FUNGICIDE LEACHING from golf greens

By Trygve S. Aamlid, Bioforsk Turfgrass Research Group
Preface

In July 2014, Bioforsk Turfgrass Research Group was commissioned by the German Golf Federation (DGV) to compile a synopsis of Scandinavian studies into the risk for fungicide leaching from sand-based golf greens. The background for the assignment was the ongoing debate about reregistration of active fungicide ingredients and formulations that are already used on German golf courses, as well as the registration of potential new products.

Since four of the five studies summarized in the synopsis were funded by the Scandinavian Turfgrass and Environment Research Foundation (STERF), DGV kindly agreed that the synopsis could be published not only by DGV, but even on STERF’s website.

It is my hope that this review will form a basis for joint research projects between DGV, STERF and perhaps other partners into the benefits, but also environmental risks associated with the use of pesticides according to IPM principles on European golf courses in the future.

Bioforsk Turfgrass Research Center Landvik, December 2014
Trygve S. Aamlid, Research leader

Introduction

During the last two decades, pesticide use on golf courses has been increasingly criticized by people who believe that current turfgrass maintenance practices are harmful to the environment. One of the greatest concerns is that pesticides from golf courses pollute drinking water. The protection of ground water and surface water is embedded in EU’s Water Framework Directive (WFD 2000/60/E) which was transposed into member State Law in 2013, and in the directive 2009/128/EC on Community Action to achieve sustainable use of pesticides (Strandberg et al. 2012).

The most intensively managed areas on golf courses are the greens. German guidelines specify three different construction methods for greens depending on the drainage capacity of the subgrade—
Method no 3 includes a drainage layer and is in close resemblance with the United States Golf Association’s recommendations for putting green construction (USGA 2004). However, common to all construction methods for greens, tees and athletic fields is that the topsoil is dominated by sand in order to ensure fast drainage of excess water. This raises concerns about leaching losses, and on constructions with a drainage layer, these concerns are further strengthened by the shallower root depth compared with most agricultural soils. On the other hand, golf greens usually have a thatch/mat layer with a high sorption capacity for pesticides and a high microbial activity that is important for pesticide degradation (Kenna & Snow 2000, Sigler et al. 2000).

Golf greens are usually mowed daily at 3-5 mm and exposed to wear and compaction from golf players. This is an extremely stressful environment which renders the grasses susceptible to a number of diseases such as anthracnose (Colletotrichum graminicola), dollar spot (Sclerotinia homeocarpa), brown patch (Rhizoctonia solani), microdochium patch (Microdochium nivale), take-all patch (Gaumeannomyces graminis), red thread (Laetisaria fuciformis), Pythium blights (Pythium spp.) and several others. Most of the pesticides used on golf greens are therefore fungicides which – in general terms – are in an intermediate position between insecticides and herbicides with respect to human toxicity. On the other hand, fungicides usually sorb more strongly to the soil than herbicides, and their degradation half lives are usually longer (Almvik et al. 2014).

Table 1 shows which fungicides are presently approved for use on golf courses in the Nordic countries. There has, over the past ten years, been some notable changes as old chemistries such as iprodione (Chipco Green, Rovral) and thiophanate-methyl (Topsin) were phased out while new chemistries, e.g. prothioconazole (Proline, Delaro) and fludioxonil (Medallion, Switch), were approved. In parallel with these changes, there were also four studies, published in peer-reviewed journals, on the leaching risks of fungicides from sand-based golf greens varying in organic matter content and with different management practices. The objective of this synopsis is to provide a summary of these studies as an input to the ongoing discussion on fungicide use on golf courses in Germany.

<table>
<thead>
<tr>
<th>Fungicide</th>
<th>Norway</th>
<th>Sweden</th>
<th>Finland</th>
<th>Denmark</th>
</tr>
</thead>
<tbody>
<tr>
<td>Acanto Prima (picoxystrobin + cyprodinil)</td>
<td>X*</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Amistar (azoxystrobin)</td>
<td></td>
<td>X*</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Banner Maxx (propiconazole)</td>
<td></td>
<td></td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>Basso (propiconazole + prochloraz)</td>
<td></td>
<td></td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>Delaro (trifloxystrobin + prothioconazole)</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Folicur (tebuconazole)</td>
<td></td>
<td></td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>Headway (azoxystrobin + propiconazole)</td>
<td></td>
<td></td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>Medallion TL (fludioxonil)</td>
<td></td>
<td></td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>Proline (prothiocoumarole)</td>
<td></td>
<td></td>
<td></td>
<td>X*</td>
</tr>
<tr>
<td>Sportak EW (prochloraz)</td>
<td></td>
<td></td>
<td></td>
<td>X*</td>
</tr>
<tr>
<td>Stratego (trifloxystrobin + propiconazole)</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Switch (fludioxonil + cyprodinil)</td>
<td></td>
<td></td>
<td>X*</td>
<td></td>
</tr>
<tr>
<td>Tilt (propiconazole)</td>
<td></td>
<td></td>
<td></td>
<td>X</td>
</tr>
</tbody>
</table>

Table 1. Fungicides approved for use on golf courses in Norway, Finland, Sweden and Denmark as of 1 November 2014 (* = minor use (formerly ‘off-label’) registration).
The data for this study was generated in 2003 from a creeping bentgrass (Agrostis stolonifera) green at Fullerö GC in Västerås, approximately 70 km west of Stockholm.

The green was constructed in 1999 with either 2%, 3% or 4% (w/w) organic matter (OM) from peat in the rootzone. Iprodione was applied at rates up to 6.8 kg a.i ha\(^{-1}\) once or twice per year in 1999, 2000 and 2001. Concentrations of up to 10 μg L\(^{-1}\) of iprodione in drainage water were measured in 2001, and this value can be compared with 17 μg L\(^{-1}\) which is the ‘Norwegian Predicted No Effect Concentration for Aquatic Organisms’ (PNEC value) and with EU’s guideline for a maximum concentration of 0.1 μg L\(^{-1}\) for any pesticide in drinking water. In 2002 there was no fungicide application, and

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**Study no 1:**
**Sorption, degradation and leaching of the fungicide iprodione in a golf green: Measurements, modelling and risk assessment**

(Strömqvist & Jarvis 2005)
samples taken of drainage water before the first application in 2003 showed only traces of iprodione (0.04 μg L⁻¹) from the applications in 1999-2001.

In 2003 the green received iprodione at a rate of 3.0 kg a.i. ha⁻¹ on 2 September and 14 November. These applications were followed by analyses for residues in soil and water samples. Decomposition of iprodione was also studied in an incubation experiment with soil from the rootzone containing 2% OM. Data were used to calibrate the pesticide leaching model MACRO, originally developed in Sweden for agricultural soils (Larsbo & Jarvis 2003), to USGA rootzones.

The highest concentration of iprodione measured in 2003 was 2.0 μg L⁻¹ in leachate from the rootzone with 2% OM. Although only one fifth of the concentration measured two years earlier, this value was higher than predicted by the MACRO model, and the authors concluded that it was most likely due to finger flow caused by soil water repellency, which was not accounted for by MACRO.

Another interesting finding was that degradation of iprodione was bi-phasic, with a rapid initial phase (half life 17 h) caused by microbial degradation. After 5 days the degradation rate slowed significantly with an expected half-life of 38 days. The rapid initial biodegradation of iprodione is in agreement with earlier studies showing that certain microbes specialize in using iprodione as their carbon source (Sigler et al. 2000). It also explains why many Scandinavian greenkeepers experienced that increasing rates of iprodione were needed to achieve the same level of control when the product was used repeatedly over several years. When withdrawn in 2009, the labeled rate of iprodione for use on Swedish golf courses was a high as 7.5 kg a.i. ha⁻¹.

Simulation using the MACRO model showed a 22 times increase in the predicted maximum concentration of iprodione in drainage water if the amount of organic matter in the rootzone was reduced from 2 to 1%. Conversely would an increase in OM to 3% reduce the predicted maximum concentration by 93.5% compared with the 2% baseline value, and this was also confirmed by analyses of drainage water.

Finally, in spite of the microbial degradation, the Swedish study showed a concentration of 1.4 mg iprodione per kg dry soil in the top 3 cm layer on 10 December 2003, approximately four weeks after the last application on 14 November and shortly prior to the first freezing event of the winter. The researchers estimated that this could potentially result in iprodione concentrations of up to 300 μg L⁻¹ in surface runoff and recommended that this aspect should be included in future work on pesticide fate on golf courses.
Study no 2: Disease control and leaching potential of fungicides on golf greens with and without organic amendment to the sand-based root zone (Aamlid et al. 2009a)

This study was conducted in 2004 and 2005 using the USGA-green field lysimeter facility at the Bioforsk Turfgrass Research Center Landvik on the Norwegian south coast (Fig. 1). The one year old USGA-greens either had straight sand (SS) rootzones with an ignition loss of 0.4 %, or rootzones amended with composted garden waste (GM = Green Mix) with an ignition loss of 2.1 %. Prochloraz (Sportak, 0.45 g a.i. ha\(^{-1}\)), azoxystrobin + propiconazole (Amistar Duo, 0.20 + 0.125 kg a.i. ha\(^{-1}\)) and trifloxystrobin + propiconazole (Stratego, 0.188 + 0.125 kg a.i. ha\(^{-1}\)) were applied in early September and late October/early November in both years. Following each application, drainage water was collected during two periods, one representing the first 1-3 days after application and the second representing the following 4-28 days depending on rainfall.

The results showed that the concentrations of azoxystrobin and propiconazole in leachate from SS rootzones were often higher than the PNEC values which are 0.95 and 0.13 μg L\(^{-1}\) for azoxystrobin and propiconazole, respectively. Among 64 samples the highest detections of azoxystrobin and propiconazole were 2.30 and 0.21 μg L\(^{-1}\) respectively, both from SS rootzones sprayed with Amistar Duo. By contrast, all samples of drainage water from the GM rootzones showed only small and insignificant traces of any fungicide, and this was also the case for prochloraz and trifloxystrobin in leachate from SS rootzones. As there was no significant difference between azoxystrobin + propiconazole (Amistar Duo) and trifloxystrobin+propiconazole (Stratego) in the control of the target diseases Microdochium nivale and Typhula incarnata, we concluded that the latter combination should be preferred for snow mold control on golf greens constructed with no organic amendment to the sand-based rootzone. However, as it has later been shown that even trifloxystrobin is rapidly broken down to the toxic metabolite CGA321113, the safest precaution will always be to include a certain amount of organic matter in the rootzone.
Fig. 1a (page 6) and b (above). From the construction of the USGA-green field lysimeters at the Bioforsk Turfgrass Research Center Landvik in 2003. The lysimeters were filled with either straight sand (SS, ignition loss 0.4 %) or Green Mix (compost-amended sand, ignition loss 2.1 %). Photo: Trygve S. Aamlid.
This study was conducted in 2006 and 2007 using the same rootzone compositions (GM and SS) as in the previous study. The fungicides tested for their liability to leaching were iprodione (Rovral 75 WG, 1.5 kg a.i. ha\(^{-1}\)) and azoxystrobin + propiconazole (Amistar Duo, 0.6 + 0.375 kg a.i.ha\(^{-1}\)). The high rate of Amistar Duo was used to simulate a situation in which the product is drenched into the soil to control take-all patch. Both fungicides were applied in May, June and October 2006 and drainage water collected during a period of 2-4 weeks after each application plus a two-week period shortly after snow melt / soil thaw in April 2007. The total rainfall and drain discharge during the collection periods were 150 and 180 mm, respectively, the difference mainly being ascribed to irrigation after fungicide application in May and June 2006.

A new experimental factor added in this study was the use of the non-ionic soil surfactant Primer 604 (Aquatrols, Paulsboro, New Jersey, USA). Even though there were no obvious dry spots in spring 2006, our hypothesis was that the surfactant would reduce soil water repellency and thus the preferential finger flow often occurring on hydrophobic soils. Primer 604 was chosen because it – at the time being – was the most widely used surfactant on golf courses in

Study no 3:
Fungicide leaching from golf greens: Effects of root zone composition and surfactant use (Larsbo et al. 2008)
Scandinavia, and it was applied at monthly intervals during the growing season 2006 at a rate of 19 L ha\(^{-1}\) diluted into an application volume of 750 L ha\(^{-1}\).

As on the previous study, the use of GM rootzones (2 % (w/w) OM from compost) almost totally eliminated the leaching of any fungicide regardless of surfactant use. On average for iprodione, azoxystrobin and propiconazole, the reduction was 99.6 % compared with the SS rootzones with 0.4 % OM. All three fungicides were detected in discharge form the SS rootzones, but at significantly lower levels on plots treated with surfactant than on untreated plots (Fig. 2).

Measurements of water droplet penetration times (WDPT) confirmed that this difference in fungicide leaching was due to a reduction in soil water repellency after the application of the soil surfactant. The figures also showed that all three fungicides, and especially propiconazole, persisted in the soil in April 2007, six months after the last application. This is an agreement with Norwegian studies showing a strong effect of soil temperature on fungicide half lives (Almvik et al. 2014).

![Fig. 2. Effects of the surfactant treatment on fungicide concentrations in drainage water for four individual collection periods in 2006 and 2007 (Larsbo et al. 2008).]
Study no 4:
Effects of surfactant use and peat amendments on leaching of fungicides and nitrate from golf greens (Aamlid et al. 2009b)

This study was also conducted in the lysimeter facility, but instead of using the compost-amended rootzones, leaching from the SS rootzones was now compared with that from rootzones amended with Sphagnum Peat (SP, ignition loss 2.5 % (w/w)). Instead of Primer 604 we also used a newer surfactant, Revolution, applied at monthly rates of 20 L ha\(^{-1}\) in an application volume of 750 L ha\(^{-1}\) from May to September. Azoxystrobin + propiconazole (Amistar Duo, 0.600 + 0.375 kg a.i. ha\(^{-1}\)) was applied on 7 June, 28 Aug. and 17 Oct. 2007, and leachate collected during the following 2-4 weeks as the previous studies.

The analyses of drainage water confirmed the critical role of OM in reducing fungicide leaching from sand-based golf greens. However, on average for collection periods and the two active ingredients, the 93 % reduction in fungicide leaching in this study was not as complete as the earlier studies with compost, and this was probably due to a lower microbial activity in the SP than in the GM rootzone (Aamlid et al. 2009a). The use of surfactant resulted in an average reduction in fungicide leaching of approximately 80 %, and there was also a corresponding reduction in the leaching of nitrate.

Table 2 shows that the PNEC-limits for azoxystrobin (0.95 μg L\(^{-1}\)) and propiconazole were exceeded 15-30 times for SS rootzones without surfactants and up to two times for SS rootzones with surfactant and SP rootzones without surfactant. Thus, only the discharge from SP rootzones treated with surfactants held an acceptable water quality in this study.

<table>
<thead>
<tr>
<th>Organic amendment</th>
<th>Surfactant</th>
<th>Azoxystrobin μg L(^{-1})</th>
<th>Propiconazole μg L(^{-1})</th>
</tr>
</thead>
<tbody>
<tr>
<td>No (Straight sand, SS)</td>
<td>No</td>
<td>13.83</td>
<td>3.98</td>
</tr>
<tr>
<td>No (Straight sand, SS)</td>
<td>Revolution</td>
<td>1.83</td>
<td>0.40</td>
</tr>
<tr>
<td>Sphagnum peat (SP)</td>
<td>No</td>
<td>1.75</td>
<td>0.21</td>
</tr>
<tr>
<td>Sphagnum peat (SP)</td>
<td>Revolution</td>
<td>0.38</td>
<td>0.04</td>
</tr>
<tr>
<td>PNEC-value</td>
<td></td>
<td>0.95</td>
<td>0.13</td>
</tr>
</tbody>
</table>

Fig. 2. Effects of the surfactant treatment on fungicide concentrations in drainage water for four individual collection periods in 2006 and 2007 (Larsbo et al. 2008).
The most important finding in these studies was the strong reduction in the risk for fungicide leaching after adding 2-3 % of organic matter to the sand-based rootzones. In particular the inclusion of a mature and uniform compost with a high microbial activity offers prospects for an almost total elimination of the risk for fungicide leaching. Green Mix from composting plants in Jutland and Sealand have for many years been used in USGA-spec. rootzones on Danish golf courses, and results from the ongoing project FESCUE GREEN suggest that such rootzones have many advantages also with regard to establishment rate and playing quality (Aamlid et al. 2014). Substitution of Sphagnum Peat with compost are likely to have a mitigating effect on the carbon balance for golf courses, but there may also be disadvantages related to content of phosphorus in drainage water. In any case it is a good thing that the German standard (FLL 2008), unlike the 2004 revision of the USGA recommendations, still requires an ignition loss of 1.5 to 2.5 % in the rootzones for all types of golf greens.

The use of soil surfactants to control localized dry spots is a common practice among golf course managers, and there are many different surfactant chemistries on the market (for a historical review on surfactant and their mode of action, see Zontek & Kostka 2012). Today, most of the products are non-ionic block polymers; organic molecules that - to the best of my knowledge - have no documented negative impact on the environment. As the availability of irrigation water for turf becomes increasingly limited in many countries, it is an added benefit if the use of such products will not only contribute to better turf quality under water stress (Kostka et al. 2007), but also to reduced risks for pesticide leaching. The need for surfactants is, however, likely to be lower on rootzones containing an optimal ratio of well-defined compost than on rootzones without organic amendment or a low content of Sphagnum peat.

The fungicides formulations tested in these studies were mostly the agricultural products that were available to Scandinavian greenkeepers six to ten years ago. It
remains to be elucidated to what extent special turfgrass formulations such as Banner Maxx (propiconazole) or Headway (azoxystrobin + propiconazole) have different chemical properties that might reduce the risk for fungicide leaching.

There should also be a joint interest for the German and Scandinavian golf industry to test the benefits and environmental risks of using fludioxonil (Medallion), boscalid (Signum), mancozeb (Dithane), prothioconazole (Proline, Delaro) or other fungicides that have already entered the turf market or are likely to do so in the near future. With reference to Table 3, the environmental risks of using fungicides will usually increase with decreasing sorption coefficients and with increasing degradation half-lives, but this has to be verified for the special root-zone compositions and fungicide formulations used on golf courses. As exemplified by trifloxystrobin and prothioconazole in Table 3, it should also be kept in mind that some fungicide are easily broken down to metabolites that are more harmful and persistent in the environment than the fungicide itself.

Finally, as these studies were limited to fungicides in drain discharge, there is a need for more research into the risk for pesticides in surface runoff from undulated golf greens and other turfgrass areas. Environmental monitoring of Norwegian agricultural areas (Bechmann 2014, Stenrød 2014) and American turfgrass areas (e.g. Slavens & Petrovic 2012, King & Balogh 2013) have shown high pesticide concentrations in surface runoff during the first days after application, but to the best of my knowledge there are no such studies with the fungicides currently approved on Scandinavian or German golf courses. This is an area that requires more attention in the near future, and we are currently considering extending and remodeling the Bioforsk lysiometer facility to include documentation of not only drainage, but also surface water. I would recommend that this should become an area for joint projects between the German Golf Federation, the Scandinavian Turfgrass and Environment Research Foundation (STERF), and perhaps other European collaborators (e.g. the Dutch Turfgrass Research Foundation).

<table>
<thead>
<tr>
<th>Fungicide or metabolite</th>
<th>Products</th>
<th>$K_{\text{foc}}$ (ML g$^{-1}$)</th>
<th>$DT_{50}$ (days)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Azoxystrobin</td>
<td>Amistar, Heritage, Headway</td>
<td>423</td>
<td>18</td>
</tr>
<tr>
<td>Boscalid</td>
<td>Signum</td>
<td>772</td>
<td>118</td>
</tr>
<tr>
<td>Cyprodinil</td>
<td>Acanto Prima, Switch</td>
<td>2277</td>
<td>45</td>
</tr>
<tr>
<td>Fludioxonil</td>
<td>Medallion, Switch</td>
<td>132100</td>
<td>21</td>
</tr>
<tr>
<td>Iprodione</td>
<td>Chipco Green, Rovral</td>
<td>373</td>
<td>84</td>
</tr>
<tr>
<td>Mancozeb</td>
<td>Dithane</td>
<td>No data</td>
<td>18</td>
</tr>
<tr>
<td>Picoxystrobin</td>
<td>Acanto Prima</td>
<td>898</td>
<td>20</td>
</tr>
<tr>
<td>Prochloraz</td>
<td>Sportak, Basso</td>
<td>1440</td>
<td>17</td>
</tr>
<tr>
<td>Propiconazole</td>
<td>Banner Maxx, Basso, Tilt, Headway, Stratego</td>
<td>2252</td>
<td>214</td>
</tr>
<tr>
<td>Prothioconazole</td>
<td>Proline, Delaro</td>
<td>2256</td>
<td>2</td>
</tr>
<tr>
<td>Prothioconazole – desthio (metabolite)</td>
<td></td>
<td>576</td>
<td>422</td>
</tr>
<tr>
<td>Pyraclostrobin</td>
<td>Signum</td>
<td>9315</td>
<td>32</td>
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<tr>
<td>Tebuconazole</td>
<td>Folicur</td>
<td>769</td>
<td>47</td>
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<tr>
<td>Trifloxystrobin</td>
<td>Delaro, Stratego</td>
<td>2377</td>
<td>7</td>
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<tr>
<td>Trifloxystrobin acid (metabolite)</td>
<td></td>
<td>121</td>
<td>70</td>
</tr>
</tbody>
</table>

Table 3. Freudlich coefficients for sorption to organic matter ($K_{\text{foc}}$-values) and degradation half lives ($DT_{50}$) under field conditions for fungicides that are currently approved or might receive approval for use on German and/or Scandinavian golf courses in the future (http://sitem.herts.ac.uk/aeru/iupac/Reports).
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