Core Cultivation and Efficacy of Benomyl Applied to Creeping Bentgrass
Leon X. Liu, Tom Hsiang and Jack L. Eggens
Leon X. Liu and Tom Hsiang, Department of Environmental Biology, University of Guelph, Guelph, Ontario, N1G 2W1. Jack L. Eggens, Department of Horticultural Science, University of Guelph, Guelph, Ontario, N1G 2W1. Corresponding author.

ABSTRACT
Hollow tine core cultivation is practiced for the management of creeping bentgrass (Agrostis palustris Huds.) golf course greens and fairways to increase water infiltration, increase turf root and shoot growth, and control thatch. Benomyl [methyl 1-(butylcarbamoyl)-2-benzimidazole carbamate] is commonly used on turf as a soil drench for the control of disease such as dollar spot (caused by Sclerotinia homoeocarpa Bennett). Our objective was to determine the effect of core cultivation on the movement of a systemic pesticide in thatch and soil and the uptake by turfgrass using benomyl as a model. Core cultivation was conducted 1, 7, and 14 days before benomyl application in a field trial during 1992 and 1993 to study the effect of coring and time of coring on the movement and uptake of benomyl and control of dollar spot disease. Fungicide levels in turfgrass clippings, thatch and soil were determined by bioassay. Core cultivation 1 day before benomyl treatment provided the longest-lasting uptake of benomyl and control of dollar spot disease compared to 7 and 14 days before benomyl treatment. Clipping, thatch, and soil samples from areas close to the coring holes had significantly higher ($P = 0.05$) levels of fungicide residues than those farther away from the coring holes. This study suggests that core cultivation shortly before benomyl application can increase movement of benomyl into thatch and soil, increase uptake of benomyl by turfgrass, and therefore improve disease control.

INTRODUCTION
Pesticides are often applied as soil drenches for the control of harmful organisms in soil or foliage of plants. This is usually achieved by applying a large volume of water to act as a carrier for the active ingredient. The biological efficacy of a pesticide depends on the distribution of the pesticide in the soil and the rooting habit of the plant (Morrod, 1982). Because infiltration is usually low on hydrophobic thatch and sand (Taylor and Blake, 1982; Miyamoto, 1985) and because thatch adsorbs large amounts of applied pesticides (Niemczyk and Filary, 1988), the movement of pesticides through thatch into soil may be limited. Niemczyk and Filary (1988) applied nine insecticides to turfgrass and found that despite 1.25 cm of irrigation immediately after treatment, 96 to 99% of the pesticide residues remained in the thatch during the seven days following application. Other studies have been conducted to increase the efficacy of pesticides in turf by applying wetting agents (Miyamoto, 1985; Liu and Hsiang, 1994) or subsurface application of pesticides (Niemczyk, 1993).

Hollow tine coring involves the use of a tine or spoon to remove soil and thatch which then leaves a hole or cavity in the sod. The depth of penetration is usually 7 to 10 cm with the cores spaced on 5- to 15-cm centres (Beard, 1973). Core cultivation is commonly used on turfgrass sites during spring or fall to increase water infiltration, stimulate root and shoot growth, alleviate compaction and control thatch (Turgeon, 1985). Byrne et al. (1965) and Canaway et al. (1986) found that coring increased water infiltration into compacted putting greens. They suggested that surface compaction, hydrophobic thatch, and surface layering can severely restrict infiltration, and if coring holes traverse these restrictions, substantial increases in infiltration capacity are possible in direct response to coring. Carrow (1988) reported that hollow tine coring was the most effective cultivation method for reducing penetrometer resistance. According to Turgeon (1985), the increase in surface area can be more than doubled when the area of the side walls of the holes are added to that of the turf surface. This increase in surface area could also account for the greater infiltration capacity of core cultivated turf.

Coring can result in an improvement of growing conditions in the immediate vicinity of the holes as long as moisture is not limiting (Turgeon, 1985). Barber and Carrow (1985) showed improved oxygen diffusion rates from hollow tine coring. Root growth in the 2 to 6 cm zone below soil surface increased by up to 35% and water extraction from this zone also increased by coring (Wiecko et al., 1993).

There has been limited investigation into the effects of core cultivation on the movement and uptake of pesticides by turfgrass. The increased infiltration and increased root growth of turfgrass may increase the efficacy of a pesticide. The objective of this study was to use the systemic fungicide benomyl as a model to examine the effect of core cultivation on pesticide movement in thatch and soil and the uptake of pesticide by turfgrass.

MATERIALS AND METHODS
Effect of Coring on Benomyl Uptake
Turf used in this experiment was a 13-year-old sand-based green seeded with 'Penncross' creeping bentgrass at the Cambridge Research Station, University of Guelph, Guelph, Ontario. The soil is Fox sandy loam (Brunisolic Gray Brown Lurisol) (76.9% sand; 17.0% silt; 6.1% clay; 1.7% organic matter; pH 5.2; CEC 12.5 c kg$^{-1}$). The turf was mowed daily at a 5 mm height and irrigated as needed to prevent wilt.

Each turf plot (1 x 2 m) was cored with a hollow tine coring machine (Ryan Greensaire, 12.5 mm diam, 7 cm depth, and 7 cm apart) on August 13, 20 or 26, 1992 and on August 12, 19 or 25, 1993. Plots were treated with benomyl on August 27, 1992 and on August 26, 1993. This allowed for a schedule of coring at 1, 7, or 14 days before benomyl treatment (DBBT). The soil cores were removed from the plots. Fungicide Tersan 1991 (50% a.i. benomyl) at a rate of 3 kg ha$^{-1}$ was applied in water at 1250 L ha$^{-1}$. The fungicide was applied with a bicycle-wheel-mounted air pressure sprayer. The plots were watered (20 mm) immediately after fungicide treatment. The plots were arranged in a randomized complete block design with four replicates for each treatment including a non-cored control.

One day after fungicide treatment, four samples of turfgrass clippings at 0 to 10, 11 to 20, and 21 to 30 mm away from the coring holes were collected and stored at -20C. Samples of the upper 10 mm of thatch (which ranged in depth from 14 to 21 mm) and the upper 10 mm of soil were also collected and stored at -20C. The thatch and soil were air-dried (24 h) before testing for both benomyl and methyl 2-benzimidazole carbamate (MBC) using sample-agar pellet bioassay (Liu and Hsiang, 1994). The compound MBC is the principal fungitoxic degradation compound of benomyl. Four samples of turfgrass clippings were collected with hand shears from each plot at 1, 3, 7, and 14 days after fungicide treatment and stored at -20C for analysis using the bioassay.

Control of Dollar Spot Disease
To determine the effects of coring on the efficacy of benomyl for control of dollar spot disease, each plot was inoculated with *Sclerotinia homoeocarpa* one day after fungicide treatment and then weekly for three weeks after treatment. The inoculum was prepared by soaking mixed cereal grains in water for 24 h, autoclaving twice in canning jars, and then inoculating with five strains of *S. homoeocarpa* separately. These strains originated from Southern Ontario. After incubating for 3 weeks at 23°C, the mixed grain was ground and mixed and passed through a 1 mm sieve. For a uniform distribution, 20 g of sand was mixed with 2 g of inoculum before application. The development of dollar spot disease was evaluated visually at 1, 7, 14, 21, and 28 days after fungicide treatment in both 1992 and 1993.

A preliminary analysis found no significant interactions between treatment and the year of the experiment although there was a significant difference between the data of two years. Analysis of variance (ANOVA) was conducted on combined data from two field seasons for fungicide concentration in turfgrass clippings, thatch and soil, and on the log number of dollar spots in each plot. Duncan's Multiple Range test was used to separate the treatment means when the ANOVA F-test indicated that the treatment effect was significant (*P* = 0.05). The test of least significant difference (LSD) was used to separate mean concentrations of benomyl in clippings for each collection date.

## RESULTS AND DISCUSSION

### Benomyl Residues in Turfgrass Clippings

#### Coring 14 Days Before Benomyl Treatment

Coring had a significant effect on the uptake of benomyl by turfgrass. Among all coring treatments, plots cored 14 DBBT gave the highest benomyl concentration in turfgrass clippings 1 and 3 days after the fungicide treatment (Fig. 1), and the concentration three days after the fungicide treatment was significantly higher than that cored one DBBT and the non-cored control. However, the concentration of benomyl in clippings of plots cored 14 DBBT was not significantly different from the non-cored control 7 and 14 days after the fungicide treatment. This could be due to the ephemeral coring holes. By two weeks after coring, vigorously growing roots and leaves, and clippings or soil may have covered or filled the holes and reduced the water infiltration and fungicide movement into the soil as has been reported by Turgeon (1985). Root growth is improved by coring (Murphy and Rieke, 1987), and therefore the higher fungicide concentration in clippings 1 and 3 days after the fungicide treatment was most likely due to the increased uptake by new roots produced within the coring holes. However, the amount of fungiciding entering the holes was likely limited by covering or filling in of the holes, and thus did not provide long-lasting effects. Benomyl/MBC could not be detected by bioassay at 21 days after benomyl application for plots cored 14 DBBT or non-cored control.

#### Coring 7 or 1 Day Before Benomyl Treatment

Coring 7 DBBT resulted in the highest level of fungicide in turfgrass clippings at 7 days after fungicide treatment (Fig. 1). By 14 days after fungicide treatment, the fungicide level in clippings decreased sharply and there was no significant difference between coring treatment of 1 and 7 DBBT. On day 21 after fungicide treatment, the fungicide level was still detectable by the bioassay in plots cored 7 DBBT, but it was significantly lower than coring 1 DBBT.

The results over the whole experimental period showed that coring 7 DBBT gave the highest peak concentration, but coring 1 DBBT gave the longest lasting detectable levels of benomyl. Coring 1 DBBT would have provided the largest surface area at time of fungicide application, and thus allowed greater inflow of fungicide into the soil with subsequent waterlogging. The degradation of fungicide in soil is much slower than in the thatch (Liu and Hsiang, 1994), and therefore a greater amount of fungicide would reach the root zone and could be taken up over a longer period for translocation to the turfgrass leaves (Peterson and Edgington, 1971). Unlike other grass crops, turfgrasses, especially creeping bentgrass, are frequently mowed, and thus fungicide in leaf blades is removed with the clippings. A high and long-lasting uptake of a systemic fungicide from the soil is advantageous for effective control of foliar turfgrass diseases.

### Benomyl Residues at Distances from Coring Holes

#### Turfgrass Clippings

One day after benomyl treatment, the clippings collected within 10 mm of the coring holes from plots cored 14 DBBT had significantly higher levels of benomyl than those of plots cored 7 or 1 DBBT (Table 1). This effect was similar to that observed when clippings from each plot were tested 1 and 3 days after fungicide treatment (Fig. 1). Core cultivation increases root growth or root hair activity (Murphy and Rieke, 1987; Wiecko et al., 1993), and this likely increased the level of benomyl uptake. Further away from the coring holes (> 11 mm away), no significant differences were found.

Benomyl level in clippings from plots of all coring treatments decreased as distance from the coring hole increased (Table 1). Between plots cored 14 and 7 DBBT, no significant differences were found in clippings collected 11 to 30 mm away from the coring holes. Benomyl in clippings from plots cored 1 DBBT and collected at 11 to 20 or 21 to 30 mm away from the coring holes, was not detectable by bioassay. Because of good air porosity and root growth from coring (Agnew and Christians, 1993; Wiecko et al., 1993), the mass of newly-grown roots near the coring holes cultivated 14 DBBT was likely higher than that of 7 and 1 DBBT at 1 day after the fungicide treatment. This may have resulted in significantly higher uptake of the fungicide as seen 1 and 3 days after fungicide treatment (Fig. 1).

For plots cored 1 DBBT, extensive root growth was not likely to have occurred within two days. Therefore, only turfgrass clippings closely surrounding the coring holes (0 to 10 mm) had a detectable level of benomyl one day after fungicide treatment (Table 1). However, the fungicide level in clippings from plots cored 1 DBBT increased very quickly in the first week and maintained the highest levels when tested 14 and 21 days after fungicide application (Fig. 1). This suggested that increased root growth and the movement of benomyl play important roles in the uptake of the fungicide.

#### Thatch

The level of benomyl in thatch was significantly higher than that in grass clippings one day after benomyl treatment (Table 1). For all coring treatments, fungicide levels decreased with increasing distance away from the coring holes. This suggested that coring improved the fungicide movement into thatch and soil especially around the coring holes. Within 10 mm of the coring holes, benomyl concentration in the thatch cored 1 DBBT was significantly higher than those cored 7 and 14 DBBT. This was likely related to the greater initial inflow of the fungicide into the coring holes by water carrier of the fungicide when turf was newly cored. The highest concentration of benomyl was found in thatch within 10 mm of the coring holes on plots cored 1 DBBT.

For thatch 11 to 20 and 21 to 30 mm away from the coring holes, the fungicide levels were not significantly different among the three coring treatment intervals. The high levels of fungicide in thatch (Table 1) also confirmed the report that a large proportion of the applied pesticide stays in the thatch layer (Nienczcyk, 1988).

#### Soil

Soil cored 1 DBBT had significantly higher concentrations of benomyl than that cored 7 or 14 DBBT at all distances from
the coring holes (Table 1). As observed in clippings and thatch, benomyl level decreased with increasing distance from the coring holes. Core cultivation can increase water infiltration capacity (Byrne et al., 1965) and thus the mass flow of water from irrigation could move the fungicide through the holes down to the soil where active roots are located. This may have allowed increased uptake by plants compared with non-cored plots. Higher fungicide levels in the soil 11 to 20 and 21 to 30 mm away from the coring holes in plots cultivated 1 DBBT compared plots cored 7 and 14 DBBT were likely due to the diffusion of fungicide from soil near the coring holes rather than movement through thatch layer.

Control of Dollar Spot Disease

The number of dollar spot patches was inversely related to the level of benomyl in turfgrass clippings, and all plots treated with benomyl had significantly fewer dollar spot patches than the untreated check (Table 2). However, except at 14 days after treatment, dollar spot patches on plots cored 14 DBBT was not significantly different from that of non-cored plots within 28 days after benomyl treatment. Again this may have been due to the covering or filling of cores cultivated 14 DBBT, which resulted in lower levels of benomyl in clippings at 7, 14, and 21 days after fungicide application (Fig. 1). Plots cored 1 or 7 DBBT had fewer dollar spot patches, and these were not visible until day 21 for both treatments. Coring 1 DBBT gave the best disease control. This was likely due to the higher level of benomyl residues in turfgrass clippings at 14 and 21 days after fungicide treatment (Fig. 1).

CONCLUSIONS

Hollow tine core cultivation increased the efficacy of benomyl applied to creeping bentgrass. Fungicide application 1 day after core cultivation provided the best control of dollar spot disease. Coring 1 day and 7 days before benomyl treatment gave significantly higher and longer-lasting benomyl residues in turfgrass clippings one week after fungicide treatment than the non-cored control and coring 14 days before fungicide treatment. Increased water infiltration and root growth from core cultivation could contribute to increased efficacy of benomyl. The number of dollar spot patches was inversely related to fungicide levels in the turfgrass clippings. In general, fungicide levels in turfgrass clippings, thatch and soil close to the coring holes were higher than those away from the coring holes. This study suggests that core cultivation shortly before benomyl application can increase movement of benomyl into thatch and soil, increase uptake of benomyl by turfgrass, and therefore improve disease control.

LITERATURE CITED

Table 1. Benomyl in turfgrass clippings (freshly-frozen), thatch (10 mm deep, air-dried) and soil (10 mm deep, air-dried) at different distances from coring holes at 1 day after benomyl treatment.

<table>
<thead>
<tr>
<th>Concentration of benomyl</th>
<th>Time of coring</th>
<th>Clippings</th>
<th>Thatch</th>
<th>Soil</th>
</tr>
</thead>
<tbody>
<tr>
<td>µg g⁻¹</td>
<td>Distance</td>
<td>Distance</td>
<td>Distance</td>
<td></td>
</tr>
<tr>
<td></td>
<td>0-10</td>
<td>11-20</td>
<td>21-30</td>
<td></td>
</tr>
<tr>
<td></td>
<td>0-10</td>
<td>11-20</td>
<td>21-30</td>
<td></td>
</tr>
<tr>
<td>14</td>
<td>1.2a</td>
<td>0.8a</td>
<td>0.7a</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>0.8b</td>
<td>0.5a</td>
<td>0.5a</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>0.6b</td>
<td>ND</td>
<td>ND</td>
<td></td>
</tr>
</tbody>
</table>

Numbers with the same letter in a column are not significantly different from each other at P = 0.05. Each number is the mean of combined data from two field seasons with four replicates each year. ND refers to not detectable by bioassay (< 0.5 µg g⁻¹), and these values were not included in the statistical analysis.

Table 2. Number of dollar spot patches on 2 m² plots treated with Tersan 1991 at 3 kg ha⁻¹.

<table>
<thead>
<tr>
<th>Dollar spot patches</th>
<th>Core cultivation</th>
<th>Days after fungicide treatment</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(days before 1)</td>
<td>7</td>
</tr>
<tr>
<td>Untreated check</td>
<td>0</td>
<td>3a</td>
</tr>
<tr>
<td>Not cored</td>
<td>0</td>
<td>0b</td>
</tr>
<tr>
<td>Cored 14 days</td>
<td>0</td>
<td>0b</td>
</tr>
<tr>
<td>Cored 7 days</td>
<td>0</td>
<td>0b</td>
</tr>
<tr>
<td>Cored 1 day</td>
<td>0</td>
<td>0b</td>
</tr>
</tbody>
</table>

The untreated check received no fungicide and was not cored.

Numbers with the same letter in a column are not significantly different from each other at P = 0.05. Each number is the mean of combined data from two field seasons with four replicates each year.
Figure 1. Effect of time of coring (DBBT, days before benomyl treatment) on level of benomyl in turfgrass clippings collected at different times after treatment with Tersan 1991 (3 kg ha$^{-1}$). For the non-cored control and plots cored 14 DBBT, benomyl was not detectable by bioassay ($< 0.5 \mu$g g$^{-1}$) at 21 days after fungicide treatment. The dashed line indicates extrapolation to non-detectable values. For each collection date, the bar above the data points represents the LSD value ($P = 0.05$). Each data point is the mean of combined data from two field seasons with four replicates in each year.