Avoid surface runoff of fungicides from golf greens

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According to the principles for Integrated Pest Management (IPM), pesticides shall only be used as a last resort when other preventative or direct control measures do not provide adequate control. One situation where adequate control is difficult to achieve without a certain use of fungicides is when golf greens are infested by microdochium patch / pink snow caused by *Microdochium nivale.*

Results from the research project *'Risks for surface runoff and leaching of fungicides from golf greens varying in rootzone composition and amount of thatch'* show little risk for contamination of the environment as long as the greens have a good infiltration capacity and surface runoff is avoided.

The concentration of commonly used fungicides and their metabolites in **drainage water** rarely exceeded the Environmental Risk Level (ERL) set by the Norwegian Food Safety Authority. In contrast, the ERL was often exceeded in **surface runoff** from sprayed greens during a winter with frozen soils, high precipitation and repeated freeze and thaw cycles. Our results emphasize the importance of strict compliance with the prescribed buffer zone distance to open water when spraying fungicides on golf greens, especially shortly before the winter seasons.

Photo 1. *Lysimeters (1 m x 2 m) for collection of drainage water from experimental USGA-spec. greens at NIBIO Landvik, Norway*

Introduction

The Nordic Golf Federation's research foundation STERF has earlier funded projects investigating the environmental fate of fungicides such as iprodion (in Chipco Green /Rovral), azoxystrobin (in Heritage, Headway, Amistar) and propiconazole (in Banner Maxx, Headway, Tilt, Basso etc.) after application on sand-based greens. These investigations were conducted using field lysimeters (Photo 1) and were all confined to drainage water, i.e. water draining through the rootzone. The studies showed a strong impact of the amount of organic matter in the rootzone on fungicide leaching. When the rootzone had an ignition loss of 2 % (w/w) from compost or peat, there were practically no detections of fungicides in the leachate.

More about these results can be found in the synopsis 'Fungicide leaching form golf greens' (Aamlid 2014).

Our newest project *'Risks for surface runoff and leaching of fungicides from golf greens varying in rootzone composition and amount of thatch'* was funded by STERF and the Norwegian Agricultural Agency's Action Plan for Sustainable Use of Pesticides. The overall objective was to secure safe and environmentally acceptable fungicide losses on golf greens. The field work was carried out at NIBIO's turfgrass research center Landvik on the Norwegian south coast (58°20'N) during the late fall and winter seasons 2016-2017 and 2017-2018.

Analyses of drainage and surface water was carried out by NIBIO's Department for Pesticide and Natural Product Chemistry.

Photo 2. *Preparing experimental greens before seeding or sodding in May 2016. Compost amended rootzones had darker color than peat-amended rootzones. All greens were prepared with a surface inclination of 5 % to the south, allowing surface water to be collected in containers in the trench to the right.*

Photo 3. *Collection of surface water.*

Materials and methods

During 2015, the sixteen experimental greens in one of the two lysimeter facilities at NIBIO Landvik were reconstructed / reshaped to allow collection not only of drainage, but also of surface water (Photos 2 and 3). The plots had a surface inclination of 5 %, i.e. slightly more than the 2-3 % commonly found on undulated putting greens.

The experiment had four blocks (replicates) and two factors, each with two levels (i.e. four combinations) as detailed below:

Factor 1: Organic amendment to the sand-based (USGA spec.) rootzone:

1. Sphagnum peat, ignition loss 1.2%, pH 5.5
2. Garden compost, ignition loss 1.0%, pH 6.5.

Factor 2: Turf age / thatch thickness:

1. Green seeded in May 2016 (Photo 4)
2. Green established in May 2016 using 2 year old sand-based sod, thatch layer 2 cm

The turfgrass used on both seeded and sodded plots was creeping bentgrass ('Penn A4', 'Penn G2' and 'Penn G6', 1/3 of each variety). The green were maintained according to good green-keeping practice, including mowing with a walk-behind single mower to 3 mm three times per week, balanced fertilizer applications every two weeks (partly liquid and partly granular) for total seasonal rate of 1.5 kg N/100 m^2/yr, aeration with a slicer every two weeks, and light topdressing once a week for a total seasonal rate of 6.5 mm straight sand. There was no ordinary play on the plots, but they were subjected to wear and compaction from a frictionary roller with golf spikes corresponding to 15000 rounds of golf per year. Photo 5 gives an impression of the thatch/mat layer on seeded and sodded plots at first fungicide application in autumn 2016.

The systemic fungicides Delaro (prothioconazole + trifloxystrobin; approved for use on golf courses in Norway) and Signum (boscalid + pyraclostrobin; off-label for use on golf courses in Germany) were sprayed on all plots on 25 Oct. 2016 and 18 Oct. 2017 at a rate of 1.0 L/ha (Delaro) and 1.5 kg/ha (Signum).

(Photo 6). Three weeks later, after mowing had been discontinued for the season, Medallion TL (fludioxonil, approved on golf courses in Germany, Finland, Sweden and Norway) was sprayed on 15 Nov. 2016 and 8 Nov. 2017 at a rate of 3.0 L/ha. The amount of drainage (collected at a soil depth of 40 cm) and surface water was monitored throughout the two winter seasons and water samples taken regularly for analyses of the fungicides and their metabolites (=degradation products).

Photo 4. *Half of the plots were established using sand-based sod of creeping bentgrass to simulate older greens with more thatch. The remaining plots were seeded directly using the same creeping bentgrass seed blend. Photo taken in May 2016.*

Photo 5. *Profiles of the top layer at the first fungicide application in October 2016. Seeded turf to the left and sodded turf to the right.*

Photo 6. *Fungicide application according to GEP standard in autumn 2016.*

Results

Drainage, surface runoff and fungicide detections during the winter 2016-2017

The total precipitation from the first fungicide application on 25 October 2016 to the final collection of water samples on 20 March 2017 was 601 mm, of which, on average for 16 plots, 91 % was recovered as drainage water and only 3 % as surface runoff. The young greens had good infiltration capacity and surface runoff was mostly collected during periods when the greens were (partly) frozen. Even from unfrozen greens, there was, however, a certain runoff after a record-high precipitation intensity on 5 Nov. 2017, i.e. between the application of Signum / Delaro and Medallion: 147 mm fell within 24 h, partly as rain and partly as snow.

The final 6 % of the precipitation between 25 October and 20 March was not accounted for. We believe that most of this was lost due to transpiration from unfrozen turf during mild spells in the late autumn and winter. The greens were frozen 'on and off' from 28 Nov to 15 March, and there were only 30 days with snow cover in 2016-17 (split between three periods).

The maximal concentration of fungicides and their metabolites in drainage water and surface runoff during 2016-17 is shown in Table 1 in comparison with estimated Environmental Risk Limits (ERL or 'MF'-values), that indicate threshold concentrations above which long-term negative effects in aquatic environments might occur. These concentration limits are based on 'No Observed Effects Concentrations (NOEC)'-data from chronic toxicity tests of aquatic organisms, and the calculation includes an assessment factor depending on the quality of these data. This calculation procedure is in accordance with guidelines for environmental quality standards (EQS) for the Water framework directive and is mainly based on the EU pesticide registration process. The orocedure can therefore be considered relevant throughout Europe.

Table 1a shows that fungicide concentrations **in drainage water** were mostly very low – in most cases one to two orders of magnitude lower than the ERL-value. This confirms our earlier findings (Aamlid 2014) that fungicide applications to golf green represent small environmental risks as long as the entire precipitation infiltrates and the rootzone contains at least 1 % organic matter.

One unexpected finding in Table 1a was the detection of fludioxonil in drainage water from sodded plots on 5 Nov. i.e. before the application of Medallion on 15 Nov. These are very likely residues of fludioxonil after fungicide treatment of the sodded gras by the sod grower. (Swedish sod grower S. Anderson, pers.comm.).

Except for one detection of the prothioconazole-metabolite desthio on 27 Oct. and one detection of fludi-oxonil on 15 Nov., the concentration in drainage water was always well below the safety limit (Table 1a).

In contrast, the maximum concentrations of prothioconazole-desthio, trifloxystrobin, boscalid, pyraclostrobin and fludioxonil in surface water were 10-200 times higher than their respective safety limits (Table 1b). The highest surface runoff of boscalid and pyraclostrobin occurred when the heavy snow fall on 5 Nov. melted about one week later, while the highest concentration of fludioxonil was detected on 7 Dec. when rain fell on partly frozen greens. In both cases, these detections were about three weeks after application of the respective fungicides. In contrast, the highest concentrations of prothioconazole and pyraclostrobin were detected as late as at the last sampling on 20 March, but these concentrations were barely above the detection limit and too low to have any practical relevance.

Regardless of fungicide, the highest concentrations during the first winter were found in surface water from plots that had been established by sodding on top of a compost-amended rootzone. This was also the treatment that had the lowest infiltration capacity in October 2016; 348 mm/h as opposed to >800 mm/h on greens established by seeding. However, even an infiltration rate of >300 mm/h is very high compared to the situation on many old golf greens.

Despite the fact that the total volume of surface water collected from 25 Oct. to 30 March was only 2 L/m^2 compared to 550 L/m^2 drainage water, the mostly 1000 fold higher concentration in surface water means that total fungicide loss to the environment was higher for water running off the surface than for water leaking through the rootzone. The only exceptions to this were the trifloxystrobin and fludioxonil metabolites for which the mass balance calculation showed more loss in drainage than in surface water.

Table 1. *Maximal detections of various fungicides and their metabolites in a) drainage water and b) surface runoff during the 2016-2017 winter season.*

a) Drainage water

Product / application date	Active ingre-dient	Active compound or metabolite detected in drainage water	Concentation, µg/L		Sampling date for maximum concentration
			Maximum detected	Norwegian ERL	
Delaro SC 325, 25.okt	Prothio-conazole	Prothioconazole	0.022	0.74	5 Nov.
		Metabolite: Desthio	0.036	0.030	27 Oct.
	Triifloxy-strobin	Trifloxystrobin	0.015	0.19	15 Nov.
		Metabolite: Trifloxystrobin-acid	21	64	15 Nov.
Signum, 25.okt	Boscalid	Boscalid	0.058	12.5	27 Oct.
	Pyra-clostrobin	Pyraclostrobin	0.022	0.4	15 Nov.
		BF500-6[1]	0.004	-[1]	18 Nov.
Medallion TL, 15.nov	Fludi-oxonil	Fludioxonil	0.058	0.050	5 Nov.
		Metabolite CGA 192155	7.0	100	28 Dec.

b) Surface runoff

Product / application date	Active ingre-dient	Active compound or metabolite detected in drainage water	Concentation, µg/L		Sampling date for maximum concentration
			Maximum detected	Norwegian ERL	
Delaro SC 325, 25.okt	Prothio-conazole	Prothioconazole	0.0039	0.74	20 Mar.
		Metabolitt: Destio	7.2	0.030	7 Dec.
	Triifloxy-strobin	Trifloxystrobin	8.5	0.19	15 Nov.
		Metabolite: Trifloxystrobin-acid	21	64	15 Nov.
Signum, 25.okt	Boscalid	Boscalid	44	12.5	15 Nov.
	Pyra-clostrobin	Pyraclostrobin	8.7	0.4	15 Nov.
		BF500-6	0.00075	-[1]	20 Mar.
Medallion TL, 15.nov	Fludi-oxonil	Fludioxonil	7.9	0.050	7 Dec.
		Metabolite CGA 192155	12.9	100	28 Dec.

[1] A Norwegian 'No Observed Effect Concentration' for the pyraklostrobin- metabolite BF500-6 has not been determined due to limited data.

Photo 7: *Experiment on 23 March 2018. Snow above ice cover had been removed three times during the winter. Photo: Trygve S. Aamlid*

Drainage, surface runoff and fungicide detections during the winter 2017-2018

The winter 2017-18 saw far more precipitation than the year before; 975 mm in total for the period from the first fungicide application of 18 Nov. to the last collection of drainage and surface water on 6 April. Since the plots were frozen during most of the winter, only 53 % of the precipitation was recorded as drainage water and as much as 32 % as surface runoff. The amount of surface water is an approximation (±10 %) as ice formation and repeated freezing/melting episodes resulted in overflow in the collection jars on a few occasions. The grass was covered with snow and/or ice for 65 days. Snow overlying ice was removed three times during winter (Photo 7) in total for these three times we estimate to have removed about 90 mm (9 %) of the total winter precipitation. As in the previous year, the remaining 6 % that has not been accounted for was probably lost as evapotranspiration in the late autumn.

The maximal concentation of fungicides and their metabolites in drainage water and surface runoff during 2017-18 are shown in Table 2. In this table we have also included information about actual application rates (as determined according to the Norwegian protocol for Good Experimental Practice), total losses and a calculated average concentration of the various fungicides and metabolites during winter. While the maximal concentrations of prothioconazole-desthio, trifloxystrobin and boscalid in drainage water were 5-10 higher than the previous year, the ERL was - as in 2016-2017 - exceeded only for prothioconazole-destio and fludioxonil. When averaged over the entire winter season, the concentration in drainage water was lower than the ERL for all fungicides and metabolites.

The maximum concentration of fungicides and metabolites in surface runoff were higher in 2017-18 than the year before. An exception was the pyraclostrobin metabolite BF500-6, which was deteced in small concentrations only in 2016-17. The ERL was exceeded by several orders of magnitude for trifloxystrobin and fludioxonil, approximately 50 times for prothioconazole-desthio and pyraclostrobin, and 17 times for boscalid. The highest concentrations of prothioconazole, trifloxystrobin, boscalid, pyraclostrobin and their metabolites were found on 20 Oct. after application of Delaro SC 325 and Signum on 18 Oct., while the highest concentration of fludixonil was found on on 17 Nov. after application of Medallion on 8 Nov. In the first case, the high concentration may be explained by 38 mm rainfall starting 30 hours after fungicide application on 18 Oct. In the second case there was no frost in the soil at the application of Medallion on 8 Nov., but a cold period followed four days later, thus resulting in frozen greens and no infiltration at the subsequent moderate rainfall (9 mm before sampling).

Table 2. *Actual application rates, total recovery of various fungicides and their metabolites, and average and maximum concentration in a) drainage and b) surface water during the 2017-18 winter season.*

a) Drainage water

Product / Application date	Active ingredient	Actual appl. rate, mg a.i./m²	Active compound or metabolite detected in drainage water	Total recovery 18 Oct.-6 Apr. mg/m²	Concentration, µg/L			Sampling date for maximum
					Weighed mean	Maximum	Norwegian ERL	
Delaro SC 325, 18 Oct	Prothioconazole	19	Prothioconazole	0.0050	0,0095	0,025	0.74	17 Nov.
			Metabolite: Desthio	0.011	0,021	0,16	0.03	25 Mar.
	Trifloxystrobin	16	Trifloxystrobin	0.00036	0,00070	0,10	0.19	17 Nov.
			Metabolite:Trifloxystrobin–acid	5.9	11	29	64	17 Nov.
Signum, 18 Oct.	Boscalid	41	Boscalid	0.27	0,047	0,59	12,5	25 Mar.
	Pyraclostrobin	10	Pyraclostrobin	0.00035	0,00069	0,007	0.4	17 Nov.
			BF500-6	0	0	0	-[1]	-
Medallion TL, 8 Nov.	Fludioxonil	36	Fludioxonil	0.00165	0,0031	0,092	0.050	17 Nov.
			Metabolite CGA 192155	0.45	0,86	6,2	100	26 Jan.

b) Surface water

Product / Application date	Active ingredient	Actual appl. Rate, mg a.i./m²	Active compound or metabolite detected in surface runoff	Total recovery 18 Oct.-6 Apr. mg/m²	Concentration, µg/L			Sampling date for maximum
					Weighed mean	Maximum	Norw. ERL	
Delaro SC 325, 18 Oct	Prothioconazole	19	Prothioconazole	0.00017	0,00054	4.1	0.74	20 Oct.
			Metabolite: Desthio	0.023	0,074	15.1	0.03	20 Oct.
	Trifloxystrobin	16	Trifloxystrobin	0.023	0,076	37,2	0.19	20 Oct.
			Metabolite:Trifloxystrobin–acid	0.034	0.11	16.3	64	20 Oct.
Signum, 18 Oct.	Boscalid	41	Boscalid	0.36	1.20	207.6	12,5	20 Oct.
	Pyraclostrobin	10	Pyraclostrobin	0.12	0.39	19.3	0.4	20 Oct.
			BF500-6	0	0	0	-[1]	20 Oct.
Medallion TL, 8 Nov.	Fludioxonil	36	Fludioxonil	0.91	2.96	78.8	0.050	17 Nov.
			Metabolite: CGA 192155	0085	0.27	14.8	100	17 Nov.

[1] A Norwegian 'No Observed Effect Concentration' for the pyraklostrobin- metabolite BF500-6 has not been determined due to too limited data.

As would be expected from the high concentrations, Table 2 shows that the total loss to the environment of most fungicides during the winter 2017-2018 was more severe in surface runoff than in drainage water. Exceptions to this were prothioconazole, the fludioxonol metabolite CGA 192155, and - most notably - the trifloxystobin metabolite trifloxystobin acid for which the highest losses were found in water that had passed through the rootzone.

There was no effect of establishment method or organic amendment to the rootzone on fungicide losses in surface runoff. In contrast, the amount of drainage water and leakage of trifloxystrobin acid (Table 3) and the fludioxonil metabolite CGA 192 155 (Table 4b) were significantly ($P<0.05$) higher from seeded than from sodded plots. Simlar tendencies although not significant, were seen for fludioxonil (Table 4a) pyraclostrobin and boscalid (Table 3).

For CGA 192155 there was also a significant effect of organic amendment with higher metabolite losses in compost than in peat (Table 4b). This was probably due to a faster microbial degradation of fludioxonil, in the compost-amended soils which had a pH more optimal for microbial metabolic activity than the peat-amended soil. Consequently, significant or almost signicant interactions suggested that seeding vs sodding had more influence on the leakage of fludixonil on peat-amended than on compost-amended plots, while this was opposite for CGA 192155 (Table 4).

Sodded greens have a thick thatch layer of roots and humic substances which strongly sorbs the pesticides. This effect was especially strong for fludioxonil and resulted in considerably lower leaching of fludioxonil from the sodded peat plots as compared to the seeded peat plots (Table 4).

Table 3. *Main effect of seeding vs sodding on amount of drainage water and accumulated leaching of some fungicides and their metabolites, 18 Oct. 2017 – 6 Apr. 2018.*

	Drainage water L/m^2	Bos-calid, $\mu g/m^2$	Pyraclo-strobin $\mu g/m^2$	Tri-floxy-strobin $\mu g/m^2$	Metabolite: Trifloxy-stro-bin-acid, $\mu g/m^2$	Prothio-conazole, $\mu g/m^2$	Metabilite: Prothio-cona-zole-desthio, µg/m2
Seeding	556	6.4	0.41	0.36	6389	5.0	11.2
Sodding	488	5.3	0.32	0.35	5303	4.9	10.9
P-value	<0.05	>0.10	>0.10	>0.10	<0.01	>0.10	>0.10

Table 4. *Accumulated leaching of a) fludioxonil and b) the fludioxonil metabolite CGA 192155 in drainage water, 18 Oct. 2017 - 6 Apr. 2018, as affected by seeding vs. sodding and type of organic amendment to the USGA rootzone.*

a) Fludioxonil

	Accumulated leaching, µg/m2			
	Peat	Compost	Mean	P-value
Seeding	2.43	1.84	2.13	0.07
Sodding	0.46	1.89	1.18	
Mean	1.45	1.86	1.65	
P-value	>0.10			Interaction: 0.06

b) CGA 192 155

	Accumulated leaching, µg/m2			
	Peat	Compost	Mean	P-value
Seeding	200	842	521	<0.05
Sodding	234	537	385	
Mean	217	689	453	
P-value	<0.001			Interaction: <0.05

Discussion and precautions

In line with former STERF projects (Aamlid 2014), the results from this project shows an overall low risk for fungicide contamination of ground og surface water from water draining through sand-based rootzones after fungicide application. As shown in Tables 3 and 4, this is espcially the case once the greens have reached a certain age and developed a thatch layer. Inclusion of at least 1 % (w/w) organic matter in the rootzone, as practiced by most greenkeepers / contractors, further reduces the risk for fungicide leaching (Aamlid 2014).

The maximum concentrations of fungicides / metabolites in surface runoff were, on the other hand, very high, and we are concerned about the high levels detected of the compounds protihoconazole-desthio, pyraclostrobin and fludioxonil that fall in the category of high chronic toxicity to aquatic organisms at one or several trophic levels.

A relevant question is if this is a typical situation on golf courses. Especially the data from 2017-2018 clearly represent a worst-case scenario with a high rainfall episode 24 h after the first fungicide application, and green freeze-up and thus limited infiltration followed by high precipitation and recurring freezing and melting episodes after the second application.

It must also be remembered that the plots at Landvik had a high surface inclination rate (5%), that the collectors for surface water placed at the end of each plot and that there was no 3 m wide buffer strip as prescribed by the Norwegian Directive on Pesticide Use (Forskrift om plantevernmidler). Some fungicides even have a wider buffer zone required on their label, e.g. 5 m on the Swedish label for Medallion TL and 10 m on the Norwegian label for Delaro SC 325. While the effect of buffer strips will be reduced if the soil freezes up shortly after application, our findings emphasize the importance of strict compliance with these zones to avoid fungicide contamination of open water, especially in the northern zone climate, with cold winters and snowmelt

There are also other precautions that may be taken by the greenkeepers to avoid surface runoff:

- The greens must be maintained and the thatch controlled so that severe reductions in infiltration rates are avoided as the greens become older. Most greens on golf courses have lower infiltration rates than the fairly new sand-based greens used in our trials. Deep aeration in the fall may be one measure that can help to avoid surface runoff at least until the soil freezes before winter.

- As documented after applying Delaro EC 325 and Signum on 18 Oct. 2017, the rainfastness of most fungicides stated on the label (usually 1-2 hours) is no guarantee that the products are absorbed or adsorbed and will no longer contaminate surface water. American studies conducted during the growing season showed significant reductions in runoff if the time from fungicide application until the first rainfall increased from 12 to 24 h (Branham et al. 2005). When applying fungicides at low temperatures in the late fall, this safety period should probably be even longer, particularly on greens with limitied infiltration capacity. For the greenkeeper, it is therefore important to observe the long-term weather forecasts and ensure there is no risk for high rainfall episodes durng the first week after application. Turfgrass fungicide sorption and the risk for surface runoff at various temperatures and rainfall timings/intensities in the autumn as well as during freezing-thawing during winter could perhaps be a topic for further studies under controlled conditions.

- It is well recognized that fungicide applications on frozen greens do not have the anticipated effect of turfgrass diseases and - on top of that – pose a threat to the environment. Perhaps less documented is the increased risk for contaminatin of surface water if the green freezes within a few days after fungicide application. As the winter climate tends to become more unstable with frequent freezing and melting episodes and higher rainfall intensities, there may perhaps be a reason to discuss the timing of the last fungicide application before winter. With the old contact fungicides it was recommended to postpone the application as close to anticipated soil-freeze up / snowfall as possible. Today the typical contact fungicides have been replaced by new chemistries (on the Scandinavian market primarily Medallion) , that are better absobed by the leaves and not so dependent on a late application date. Earlier timing of the last fungicide application befor the winter is likely to reduced the risk for surface runoff due to rain falling on frozen greens.

- Finally, greenkeepers and golf course architects are encouraged to discuss to what extent it is feasible to constuct special basins or collection areas where surface water from greens can accumulate before infiltration. A relevant question is if green bunkers may play a role in this regard.

References

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