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Effect of a Wetting Agent on Adsorption, Movement and Uptake of Benomyl Applied to Creeping Bentgrass[1]

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ABSTRACT

Laboratory and field experiments showed that the wetting agent Aqua-Gro (AG) (polyoxyethylene ester and ether of cyclic acid and alkylated phenols) significantly reduced the adsorption of the fungicide benomyl [methyl 1-(butylcarbamoyl)-2-benzimidazole carbamate] by creeping bentgrass (*Agrostis palustris* Huds.). With AG, significantly less fungicide was initially adsorbed and significantly more fungicide was desorbed from the thatch layer after 20 mm of water irrigation (P = 0.05). Aqua-Gro increased movement, uptake, and biological availability of the fungicide and resulted in a higher residue level of fungicide in the grass clippings. For dollar spot disease, benomyl applied at 1 kg ha^{-1} with AG gave as good control as the recommended rate of 1.5 kg ha^{-1} without AG.
Keywords: Benomyl, thatch, adsorption, Aqua-Gro, *Agrostis palustris*, *Sclerotinia homoeocarpa*.

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INTRODUCTION

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The primary functions of a surfactant added to a pesticide solution are to promote wetting, coverage and uptake of the pesticide by leaves. However, the hydrophilic-lipophilic properties of surfactants suggest that they may have additional functions. Gillard (1987) proposed that the addition of a surfactant to a standard formulation would enhance product efficacy. This is achieved by altering the physical characteristics, extending the period of activity, overcoming resistance developed by a target species to a pesticide, and enabling lower doses of pesticides to be used. Rawlins and Booth (1968) showed that the surfactant Tween-20 increases the root uptake of benomyl for the control of Verticillium wilt of cotton. Nowacka et al. (1979) demonstrated that the surfactants Euphytan® (98.8% mineral oil and 1.2% emulsifier) and Triton CS® (36% alkylarile polyetoxylate and 40% sodium salt) permitted a three-fold reduction of spray concentration of benzimidazole fungicides without lowering the efficacy of those compounds for the control of apple scab.

Thatch is a tightly intermingled layer of dead and living stems and roots that develops between the zone of green vegetation and the soil surface (Beard, 1973). Thatch and sand grains on golf greens can be difficult to wet because the surface of thatch and sand grain particles may be water-repellent which can lead to localized dry spots (Miller and Wilkinson, 1977; Taylor and Blake, 1982; Miyamoto, 1985). Wilkinson and Miller (1978) reported that the infiltration rate within the dry spots was 20% of that for normal turf. Miller and Letey (1975) and Pelishek et al. (1962) reported that wetting agents increase infiltration rates into hydrophobic thatch and soil.

Aqua-Gro (AG) (50% polyoxyethylene ester and 50% polyoxyethylene ether of cyclic acid and alkylated phenols with silicone anti-foam emulsion; Aquatrols Corp. of America, Pennsauken, NJ) is a nonionic surfactant and has been used on turf to increase the water infiltration into poorly wettable thatch and sand (Wilkinson and Miller, 1978; Endo et al., 1969). Aqua-Gro has low phytotoxicity and does not reduce root growth and quality of annual bluegrass at application rates of 4.2 or 8.4 L ha^{-1} (Cooper et al., 1987). Aqua-Gro has been shown to be tightly adsorbed to the top 1 cm of soil and has a long-lasting effect (Miller and Letey, 1975).

Benomyl is a xylem-mobile compound (Solel et al., 1973), that has been recommended for turfgrass as a soil drench to control diseases such as dollar spot (caused by *Sclerotinia homoeocarpa* F.T. Bennett) and brown patch (caused by *Rhizoctonia solani* Kuhn). The fungicide must move to the root zone for root uptake and translocation to the leaves to provide full systemic protection of the plant. Limited foliar uptake has also been observed (Baude et al., 1973). Surfactants have been shown to improve fungicide mobility (Bateman, 1984; Morrod, 1982) and increase uptake of systemic pesticides by roots in soil (Rawlins and Booth, 1968). In turfgrass, however, little work has been done on the effects of wetting agents on pesticide movement in thatch and uptake by roots. The objective of this investigation was to examine the effect of AG on the adsorption, movement, and uptake of benomyl and control of dollar spot disease.

MATERIALS AND METHODS

Adsorption and desorption of benomyl from thatch in laboratory experiments

Turf used in this experiment was from a 12-year-old sand golf green seeded with `Penncross' creeping bentgrass (*Agrostis palustris* Huds.) at the Cambridge Research Station, University of Guelph, Guelph, Ontario. The soil was Fox sandy loam (Hatludals: 76.9% sand; 17.0% silt; 6.1% clay; 1.7% organic matter; pH 5.2; CEC 12.5 c/kg). The site was mowed daily at 5 mm height (clippings removed) and irrigated as needed. Thatch thickness was not uniform and a few localized dry spots were observed on the experiment plot. Care was taken to avoid sampling turfgrass/thatch/soil from or close to localized dry spots.

Thatch thickness at different locations was initially determined using a soil sampler (2.5 cm in diameter). Three cores were then taken with a putting green cup cutter (10 cm in diameter) from each location. The thatch and soil were separated, and thickness and weight of the thatch layer were recorded. Thatch plugs were then placed in porcelain funnels (10 cm in diameter), and the wall of each funnel was coated with octadecyl chlorosilane to form a water-proof barrier.

Three rates (0, 1 and 1.5 kg ha^{-1}) of benomyl (Tersan 1991, with 50% a.i. benomyl, was used) in water were mixed with two rates of AG (0 and 5 L ha^{-1}) and applied at 1250 L ha^{-1}. Each suspension was applied to a thatch plug in the funnel with a small (100 mL) pressurized spray pack. To simulate sprinkler irrigation, a volume of water equivalent to 20 mm was applied after fungicide treatment. The volume of water was divided into three and applied at 30-minute intervals. Leachate was collected and tested for benomyl and methyl 2-benzimidazole carbamate (MBC), which is the major toxic degradation compound of benomyl, using the paper disc bioassay (Liu and Hsiang, in press). The concentration of fungicide in the leachate was used to estimate the amount of fungicide remaining in the thatch. The thatch was then air dried to the same weight as prior to fungicide application and kept in a moist box at 20C. After 3 days irrigation and collection of leachate were repeated. All treatments were replicated four times.

Adsorption and uptake of benomyl in field experiments

On the previously mentioned creeping bentgrass green, the same treatments as in the previous experiment were applied in late July 1992 and 1993 to 1 x 2 m plots of an area with relatively uniform thatch thickness. The plots were laid out in a Randomized Complete Block design. Fungicide suspension was applied to each of four plots using a bicycle-wheel-mounted air pressure sprayer (1 m in width, 240 kPa). Plots were watered (20 mm) immediately after treatment and every three days thereafter, depending on rainfall. Turfgrass clippings were collected at 1, 3, 7, 14 and 21 days after fungicide treatment. At each sampling time, 10 cores (2.5 cm in diameter) were taken from each plot and the thickness of thatch from each core recorded. Clippings collected from sets of ten cores were mixed together and frozen at -20C for 24 h, as was the thatch. Four subsamples from each of the clipping and thatch mixtures were then tested for fungicide concentration using the agar-grass and agar-thatch pellet bioassays (Liu and Hsiang, in press).

Control of dollar spot disease by benomyl

To determine the preventive control of dollar spot disease by benomyl, AG, and combinations of benomyl with AG, each turfgrass plot was inoculated one day after treatment and then weekly for three weeks. Inoculum was prepared by soaking chicken scratch in water for 24 h, autoclaving twice in canning jars, and then inoculating with five strains of *Sclerotinia homoeocarpa* (collected in Southern Ontario) separately. After incubating for 3 weeks at 23C, the chicken scratch was air-dried, ground, mixed and passed through a 1 mm sieve. For a uniform distribution, 20 g of soil was mixed with 2 g of inoculum and applied to each plot. The development of dollar spot disease was evaluated visually 1, 7, 14, 21, and 28 days after fungicide treatments.

Data Analysis

The average thickness of thatch was adjusted to the same level for all plots using covariance analysis since thickness of thatch has a significant effect on pesticide adsorption (Niemczyk et al., 1988). Analysis of variance (ANOVA) was conducted on fungicide concentration in turfgrass clippings and the log number of dollar spots on each plot. Duncan's Multiple Range test ($P = 0.05$) was used to separate the treatment means when the ANOVA F-test indicated that the treatment effect was significant.

RESULTS AND DISCUSSION

Effect of AG on adsorption and movement of benomyl in thatch

The thickness of the thatch layer had a significant effect on fungicide adsorption *in vitro*. Near linear relationships (r ranged from 0.93 to 0.97) were found between the percentage of fungicide adsorbed and the thickness of thatch for all treatments (Fig. 1). The percent of applied fungicide that was adsorbed increased with thatch thickness.

[FIG. 1 HERE]

When the thatch layer was 20 mm thick, and without applying AG, over 80% of the fungicide was adsorbed; this was approximately 30% more than when AG was used (Fig. 1). When the thatch thickness was over 16 mm, the difference in adsorption with and without AG was much greater than the difference in adsorption between the two benomyl rates (1 and 1.5 ha^{-1}).

Fungicide adsorbed by the thatch *in vitro* was desorbed from the thatch layer with irrigation water three days after initial treatment (Fig. 2). Twenty to forty percent of the fungicide adsorbed in the thatch layer was washed off three days after initial application of fungicide and AG. The amount of fungicide desorbed increased with thatch thickness (Fig 2).

[FIG. 2 HERE]

When AG was not used, significantly less fungicide was washed off the thatch layer (Fig. 2). This could have been due to the hydrophobicity of the thatch layer which has a lower infiltration rate (Miyamoto, 1985). Under such conditions, the fungicide and irrigation water tended to stay within the thatch layer and not penetrate into the hydrophobic sandy soil. The adsorbed fungicide molecules were not washed off with irrigation. Whereas when AG was used, the thatch layer could become less hydrophobic, and more fungicide could be desorbed until the water flow stopped.

The reason for reduced benomyl adsorption and the subsequent increased desorption by thatch when applied with AG is not clear. Valoras et al. (1969) reported that the equilibrium between Pachappa sandy loam soil and AG solution was either complete or nearly complete after one hour. This suggested that AG has a very strong tendency to be adsorbed compared to benomyl which has a equilibrium time of 4 to 6 hours in Fox sandy loam soil (Aharonson and Kafkafi, 1975). According to Miller and Letey (1975), AG was strongly and irreversibly adsorbed within the top 1 cm of a sandy loam soil. They suggested that AG could give a long wetting effect of the thatch layer and maintain a high infiltration rate in subsequent watering. Similar results have been reported by Miyamoto (1985) and Mane et al. (1993). Possibly, the fungicide may not reach an equilibrium with the thatch because of the fast movement of irrigation water which acts as a carrier for the fungicide.

Effect of AG on uptake of benomyl by turfgrass

Aqua-Gro had a significant effect on the uptake of benomyl by turfgrass *in situ*. One day after treatment with benomyl and AG, the fungicide concentration in turfgrass clippings could be detected by bioassay (Table 1); whereas the concentration was not detectable at day 1 if no AG was applied. This is likely due to the wetting effect of AG on plants. Benomyl may be adsorbed or even absorbed by foliage shortly after application (Nowacka et al., 1979).

Table 1. Concentration of benomyl in turfgrass clippings (µg g^{-1} fresh clipping weight).

Benomyl Treatment	Concentration of benomyl (µg g^{-1}) Days after treatment 1	3	7	14	21
1 kg ha^{-1}	ND[†]	0.6c[‡]	2.8b	0.4c	ND
1.5 kg ha^{-1}	ND	1.0b	3.5a	0.9b	ND
1 kg ha^{-1}+AG[¶]	0.6a	1.2b	2.6b	1.1b	ND
1.5 kg ha^{-1}+AG	0.9a	1.7a	3.3a	1.8a	0.7

[†] ND - not detectable.
[‡] Means followed by the same letter in a column are not significantly different from each other at P = 0.05. Each mean is derived from four replicates in each of the two-year study.
[¶] AG is Aqua-Gro applied at 5 L ha^{-1}.

If no AG was used, the fungicide in the grass was not detected until 3 days after treatment. This could be due to the slow uptake by roots, stems or stolons of the grass. After this initial period, however, the rate of uptake was very fast and, at the same application rate, there were no significant differences between the amount of fungicide in clippings at seven days after treatment with fungicide alone or those treated with fungicide and AG (Table 1). Figures 1 and 2 indicate that, if AG was not used, more fungicide was adsorbed in the thatch layer and less was desorbed and leached down to the soil layer. This meant that the concentration of fungicide in thatch was higher in plots treated with fungicide alone. This is in agreement with our results of bioassay on thatch (Table 2). Therefore, it is likely that the fungicide taken up by grass treated with fungicide alone was mainly from the reservoir that stayed in the hydrophobic thatch layer.

Table 2. Concentration of benomyl in thatch (µg g^{-1} dry thatch weight).

Benomyl Treatment	Concentration of benomyl (µg g^{-1}) Days after treatment 1	3	7	14
1 kg ha^{-1}	17.2b[†]	14.4b	9.5b	4.1a
1.5 kg ha^{-1}	25.6a	21.0a	12.7a	4.6a
1 kg ha^{-1}+AG[‡]	6.2d	4.5d	2.8c	0.8b
1.5 kg ha^{-1}+AG	9.9c	6.5c	3.2c	0.8b

[†] Means followed by the same letter in a column are not significantly different from each other at P = 0.05. Each mean is derived from four replicates in each of the two-year study.
[‡] AG is Aqua-Gro applied at 5 L ha^{-1}.

When AG was used, significantly higher concentrations of fungicide were found in the grass 14 days after treatment. Less adsorption, more desorption and improved movement of fungicide into soil (Bateman, 1984), as has also been shown for herbicides (Bayer, 1967), could increase the fungicide level in soil beneath the thatch where the actively growing roots are located.

Microbial activity is one of the main factors for the degradation of benomyl (Yarden et al., 1987). The rate of microbial degradation of benomyl and other pesticides in soil is much lower than that in thatch (Liu and Hsiang, in press; Branham et al., 1993), which is likely due to the higher populations of microorganisms in thatch (Mancino et al., 1993). These results suggested that fungicide levels in soil last longer compared to thatch. This may contribute to the higher concentrations of fungicide in grass clippings at 14 days after treatment with fungicide plus AG. After 14 days, the concentration of fungicide in grass decreased quickly in all treatments. At the lower fungicide application rate (1 kg ha^{-1}), the concentration could not be detected (< 0.2 ppm) by bioassay 21 days after treatment with or without AG. Only for the treatment with 1.5 kg ha^{-1} of benomyl plus AG, was benomyl detected at 21 days.

Effect of AG on control of dollar spot disease by benomyl

The development of dollar spot disease was reduced by treatment with benomyl and AG (Table 3). Dollar spot patches were seen on day 14 after treatment with benomyl at 1 kg ha^{-1} without AG (Table 3). With AG, dollar spot patches were not seen until day 21 after treatment, and the rate of development was slower compared with that treated with fungicide alone. Because more fungicide was taken up by turfgrass in the first week after treatment (Table 1), and because of faster microbial degradation of benomyl in thatch (Liu and Hsiang, in press), there was likely not enough fungicide in thatch and soil to be taken up and to maintain a threshold of fungicide in the turfgrass two weeks after treatment with fungicide alone.

Table 3. Number of dollar spot patches after treatment on 2 m^2 plots.

Benomyl Treatment	Dollar spot patches per plot, Days after treatment: 1	7	14	21	28
1 kg ha^{-1}	0	0	2b†	18c	41b
1.5 kg ha^{-1}	0	0	0c	3d	19c
1 kg ha^{-1}+AG‡	0	0	0c	2d	17c
1.5 kg ha^{-1}+AG	0	0	0c	0d	8d
AG	0	4	13a	42b	117a
Control	0	2	16a	63a	122a

† Means followed by the same letter in a column are not significantly different from each other at $P = 0.05$. Each mean is derived from four replicates in each of the two-year study.
‡ AG is Aqua-Gro applied at 5 L ha^{-1}.

Aqua-Gro can extend the residual efficacy of benomyl (Table 3). Turfgrass treated with 1.5 kg ha^{-1} benomyl plus AG did not show dollar spot patches on day 21 after treatment. At 1.5 kg ha^{-1} benomyl without AG, dollar spot patches were not seen until day 21, and patch development was not significantly different from that at 1 kg ha^{-1} benomyl plus AG. These results suggest, that, when benomyl is applied at two-week intervals, fungicide application can be reduced by approximately 30 percent of the recommended rate if applied with AG and irrigated immediately after.

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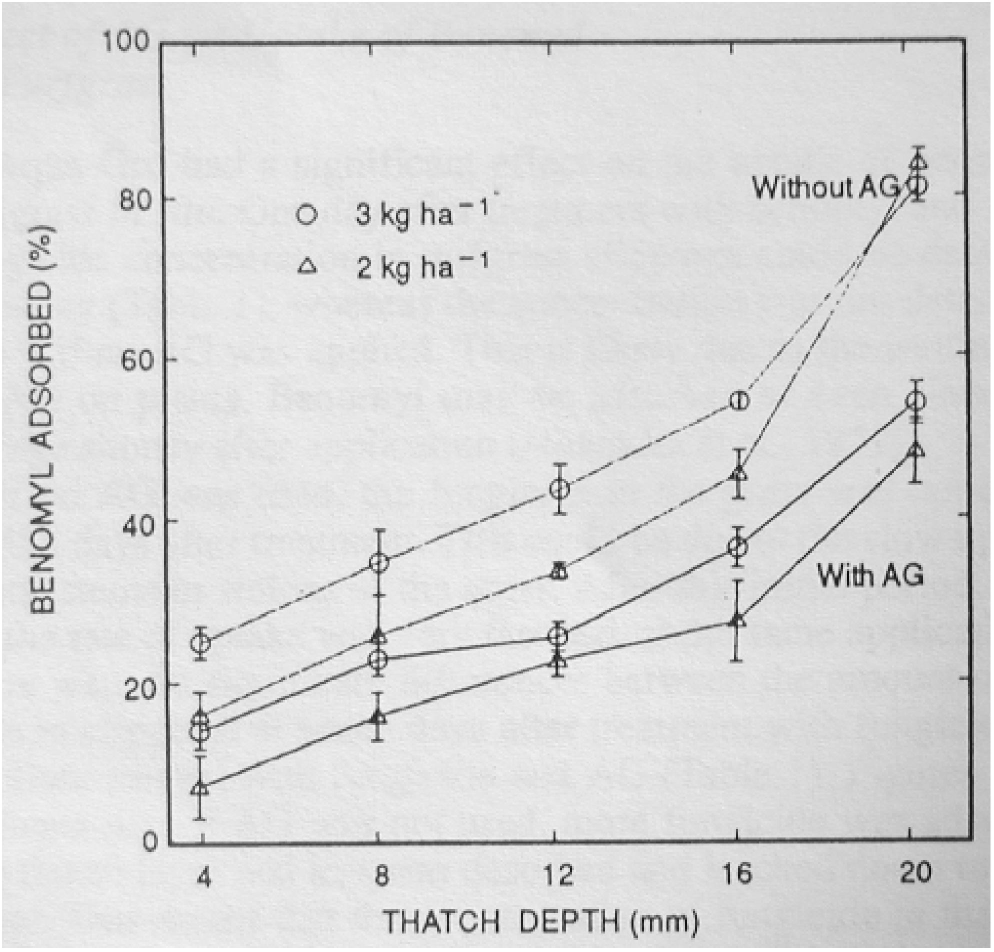

Figure 1. Effect of thatch on adsorption of benomyl applied with and without Aqua-Gro *in vitro*. Benomyl levels were detected using the paper disc bioassay on leachate immediately after fungicide treatment. Each data point is the mean of 4 replicates.

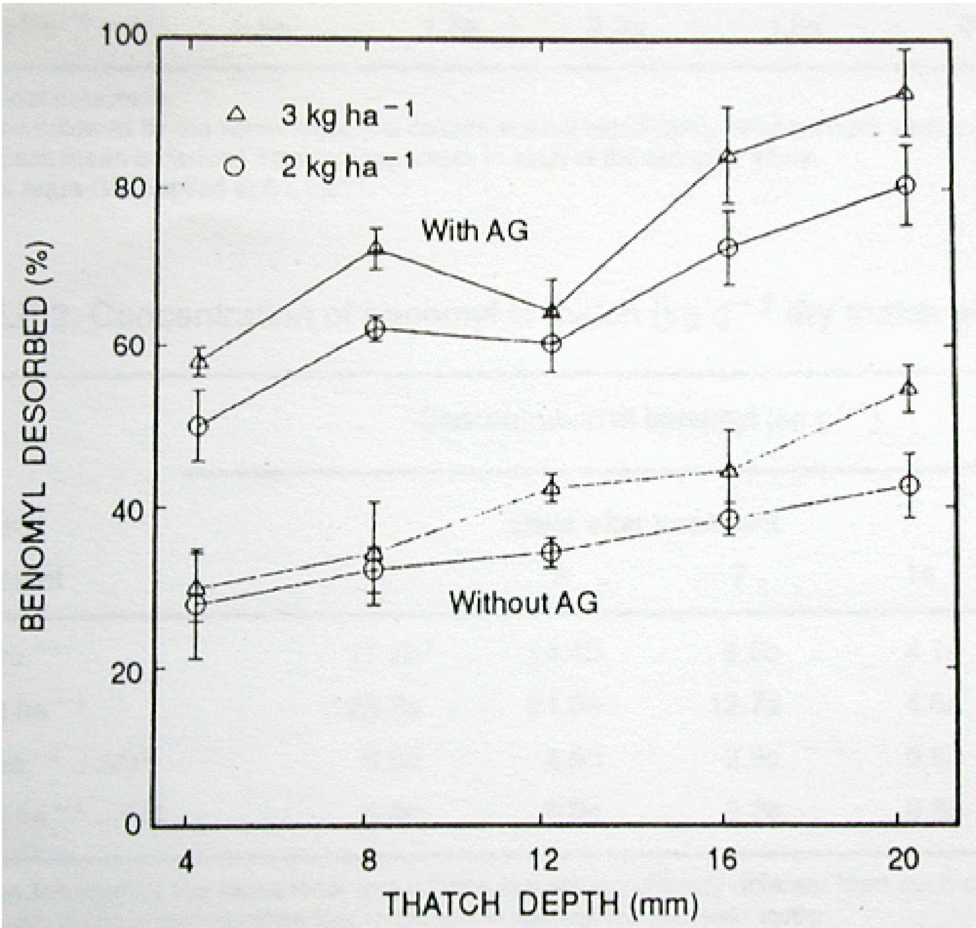

Figure 2. Effect of thatch on the desorption of benomyl applied with and without Aqua-Gro *in vitro*. Benomyl levels were detected using the paper disc bioassay on leachate 3 days after fungicide treatment. Each data point is the mean of 4 replicates.