours	At application			Hours before first rain after application	Actual application rate, Primo Maxx II (target: 1.00 l/ha)
		Air temp °C	Relative humidity, %	Wind speed m/s		
4 May	09.00-09.10	11.8	53	2.1	>24	1.01
24 May	15.45-16.10	15.5	70	1.5	>24	0.97
14 June	14.00-14.15	18.2	53	1.8	5	0.96
7 July	09.00-09.30	15.9	46	2.1	6	1.02
26 July	17.00-17.30	20.4	61	3.1	12	0.99
17 Aug.	08.00-08.30	19	65	0.7	>24	0.96
7 Sep.	11.45-12.15	23.1	65	3.1	>24	0.97
30 Sep.	08.00-08.30	9.7	73	2.6	6	0.95

Maintenance common to all treatments

Mowing

The turf was mowed to 15 mm every Monday and Friday using a John Deere triplex fairway mower. The first mowing in spring was on 29 April and the last mowing in fall on 7 October. Clippings were returned except on eight occasions when they were collected and used for determination of growth rate and nitrogen content.

Fertilizer inputs

Except for an initial application of the agricultural fertilizer Fullgjødsel® 12-4-18 Micro, the turf received controlled-release, coated fertilizers, mostly from Indigrow, at six week intervals (Table 3).

Table 3. Fertilizer applications.

		kg pr 100 m2						
Date	Fertilizer type	Product	N	P	K	Mg	S	Ca
08 Apr.	Fullgjødsel 12-4-18 Micro	1.0	0.118	0.040	0.176	0.016	0.095	0.020
20 Apr	Everris Proturf 18-0-7	1.0	0.180	0.000	0.058	0.018	0.140	0.021
31 May	Impact 26-5-8	0.7	0.180	0.000	0.058	0.018	0.140	0.021
12 July	Impact 26-5-8	0.7	0.180	0.000	0.058	0.018	0.140	0.021
23 Aug.	Impact 26-5-8	0.7	0.180	0.000	0.058	0.018	0.140	0.021
04 Oct.	Impact 16-5-16	0.7	0.118	0.040	0.176	0.016	0.095	0.020
	Total		0.956	0.080	0.584	0.104	0.750	0.124

Wear

The turf was subjected to lenient wear using a tractor-pulled golf-type wear machine with golf spikes (Photo 4) for a total of 67 passes over the season.

Photo 4. Golf-type friction wear drum used in trial. Photo: Trygve S. Aamlid

Data collection

Volumetric soil water content (SWC) was measured every Tuesday and Friday from 29 April to 4 October. Three random measuresment were made per plot and the mean value and coefficient of variation calculated, the latter as an indicator of horizontal uniformity. (On Tuesdays, the mean SWC was used to calculate the amount of irrigation water needed to replenish FC on irrigated plots).

Turf quality and tiller density were rated visually every three weeks on a scale from 1 to 9 where 9 is the highest quality and tiller density. The registrations were always performed eight or nine days after the last application of Primo Maxx II.

Turfgrass color was rated every three weeks on days with sufficient brightness using a Field Scout CM 1000 chlorophyll meter (Spectrum Technologies, Aurora, IL, USA). Five readings were taken per plot an the mean value and coefficient of variation calculated, the latter as an expression for uniformity in turfgrass color (Photo 5).

Photo 5. Measuring turfgrass color using a chorophyll meter. Photo: Trygve S. Aamlid

Per cent of plot area covered by weeds or showing symptoms of disease or localized dry spots was rated every three weeks on the same day as turf quality and tiller density.

Turfgrass ball lie (mm) was determined every three weeks using a custom-made instrument that determined the ability of the turf canopy to carry a standard golf ball above ground (Photo 6). Three measurements were made per plot and the mean value calculated.


Photo 6a,b. Custom-made instrument used to determine golf ball lie on fairways. Photo: Trygve S. Aamlid

Photo 7. Prism used for accurate measurement of turfgrass height. Photo: Trygve S. Aamlid.

Turfgrass height (mm) was measured using a John Deere prism at three random sites per plot before each mowing. These obsevations allowed the calculation of daily height increments and accumulated height growth over the season.

Clipping yield and nitrogen concentation. Clippings were collected every third Friday from 13 May to 10 Oct. always, nine days after application of Primo Maxx II. The clippings were collected from an area of 0.56 x 2.5 m using a single mower adjusted to a mowing height of 15 mm. The clippings were dried for 48 h at 60 °C and weighed. At the end of the growing season, all clippings from each individual plot were pooled and a sample sent to the IMV laboratory at the Norwegian University fo Life Sciences for determination of total nitrogen concentration.

Thatch thickness was recorded in spade samples taken from each plot on 6 September (block 1 and 2) and 12 September (block 3 and 4).

Potential soil water repellency was determined as water drop penetration time in the same spade samples. The samples were dried at room temperature for 48 hours before measuring the time for three droplets, placed at 5 mm (just below thatch layer), 15 mm and 50 mm depth to penetrate. The mean value for three drops was calculated and used in subsequent analyses.

Turfgrass diseases (per cent of plot area) and **color** (scale 1-9, 9 is most green) were rated in early spring 2017 (27 February and 20 March).

Statistical analyses

All results were subjected to analyses of variance using the SAS procedure PROC ANOVA. Treatment means were separated by the Least Significant Difference (LSD) at the 5 % probability level ($P \leq 0.05$). P-values up to 0.10 have been indicated in the tables and will be referred to as 'tendencies' or 'trends'.

Weather data

April, May, June and especially September 2016 had higher-than normal temperatures, while July and August were close to the 30 year average (Table 4). The year's maximum temperature, 27.3 °C, was recorded on 3 June (Fig. 1).

The first four months of the season had higher than normal rainfall, but September and, to a lesser extent, October were drier than the 30 year average (Table 4).

The winter 2016-2017 started early with 20 cm of snow on unfrozen soil on 5-6 November. The snow meltet after one week, and there was no snow in either December or January. The longest periods with snow cover were from 7 to 22 February and from 5 to 14 March. Table 4 shows that December, January, February and March had temperatures significantly higher than thre 30 year normal values. There was hardly any frost in the soil as the grass was covered by snow during cold spells. The winter's minimum temperature was -12.1 °C on 8 March.

Table 4. Mean monthly temperatures and monthly precipitation at Landvik weather station as compared with 30 year normal values (1961-1990).

	Mean monthly temp., °C		Precipitation, mm	
	2016/17	30 yr normal	2016/17	30 yr normal
April 2016	6.1	5.1	104	58
May 2016	12.3	10.4	97	82
June 2016	15.8	14.7	110	71
July 2016	16.4	16.2	101	92
August 2016	15.5	15.4	123	113
September 2016	15.1	11.8	37	136
October 2016	7.6	7.9	117	162
November 2016	2.7	3.2	256	143
December 2016	3.7	0.2	44	102
January 2017	1.7	-1.6	65	113
February 2017	0.4	-1.9	139	73
March 2017	3.4	1.0	118	85
Year	8.4	6.9	1311	1230
April 2017	6.5	5.1	67	58

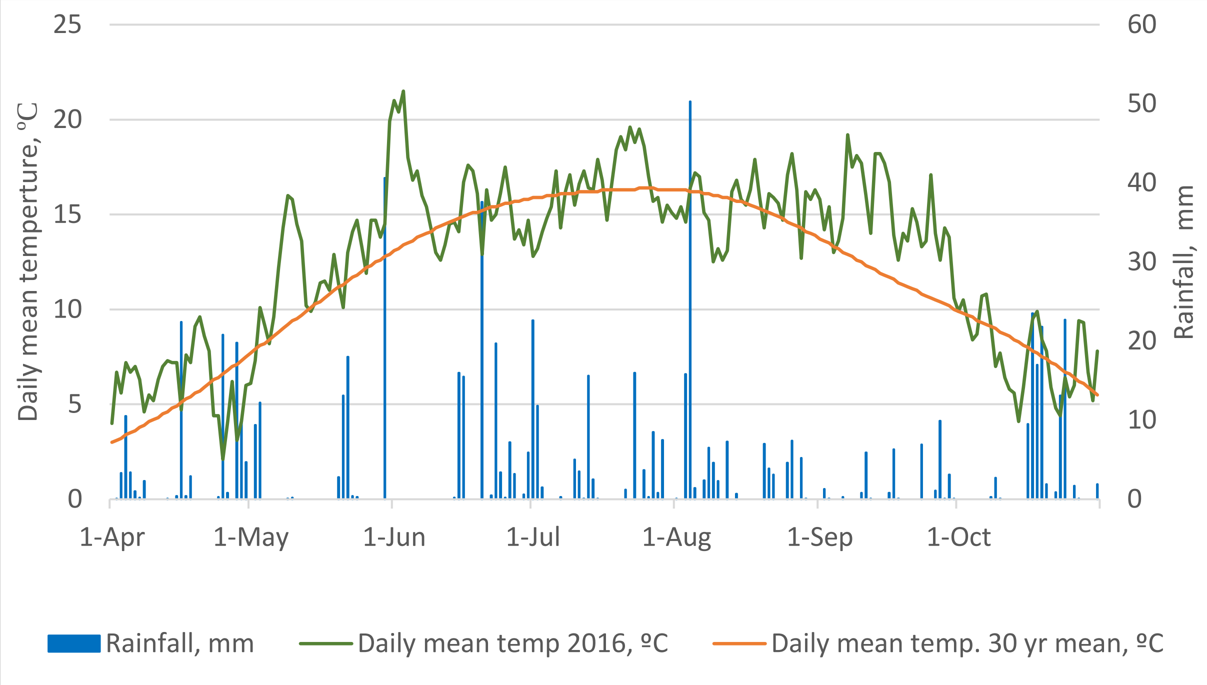


Fig. 1. Daily mean temperature and rainfall, 1 April – 1 Oct. 2016

RESULTS

Soil water content and consumption of irrigation water

At most measurements, the volumetric soil water content (SWC) at 0-12 cm depth was significantly lower on unirrigated plots than on plots irrigated to FC once a week (Fig. 2). On average for 42 observations from 6 May to 4 Oct., the SWC was 3.2 per cent units higher on irrigated plots (Table 5). Irrigation also caused a significant reduction in the horizontal variation in SWC (Table 5).

Application of Qualibra had no significant effect on SWC on average for the 42 observations (Table 5). Significant ($P \leq 0.05$) reductions in SWC due to Qualibra were observed three times, and similar tendencies ($P \leq 0.10$) another five times (out of 42 observations). The trend to lower SWC after application of Qualibra occurred regardless of irrigation or not. The lowest soil water contents were recorded on 18 May, 10 June and 14 June (Fig. 2). On these days, the SWC without and with Qualibra were 3.4 and 3.1 %, 2.6 and 2.0 % and 0.8 and 0.6 %, respectively As a result of slightly lower SWC, the total amount of water needed to replenish FC on irrigated plots was 3 % higher after treatment with Qualibra than on untreated plots (Table 5, difference not statistically significant). The horizontal variation in SWC was not affected by Qualibra (Table 5).

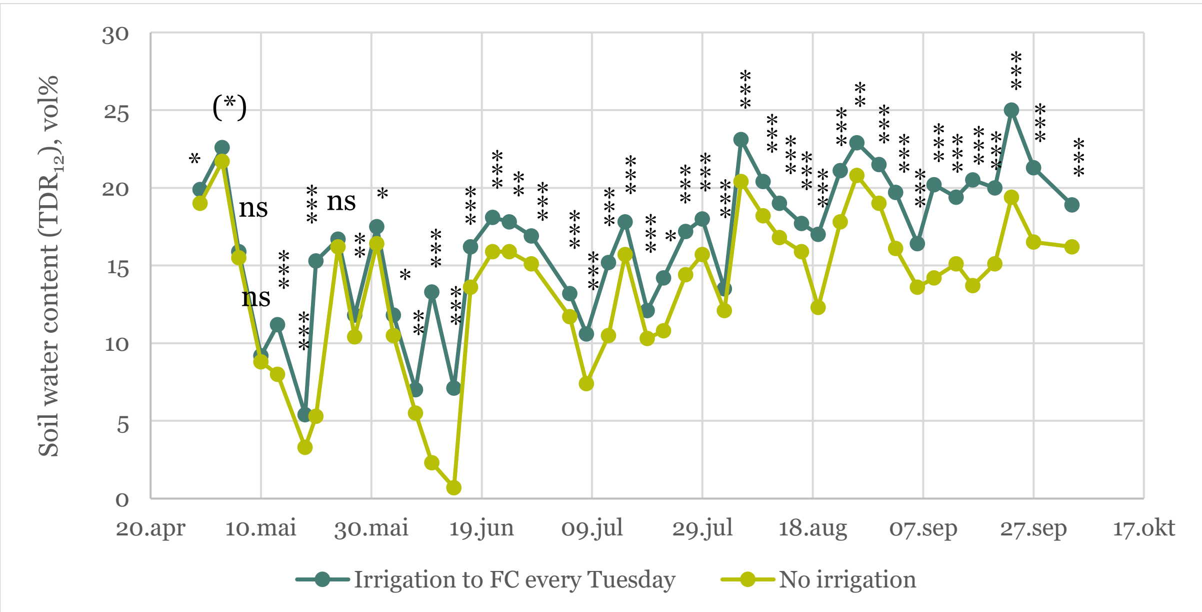


*Fig. 2. Soil water content on irrigated and unirrigated plots during the 2016 growing season. Means of treatments with and without soil surfactant and with and without plant growth regulator. The first irrigation treatment was conducted on 3 May. Significance symbols used in this and the following figures and tables: ***: P≤0.001, **:0.001<P≤0.01, *:0.01<P≤0.05, (*):0.05<P≤0.10, ns: not significant.*

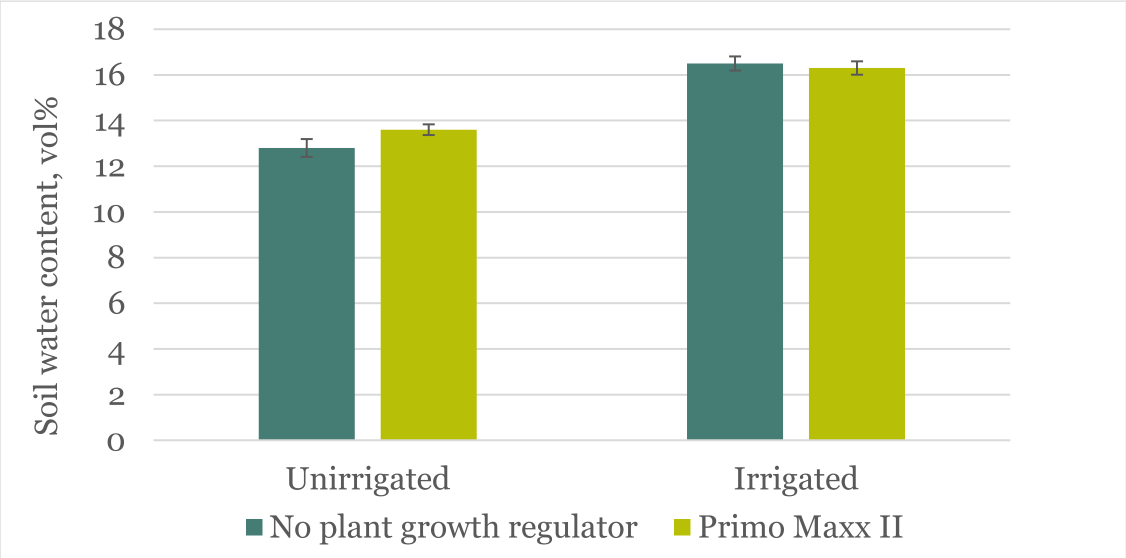
Table 5. Main effects of irrigation, soil surfactant and plant growth regulator on mean value and horizontal coefficient of variation in soil water content (three spatial readings per plot per observation date). Mean of 42 observation dates during the growing season 2016. The amount of irrigation water needed to replenish FC was calculated weekly from the SWC on individual plots.

	Soil water content (vol%)	Horizontal variation in soil water content (CV, %)	Seasonal amount of water needed for weekly replenishment of FC, mm
Irrigation			
Unirrigated	13.2	12.2	0
Irrigated to FC once a week	16.4	6.7	327
P-value	***	***	ns
Soil surfactant			
No surfactant	14.9	9.4	322*
Qualibra	14.6	9.5	332*
P-value	ns	ns	ns*
Plant Growth Regulator			
No PGR	14.6	9.9	325*
Primo Maxx II	14.9	9.1	330*
P-value	ns	ns	ns*

**Figures and analyses for irrigated plots only.*

Application of Primo Maxx II had no significant effect on the mean SWC (Table 5) or water consumption on irrigated plots (Table 5). However, at 13 out of 42 observations, there were either a significant ($P \leq 0.05$) or a trend ($P \leq 0.10$) to an interaction with irrigation, as an increase in SWC due to Primo Maxx II occurred on unirrigated but not on irrigated plots (Fig. 3a). Concomitantly, Primo Maxx II also lowered the horizontal variation in SWC on unirrigated plots (Fig. 3b).

a)



b)

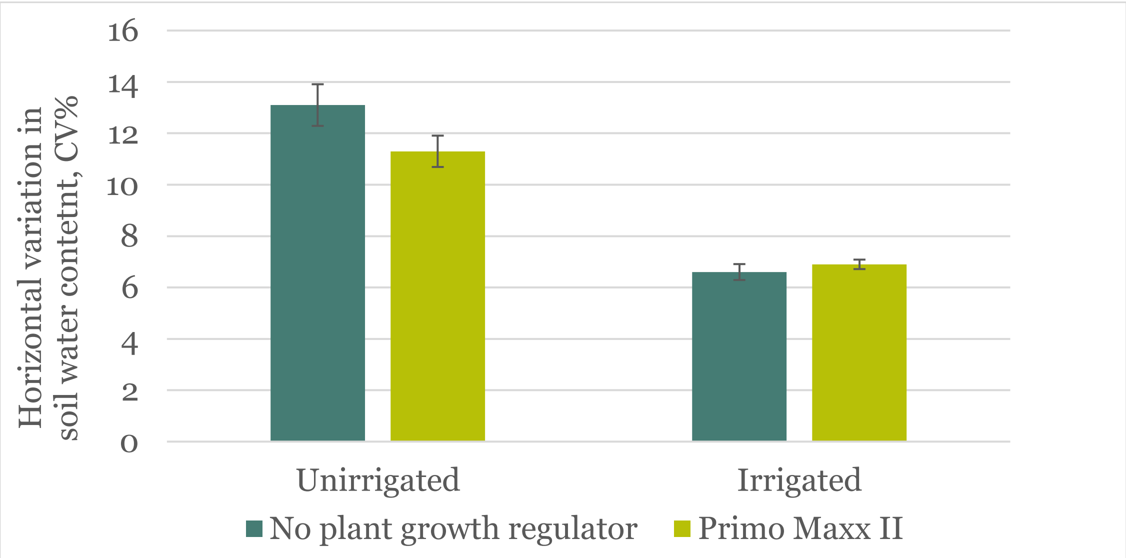


Fig. 3. a) Mean and b) horizontal variation in soil water content at 0-12 cm depth on unirrigated and irrigated plots as influenced by application of Primo Maxx II every third week. Mean of 42 observations from 6 May to 4 October 2916. P*-values for the interaction 'Irrigation x Primo Maxx II' were 0.13 and 0.07, respectively. Vertical bars indicate ±1 Standard Error (SE).*

Visual turfgrass quality, tiller density and leaf chlorophyll concentration

Turfgrass quality was, on average for eight observations from 12 May till 12 Oct., significantly higher on irrigated than on unirrigated plots (Table 6). The effect was most conspicuous during the dry period in mid June (Photo 8). Qualibra had no effect on turfgrass quality, while Primo Maxx II tended (P=0.09) to lower the quality on average for all observations. However, among individual observations, the effect of Primo Maxx II was significant only on two dates (Fig. 4).

The turfgrass tiller density was, on average for observations, significantly higher on irrigated than on unirrigated plots, but it was not influenced by either Qualibra or Primo Maxx II (Table 6). The average leaf chlorophyll concentration was not significantly affected by irrigation or surfactant, but it was higher on plots treated with Primo Maxx II than on untreated plots (Table 6). Further analyses of the data showed that this increase in leaf chlorophyll concentration mainly occurred after midsummer (data not shown, but see darker green color in Photo 9).

The coefficient of variation among the five chlorophyll readings in each plot indicated that irrigated plots were more uniform in color than unirrigated plots, and that both Qualibra and Primo Maxx II led to more color variation. While none of these main effects were statistically significant, there was a significant interaction (P=0.02) as control plots not receiving either Qulibra or Primo Maxx II were more uniform in color than plots treated with at least one of the two products (Fig. 5). The only observation at which Qualibra caused a higer color uniformity than untreated plots was on 4 May, before the treatments with Primo Maxx II had started.

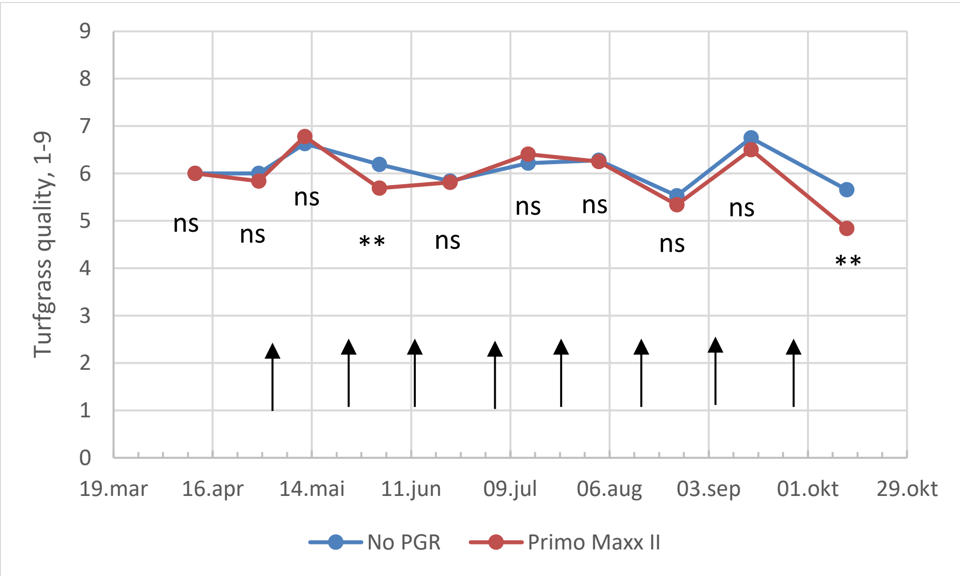


Fig. 4. Main effect of Primo Maxx II on turfgrass quality during the 2016 growing season. Arrows indicate application dates. Significance symbols as in Fig. 2.

Table 6. Main effects on irrigation, surfactant and plant growth regulator on turfgrass quality, tiller density, mean value and variation in leaf chlorophyll concentration, ball lie and encroachment with Poa annua *and broadleaved weeds. Mean of observations from 12 May to 12 Oct. 2016.*

	Turf-grass quality (1-9)	Tiller den-sity (1-9)	Chlorophyll concentration		Ball lie, mm above ground	*Poa annua*, %	Broad-leaved weeds, %
			Mean value	Variation within plots (CV, %)[1]			
Number of observations in time	8	7	5	5	8	7	2
Irrigation							
Unirrigated	5.7	5.7	242	7.4	7.6	3.0	0.2
Irrigated to FC once a week	6.4	6.3	246	6.8	7.9	3.6	0.4
P-value	***	***	ns	ns	*	(*)	*
Soil surfactant							
No surfactant	6.1	6.1	246	6.6	7.7	3.4	0.3
Qualibra	6.0	5.9	243	7.5	7.8	3.2	0.3
P-value	ns	ns	ns	(*)	ns	ns	ns
Plant Growth Regulator							
No PGR	6.1	6.1	239	6.7	8.0	4.2	0.2
Primo Maxx II	6.0	6.0	250	7.5	7.6	2.5	0.4
P-value	(*)	ns	***	ns	**	***	*

[1]*Based of five measurements within each plot on each observation date.*

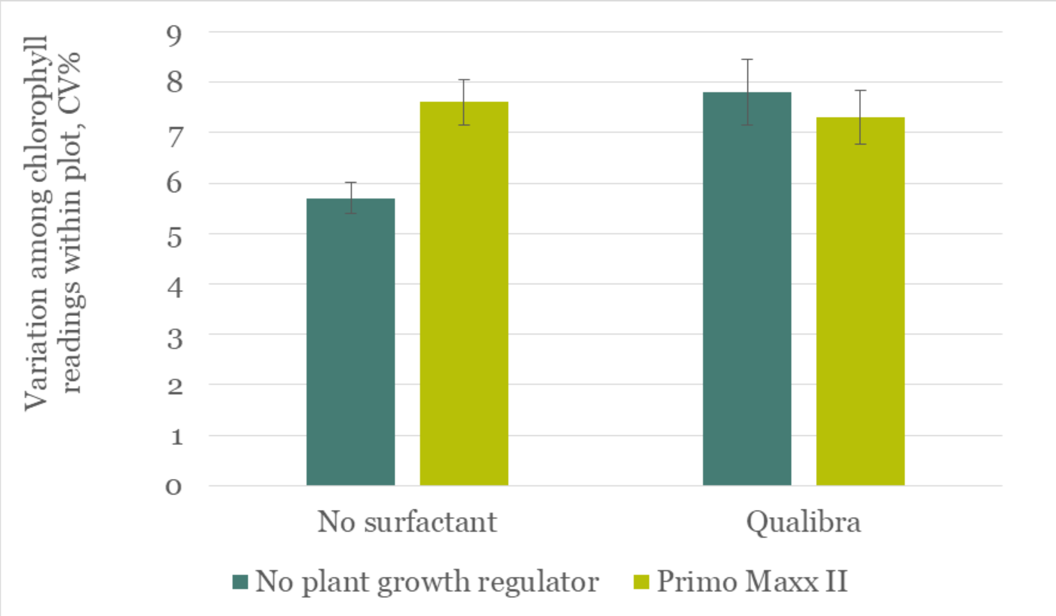


Fig. 5. Coefficient of variation among the five chlorophyll readings within plot as influenced by surfactant and plant plant growth regulator. Mean of five observation dates.

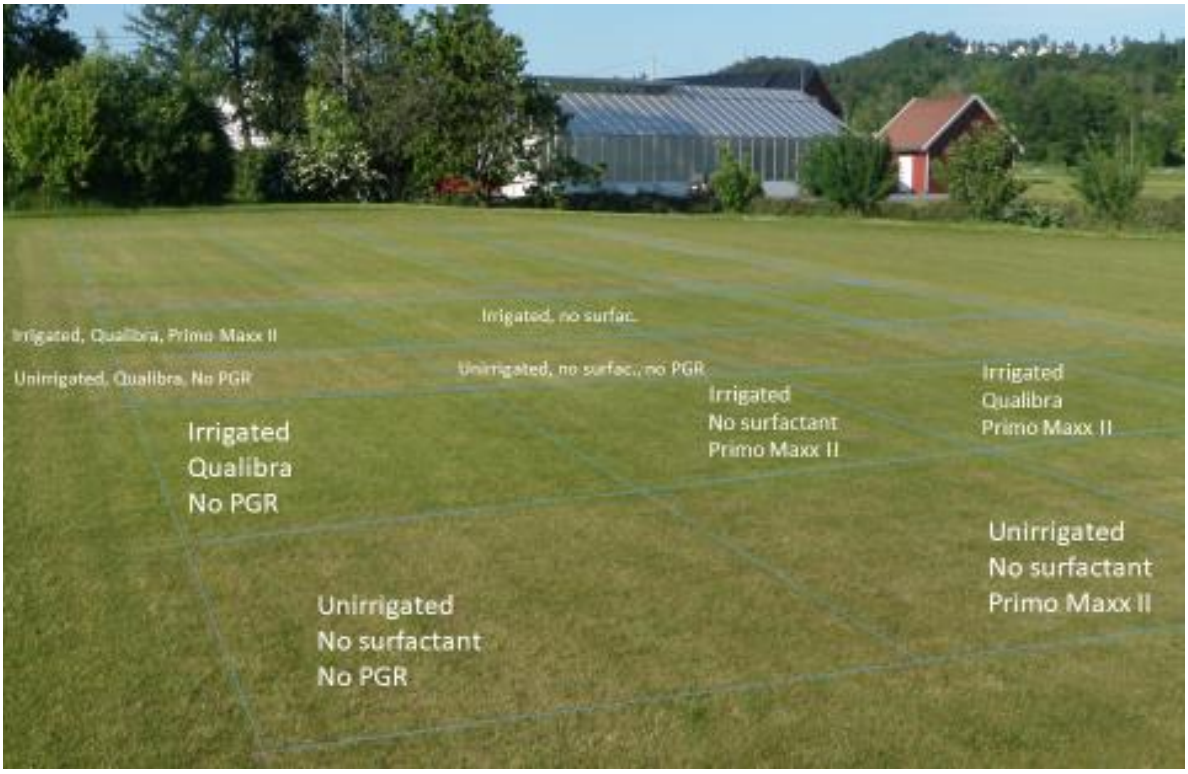


Photo 8. Irrigation caused a significant improvement in turfgrass quality and chlorophyll concentration during the dry period in mid June. The effects of Qualibra and Primo Maxx II were less visible, but Primo Maxx II tended to produce dark green patches and less uniform color than in the untreated control. Photo taken on 13 June 2016 by Trygve S. Aamlid.

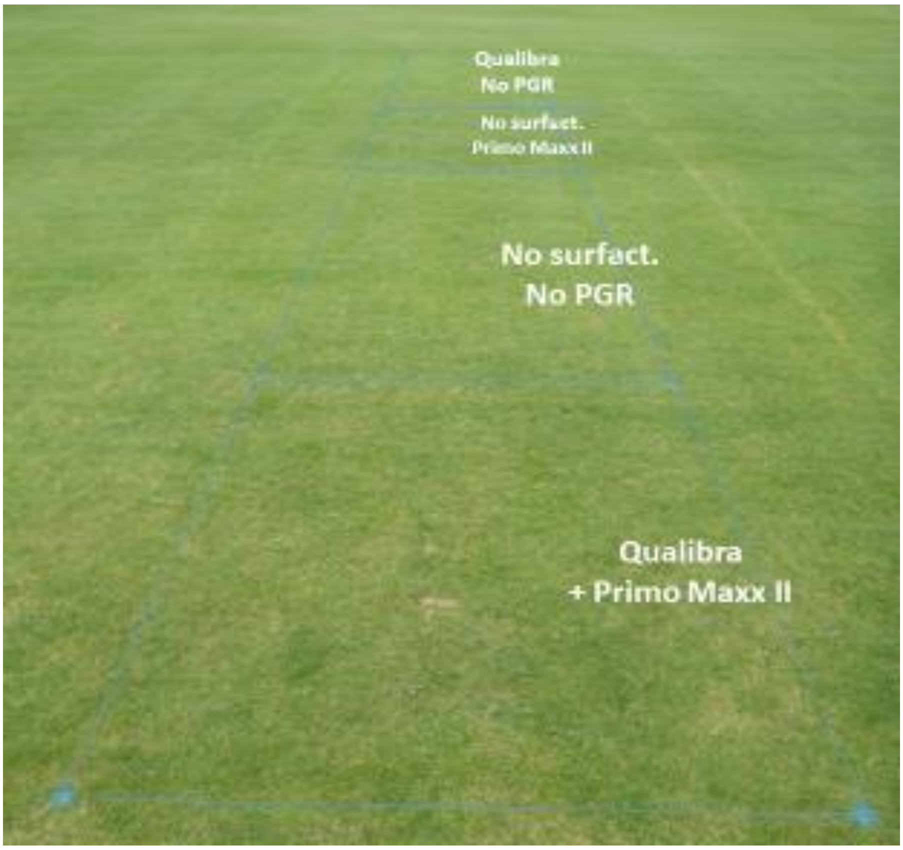


Photo 9. Primo Maxx II resulted in darker green color, notably after midsummer. These plots were all irrigated. Photo taken on 16 Sep. 2016 by Trygve S. Aamlid

Golf ball lie

Measurements of golf ball lie showed that the ball was sitting closer to the ground on unirrigated than on irrigated plots and closer to the ground on plots treated with Primo Maxx II than on untreated plots (Table 6). The effect of Qualibra and interactions were not significant.

Weed encroachment, diseases and localized dry spots

The occurrence of *Poa annua* and was higher, and the occurrence of broadleaved weeds tended (*P*=0.06) to be higher on irrigated than on unirrigated plots (Table 6). Qualibra had no effect on any of these characters. Primo Maxx II resulted in more broadleaved weeds but less *Poa annua*. While significant on all individual observation dates, the effect of Primo Maxx II on *Poa annua* was most pronounced on 12 May when this unwanted grass species was reduced from 4.1 to 1.5 % of plot area. This coincided with the main flowering season for *Poa annua* and may perhaps be due to lower seed stalks.

The only turfgrass disease observed in the trial in 2016 was red thread (*Laetisaria fuciformis*) in August and September, but its severity was not affected by any of the experimental factors (data not shown). There were also no visible dry spots in any treatment during the trial period.

Turfgrass height growth

Irrigation had no significant effect on turfgrass height growth on average for 43 observations from 9 May to 10 Oct. (Table 7). The average daily height increment was 1.64 mm on unirrigated plots vs. 1.71 mm on irrigated plots. Not surprisingly, the strongest increases in height growth due to irrigation (>10%) were seen from 16 to 20 May and from 10 to 20 June, coinciding with the lowest soil water contents (Fig. 2). In contrast, the turfgrass tended to grow more in height on unirrigated than on irrigated plots during the wet period from 4 to 11 July, and in September.

Qualibra had a significant effect on turfgrass height growth only at two observations, 17 June and 2 Sep (individual observations not shown in table). On these dates, the reduction in height growth due to Qualibra was 15 and 13%, repectively. The first of these observations coincided with the very low SWC measured on 14 June (Fig. 2). On average for 43 observations, there was no effect of Qualibra on accumulated height growth (Table 7), and there was no interaction with irrigation (not shown).

Table 7. Main effects on irrigation, soil surfactant and plant growth regulator on accumulated height growth, seasonal dry matter production in clippings, average N concentration in clippings and total N uptake in clippings.

	Accumulated growth in height, 180 d growing season, mm	Total dry matter production, 180 days g/m2	N in clipping dry matter, %	Total N uptake in clippings, 180 days g/m2
Irrigation				
Unirrigated	331	140	3.42	4.8
Irrigated to FC once a week	345	155	3.38	5.2
P-value	Ns	*	ns	(*)
Soil surfactant				
No surfactant	341	151	3.35	5.1
Qualibra	335	144	3.45	5.0
P-value	Ns	ns	**	ns
Plant Growth Regulator				
No PGR	362	168	3.38	5.7
Primo Maxx II	314	127	3.42	4.4
P-value	***	***	ns	***

The total reduction in accumulated height growth due to Primo Maxx II was from 362 to 314 mm, or 13 % (Table 7). The trend lines in Fig. 6 show a bimodal distribution in height growth with peaks in May and late August/early September. The maximal reduction in height growth due to Primo Maxx II occurred during these periods, while there was little reduction in July and early August. Plant height was measured before mowing every Monday and Friday, and it's an interesting observation that the daily height increment from Monday to Friday was usually less than from Friday to Monday. This is probably a reflection of more activity on the plots during the week, in particular the wear from the wear machine.

The interactions between Primo Maxx II and the other experimental factors were not significant for turfgrass height growth.

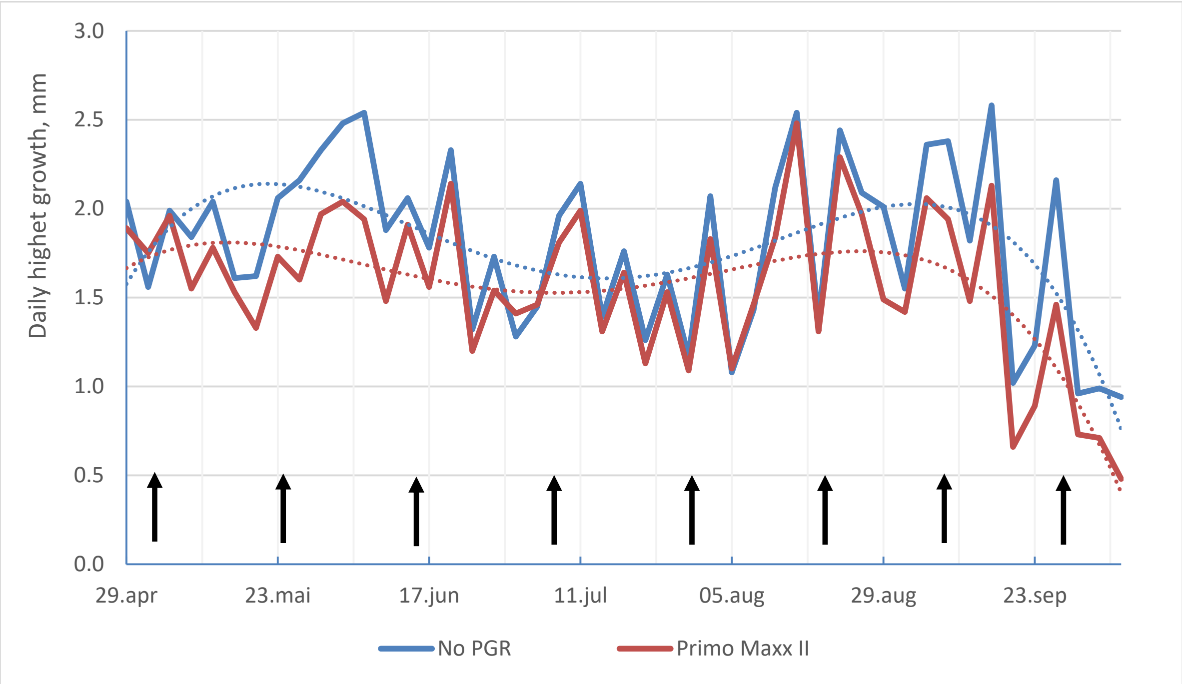


Fig. 6. Effect of Primo Maxx II on daily height growth during the growing season. Mean of irrigation and surfactant treatments. Trend lines and application dates for Primo Maxx II have been indicated.

Turfgrass clipping yields and nitrogen uptake

The effect of irrigation on turfgrass dry matter production was significant on three out of eight observation dates (individual dates not shown); the mean values were also significantly different with an increase corresponding to 11 % on irrigated plots (Table 7). Nitrogen analyses of the pooled samples of clipping dry matter yields showed an average of 3.4 % N regardless of irrigation. This is in agreement with STERFs fertilizer guidelines recommending 3.0-3.5 % N for healthy turf (Ericsson et al. 2012). Regardless of irrigation, the total nitrogen uptake in clippings was about one half of the nitrogen amount given in fertilizer during the growing season (compare Tables 3 and 7).

As a main effect Qualibra reduced clipping yields significantly on two observations dates and tended (P<0.10) to do the same on three more dates. Yet, the total reduction in clipping yield was only 5 % and not significant. Qualibra also caused a significant increase in the nitrogen concentration in the pooled sample of dry matter clippings from 3.35 to 3.45 % (Table 6).

On 24 June there was a significant interaction as Qualibra reduced growth only on unirrigated plots. A similar tendency (P=0.07) was recorded on 13 May. Further analysis of the total seasonal clipping yield also showed that the growth reduction due to Qualibra only occurred on unirrigated plots (-12 %) while there was a small increase (+2%) on irrigated plots At the same time, the increase in the nitrogen concentration in clippings due to Quaibra was also stronger on unirrigated plots (from 3.36 to 3.49 %) than on irrigated plots (from 3.35 to 3.41 %). These interactions between irrigation and Qualibra for total clipping yields and nitrogen concentation were, however, not statistically significant and they are therefore not shown in tables or figures).

The average reduction in clipping yields due to Primo Maxx II was 24 %, i.e. a stronger reduction than for height growth (Table 7). The strongest reduction in clipping yields occurred in May and June and from late August to October, while they was less effect of Primo Maxx II at the two clippings in early July and early August (Fig. 7). The nitrogen concentration in clippings was not affected by Primo Maxx II, but the total N uptake in clippings was reduced due to less clipping yield (Table 7). None of the two og three factor interactions with irrigation og soil surfactant were significant of showed any tendencies for these characters.

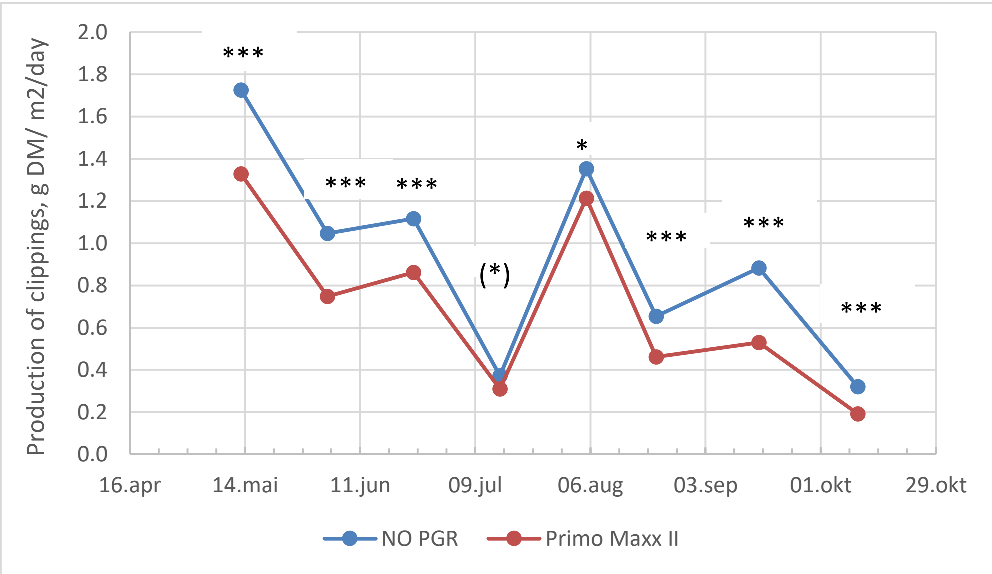


Fig. 7. Effect of Primo Maxx II on dry matter production in clippings during the growing season. Significance symbols as in Fig. 2.

Thatch development

Since the fairway was only 14 months old, it had only developed 3-5 mm thatch by September 2016 (Table 8, Photo 10). On average for irrigation and surfactant treatments, the thatch layer, was, however, significantly thicker on plots treated with Primo Maxx II than on untreated control plots (Table 8). There was also a significant interaction (*P*<0.01) as Qualibra led to more thatch buildup on irrigated plots, but had the opposite effect on unirrigated plots (Fig. 8).

Table 8. Main effects on irrigation, surfactant and plant growth regulator on accumulated height growth, seasonal dry matter production in clippings, average N concentration in clippings and total N uptake to clippings.

	Thatch thickness, mm	Water drop penetration time, seconds		
		5 mm from surface	15 mm from surface	50 mm from surface
Irrigation				
Unirrigated	3.5	27.8	1.4	<1
Irrigated to FC once a week	4.0	36.8	1.8	<1
P-value	ns	ns	ns	ns
Soil surfactant				
No surfactant	3.6	58.0	2.1	<1
Qualibra	3.8	6.6	1.1	<1
P-value	ns	*	*	ns
Plant Growth Regulator				
No PGR	3.2	21.0	1.6	<1
Primo Maxx II	4.3	43.6	1.6	<1
P-value	*	ns	ns	ns

Potential soil water repellency

Although there were no visible dry spots in the field, the spade samples taken in early September showed potential soil water repellency at 5 mm depth on plots not treated with Qualibra (Table 8). Regular use of Primo Maxx II resulted in longer penetration times, but this effect was not significant. According to the definition by Dekker & Jungerisus (1990), all samples were wettable (<5 s penetration time) at 15 and 50 cm depth.

Photo 10. Thatch development in samples from neighbor plots on 12 Sep. 2016. Plot 301 had not been irrigated or treated with plant growth regulator, but it had received Qulibra monthly. Plot 302 had been irrigated and treated with both Qualibra and Primo Maxx II. Photo: Trygve S. Aamlid.

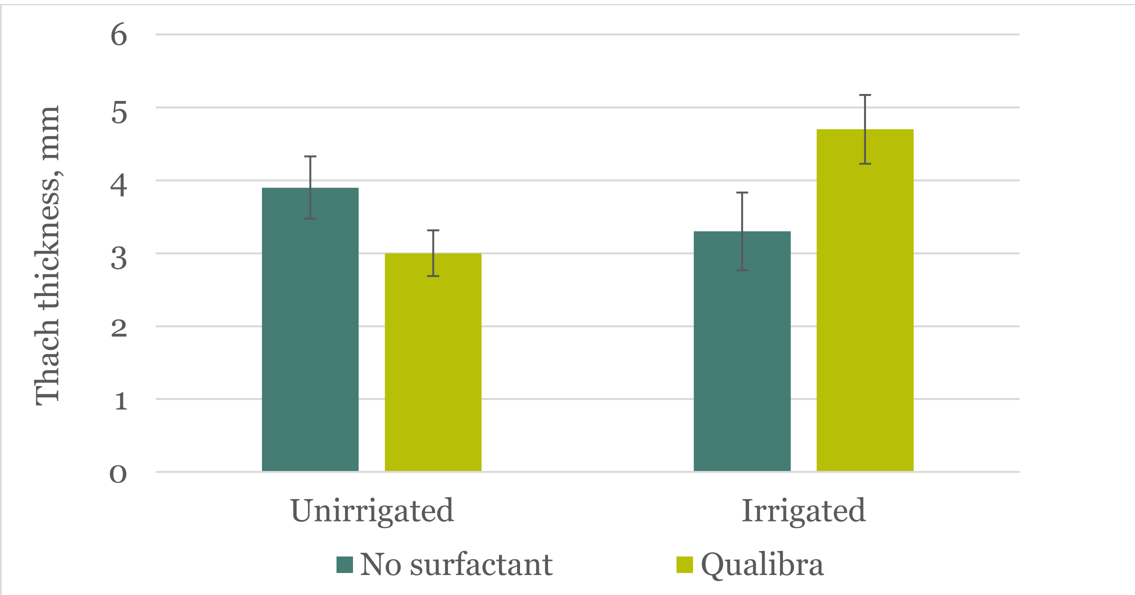


Fig. 8. Combined effect of irrigation and surfactant treatments for on thatch thickness in Septemeber 2016. Bars indicate ±1 Standard Error (SE).

Spring observations 2017

Although the first spring observations on 27 Feb. were done shortly after a 15 day period with snow cover, there were no symptoms of snow mold in any plots. In contrast, the red thread disease, which had also been observed during 2016, was very visible at this stage, and there was significantly more of this disease on irrigated that on unirrgated plots and significantly less on plots sprayed with Primo Maxx II than on untreated plots (Table 9).

On 27 Feb., we also observed superficial fairy rings on some of the plots (Photo 11), and there was a significant (P<0.01) interaction between surfactant and plant growth regulator as these rings only occurred on plots that had revieved Primo Maxx II, but not Qualibra, in 2016 (Table 8, Photo 9). Five out of eight plots that had received this treatment combination showed visible symtoms, on average covering 3.7 % of plot area, while there were no fairy rings in any of the other treatment combinations. The occurrence of fairy rings was not affected by irrigation in 2016.

The assessment on 27 Feb. showed better turfgrass color on unirrigated than on irrigated plots, and this was also confirmed by the final observation on 20 March (Photo 12). Neither Qualibra nor Primo Maxx II had any significant effect on spring color.

Table 8. Main effects on irrigation, surfactant and plant growth regulator in 2016 on diseases and turfgrass color in early spring 2017.

	Red thread	Fairy rings	Turfgrass color (1-9, 9 is most green)	
	27 Feb., % of plot area		27 Feb.	20 Mar.
Irrigation				
Unirrigated	0.4	0.8	5.6	5.4
Irrigated to FC once a week	1.1	1.1	4.7	4.8
P-value	**	ns	**	**
Soil surfactant				
No surfactant	0.7	1.9	5.1	4.9
Qualibra	0.8	0	5.2	5.3
P-value	ns	**	ns	ns
Plant Growth Regulator				
No PGR	1.0	0	5.3	5.2
Primo Maxx II	0.5	1.9	5.0	5.0
P-value	*	**	ns	ns

Photo 11. Superficial fairy ring observed on 27 Feb. 2017 in plot that had received Prim Maxx II, but not Qualibra in 2016. Photo: Trond Pettersen .

Photo 12. Experiment on 20 March 2017. Plots that had been irrigated in 2016 were less green than unirrigated plots. Photo: Trond Pettersen.

DISCUSSION

The objective of this experiment was to investigate if Qualibra and Primo Maxx II can contribute to more sustainable fairway management with regard to mowing, irrigation and fertilization. The results were – all taken together - disappointing for Qulibra, and not very convincing for Primo Maxx II either.

Qualibra

The reason for the mostly negative results with Qualibra may partly be that the growing season 2016 had a realtively high precipitation and that the turf was exposed to drought only during short periods in May and June However, even during those periods, Qualibra did not improve turf quality or greenness; it did not level out the horizontal variation in soil water content or turf color, and it did not contribute to more plant available water in the top 12 cm of the soil. While the water drop penetration test left no doubt that Qualibra prevented soil water repellency, our results confirm previous findings that the penetrant characteristics of this surfactant predominated over its polymer characteristics (Aamlid et al. 2016). As a result, the amount of irrigation water needed for weekly replenishment of field capacity was not lower, but in fact slightly higher on plots treated with Qualibra than on plots not treated with surfactant. It could have been assumed that the higher water percolation rate would also have resulted in more loss of nitrogen from the rootzone, but that effect was less pronounced as the N concentration in turfgrass leaves was higher on plots treated with Qualibra than on untreated plots. The latter can probabaly be interpreted as a concentration effect due to a stronger reduction in growth than in N uptake after treatment with Qualibra.

The finding that Qualibra resulted in more thatch on irrigated plots but less thatch on plots only receiving natural rainfall was unexpected and contradictory to our findings in green trials (Aamlid et al. 2016). Possible reasons for this may be different physical og chemical condtions in the relatively thin, but very dark thatch on the fescue-dominated fairway compared to the 5-6 times thicker thatch on the creeping bentgrass green. Given the young turf and short duration of the present experiment, the effect of Qualibra on turfgrass growth rates and thatch formation was probabaly more important than the effect on oxygen availability and thatch decomposition.

This finding that Qualibra eliminated superficial fairy rings at the first observation in spring is in agreement with Fidanza et al. (2007) who documented a role of soil surfactants in the control of this disease. It is still noteworthy that Qualibra was able bo control the fairy rings by itself, without any addition of fungicide. This finding ought to be confirmed by new experiments and may perhaps be an argument for using Qualibra of golf courses where fairy rings are a problem.

Primo Maxx II

The – on average – 13 % reduction in turfgrass height growth and 24 % reduction in clipping yields caused by Primo Maxx II was less than in former Scandinavian trials Aamlid (Vågen et al. 2013). Reasons for this may be that the rate of Primo Maxx II was lower (1.0 vs. 1.2 l/ha), that the turf was dominated by red fescue which is less responsive to Primo Maxx II than bluegrasses (Aamlid et al. 2009) and that the seasonal fertilizer level was lower (0.96 vs. 1.13 kg N/100 m^2).

We have in early trials documented that fairways tend to become less uniform and more infested by broadleaved weeds after use of Primo Maxx II (Aamlid et al. 2009, Vågen et al. 2013), and this may well be more of a problem in Scandinavia than elsewhere due to more restrictive use of herbicides. The coefficient of variation among chlorophyll readings in this report also confirmed our earlier visual observations that unirrigated fairways with a mixed botanical composition tend to become less uniform after treatment with Primo Maxx. Furthermore, the lower ball lie on Primo-treated than on untreated plots suggests that the turf was not stiffer or denser after treatment with Primo Maxx II, and this was also confirmed by the visual observations of tiller density. A stronger reduction in clipping yield than in height growth is another indication that Primo Maxx II not only caused a reduction in the vertical, but also in the horizontal growth rate, i.e. tillering. On the other hand, most golfers will perceive it as an advantage that *Poa annua* seeds head become less visible after treatment with Primo Maxx II; this effect is also confirmed by American literature showing Primo Maxx II to reduce the height but not the number of *Poa annua* infloresences (e.g. Kane & Miller 2003).

One benefit of Primo Maxx II in this trial was its tendency to cause a higher and more uniform soil water content. This is in agreement with Bigelow et al. (2011) who documented a 6.4 % reduction in water consumption after use of Primo Maxx and can be interpreted as a direct implication of less evapotranspiration resulting from less aboveground growth.

The increased thatch build-up due to applications of Primo Maxx II was unexpected, although Rossi et al. (1996) documented a similar effect for the other gibberellin biosynthesis inhibitor flurprimidol but inconsistent effects of trinexapac-ethyl. Increased thatch formation despite reduced clipping yield may suggest that the turf allocated more of its resouces to rhizomes and/or to roots immediately below the soil surface rather than to tillers. This explanation would be compatible with the increased divot resistance previously reported for Primo-treated Kentucky bluegrass sod (Serentis 2008). However, increased thatch formation on a golf course fairway may also have many negative implications, as examplifed by more fairy rings in this trial.

REFERENCES

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® (trinexapacethyl)on Nordic golf courses. Results from the second evaluation year 2008 and recommendations. Bioforsk Report 4 (4): 1-28.

Aamlid, T.S., T. Pettersen & A. Kvalbein 2016. Evaluation the soil surfactant Qualibra on a sand-based putting green 2014-2016. NIBIO Confidential Report, Archive 16/1528. 39 pp.

Bigelow, C., Y. Jiang, W.T. Tudor Jr. & F. Beck 2011. Plant growth regulator effects on creeping bentgrass growth and water use. Abstarcts, 2011 International Annual Meetings: ASA-CSSA-SSSA p. 66240.

Dekker, L.W. & P.D. Jungerius 1990. Water repellency in the dunes with special reference to the Netherlands. Catena Suppl. 18: 173–183.

Ekeberg, E. & A. Njøs 1970. Physical analyses of soil profiles from Landvik, Norway. Scientific reports from the Agricultural College of Norway 49 (10): 1-11.

Ericsson, T., K. Blombäck, and A. Neumann. 2012. Demand-driven fertilization. Part I: Nitrogen productivity in four high-maintenance turf grass species. Acta Agric. Scandinavica Section B – Soil and Plant Sci. 62: 113-121.

Fidanza, M., F. Wong, B. Martin & S. McDonald 2007. Treating fairy ring with fungicides,new soil surfactant. Tank-mixing a fungicide and a soil surfactant may control fairy ring symptoms in many locations. Golf Course Management 75(5): 121-125.

Kane, R. & L. Miller 2003. Field testing plant growth regulators and wetting agents for seedhead suppression of annual bluegrass. USGA Green Section Record 41(4): 21-26.

Rossi, F.S., E. Buelow & A. Sausen 1996. Influence of plant growth regulators on vertical leaf extension, divot recovery and thatch development on golf course fairway turf. The Grass Roots. 24(2): 54-55.

Serentis, T. J. 2008. Effects of trinexapac-ethyl and cultivation on the divot resistance of Kentucky Bluegrass cultivars. M.S. Thesis: Pennsylvania State University. 218 pp.

Vågen, I.M., O. Niemeläinen, T. Espevig, T. O. Pettersen, P. Ruuttunen & T.S. Aamlid 2013. Comparison of current and new Primo Maxx formulations for turfgrass. Bioforsk report 8(186): 1-42.

*