COOPERATIVE IMPACT ASSESSMENT REPORT

THE BIOLOGIC ASSESSMENT OF THIOPHANATE-METHYL

UNITED STATES DEPARTMENT OF AGRICULTURE IN COOPERATION WITH STATE AGRICULTURAL EXPERIMENT STATIONS COOPERATIVE EXTENSION SERVICE OTHER STATE AGENCIES U.S. ENVIRONMENTAL PROTECTION AGENCY

TECHNICAL BULLETIN NUMBER 1679
THE BIOLOGIC ASSESSMENT OF

THIOPHANATE-METHYL

A report of the Thiophanate-methyl assessment team to the rebuttable presumption against registration of Thiophanate-methyl

Submitted to the Environmental Protection Agency
in December 1978
PREFACE

This report is a joint project of the U.S. Department of Agriculture, the State Land-Grant Universities, and the U.S. Environmental Protection Agency, and is the thirteenth in a series of reports recently prepared by a team of scientists from these organizations in order to provide sound, current scientific information on the benefits of, and exposure to, thiophanate-methyl.

The report is a scientific presentation to be used in connection with other data as a portion of the total body of knowledge in a final benefit/risk assessment under the Rebuttable Presumption Against Registration Process in connection with the Federal Insecticide, Fungicide, and Rodenticide Act.

This report is a slightly edited version of the reports submitted to the Environmental Protection Agency in December 1978. The editing has been limited in order to maintain the accuracy of the information in the original reports.

Sincere appreciation is extended to the Assessment Team Members who gave so generously of their time in the development of information and in the preparation of the report.

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SUMMARY

Thiophanate-methyl (TPM) is an outstanding broad-spectrum benzimidazole fungicide that is similar to benomyl. It was first introduced in the United States in 1973 and is of economic importance to the turfgrass and ornamental industries. TPM is labeled and widely used for the control of soilborne diseases of ornamental plants and for many of the most damaging diseases of turfgrass.

Applicator Exposure

Like benomyl, the principal conversion product of thiophanate-methyl on plant surfaces and in plant tissue is methyl 2-benzimidazolcarbamate (MBC). The only recognizable effects of MBC in mammals are based on antimitotic action. Threshold limits can be established for antimitotic activity. The limits are of the same order of magnitude as those established for teratogenicity and reduction in spermatogenic activity in the EPA-Benomyl Position Document 1. Applicator safety margins for antimitotic activity of thiophanate-methyl are very favorable. They range from 6,818 to 37,500 for field applicators and from 14,204 to 1,041,666 for home garden applicators.

Toxicity to Earthworms

The amount of MBC-generating fungicides applied annually to most agricultural areas in the United States is equivalent to less than 1.34 pounds of benomyl/acre, a level that had no adverse effects on earthworms. Any adverse effects that might result from practical use of TPM should be confined to the area of application since its main degradation products show little or no tendency to move in soil away from the site of application.

Rates and Frequency of Application

Thiophanate-methyl, like benomyl, is a systemic fungicide. Because of this property, TPM is applied on a longer interval than is used for alternate contact fungicides. In addition, TPM is effective at low rates; this results in a reduction of environmental exposure and applicator exposure, as well as in a savings in energy and labor costs. In many situations, turfgrass managers wait until a disease is actually present before initiating a treatment program, thus reducing considerably the number of fungicide applications necessary in a growing season. TPM also has therapeutic properties within plant tissues, a feature that is lacking in contact fungicides.

Disease Control With Thiophanate-methyl and Alternatives

The value of thiophanate-methyl to the ornamental industry lies in the fact that it effectively controls diseases that would otherwise produce high-volume losses in very high-value crops. No single alternative, other than benomyl, controls as broad a spectrum of soilborne diseases as does TPM, and when TPM is incorporated with Terrazole®, it controls soilborne diseases better than all alternative chemicals. There are no alternatives to chemical control of diseases in ornamentals.

For control of diseases of turfgrasses thiophanate-methyl and its
equivalent alternatives thiophanate and benomyl are the cheapest and the most effective fungicides currently available. The observance of nitrogen fertility levels, the removal of gutta- tion water and, in some cases, the use of resistant varieties can be instrumental in reducing disease severity; however, these cultural practices are not effective control measures in themselves. Chemical control is the only effective control for most of the damaging diseases of turfgrass.

Failure to reregister thiophanate-methyl for turfgrass and ornamental crop uses would result in marked increase in disease losses. In addition, TPM controls these diseases for longer periods of time with the use of less chemicals.

Keywords: Thiophanate-methyl, carbendazin, MBC, fungicide, pesticide registration, biologic assessment, economic impacts, RPAR, human exposure, environmental exposure, crop losses, alternatives to thiophanate-methyl.
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PART 1
AN EVALUATION OF THE TRIGGERS AND THE IMPORTANCE OF THIOPHANATE-METHYL TO AGRICULTURE

Introduction

The purpose of this report is to evaluate the benefits and risks of the fungicide thiophanate-methyl (dimethyl [(1,2-phenylene)bis(iminocarbonothioyl)] bis[carbamate]), manufactured and sold under several trade names, including Topsin®-M, Cercobin®-M, and Fungo®. In this section, Part 1: An evaluation of the triggers and the importance of thiophanate-methyl to agriculture, special emphasis is given to exposure related to the presumed risks as stated by the Environmental Protection Agency (EPA). Only a general summary of the importance of thiophanate-methyl will be included because Part 2 will be concerned primarily with the benefits of the fungicide to agriculture.

Chemical and Physical Properties

Thiophanate-methyl is the accepted common name for the fungicide dimethyl [(1,2-phenylene)bis(iminocarbonothioyl)] bis[carbamate]. Thiophanate-methyl has a molecular weight of 342. It is a colorless crystalline solid that melts at 178°C with decomposition. The compound has the following structural formula:

![Chemical Structure of Thiophanate-Methyl](image)

The compound is slightly soluble in water and n-hexane but is moderately soluble in methanol, acetone, and cyclohexane. It is stable in acidic solutions, but is unstable under alkaline conditions. Thiophanate-methyl undergoes transformation to methyl 2-benzimidazolecarbamate (MBC) as illustrated at the top of page 2.

The rate of transformation is negligible at pH 5.5 but is appreciable at pH 8.3 (51). The transformation to MBC at 70°C is quite rapid at pH 8.0 (51).

MBC, commonly referred to as carbendazim, is of particular interest because it is considered to be an intermediate through which the fungitoxic activity of thiophanate-methyl (51) and benomyl are mediated (6). MBC is a relatively stable molecule under neutral or acidic conditions but is converted to 2-aminobenzimidazole (2-AB) under alkaline conditions. The MBC molecule can exist as the neutral form (non-ionic) or as a cationic form depending on the solution pH. The pH at which equivalent amounts of the neutral and cationic forms exist (pKₐ) is approximately 4.0 (20). Therefore, approximately 90 percent of the MBC exists as the cation at pH 3, approximately 90 percent exists as the neutral molecule at pH 5, 99 percent at pH 6, and 99.9 percent at pH 7. The interconversion between the two forms of MBC is illustrated as follows:

$$\text{MBC} + H^+ \rightleftharpoons \text{MBCH}^+$$

This ready interconversion is highly significant in regard to aqueous solubility of MBC. The neutral molecule is reported to be soluble only to the extent of 8 µg/ml at pH 7.0 (37), but solubilities of several thousand µg/ml of the cationic (salt) form in acidic solutions are reported (12). A number of MBC salts, such as the hydrochloride, nitrate, and lactate, have been prepared by acidification with the appropriate acid (12).

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1/ Numbers in parentheses refer to the references at the end of this publication.
Biological and Environmental Fate

Fate in Plants and Micro-organisms

The half-life of thiophanate-methyl applied to leaves of apple and grape plants was about 2 weeks (23). The main metabolite was MBC; a minor metabolite, dimethyl 4,4'-o-phenylenebis allophepane, was also detected. After root application of thiophanate-methyl to several plants, a rapid conversion to MBC occurred (5,16). Nearly all of the thiophanate-methyl in cotton plants was converted to MBC within 6 days (5). Catalyzing factors are apparently present in plants because the conversion to MBC is more rapid than in water. Thiophanate-methyl is rapidly converted to MBC in the presence of slices of plant tissue and homogenates of plants (16).

Photochemical transformation of thiophanate-methyl apparently takes place on or in plants (4). This may be an important factor in the conversion to MBC. Studies of MBC conversion in plants (35, 39) indicate that the compound is relatively stable but that some transformation to 2-aminobenzimidazole and other metabolites occurs.

Active conversion of thiophanate-methyl to MBC has been reported to occur in fungi (12). Among the fungal breakdown products of MBC, 2-AB and 5-hydroxy-MBC have been identified (16).

Fate in Animals

Thiophanate-methyl orally administered to mice and dogs was excreted via the urine and feces and expired as gas within 96 hours (23). When oral doses of 14C or 35S thiophanate-methyl, labeled in one of the thioureido groups, were administered, about 80 percent of the 14C and the 35S was eliminated in the urine and about 20 percent of the 14C and 35S was eliminated in the feces (27).

The major component in faecal excretions was reported to be unmetabolized thiophanate-methyl while minor parts consisted of 4-hydroxythiophanate-methyl, dimethyl 4,4'-o-phenylenebis allophepane, MBC, and 5-hydroxy-MBC (24). In the urine, conjugates of these compounds were found together with other metabolites (24). The main metabolites of thiophanate-methyl found in mice and dogs were MBC and 5-hydroxy-MBC and their glucuronide derivatives (23). A minor metabolite, dimethyl 4,4'-o-phenylenebis allophepane, was also detected.

Douch (11) found that, in mice and sheep, thiophanate-methyl is converted to MBC and various hydroxylated intermediates. The hydroxylated derivatives were excreted as the glucuronide or sulfate conjugates.

Metabolism of thiophanate-methyl and MBC by mammals and excretion of the resulting metabolites and parent compounds are important factors in decreasing toxicity and preventing the fungicides from accumulating in tissues.

Fate in Soil

Thiophanate-methyl undergoes rapid transformation to MBC in soil (15). The rate of conversion is four times faster in soil at pH 7.4 than at pH 5.6. The rate of conversion to MBC was reduced by steam treatment of soil (13).
The MBC was relatively stable in soil. Recovery of $^{14}$C in acetone extracts of $^{14}$C-MBC-treated soils was 79 to 91 percent when extracted immediately and 53 to 78 percent when extracted 43 days after treatment. Nearly all of the extracted $^{14}$C appeared to be in MBC (13). Since thiophanate-methyl converts to MBC, the behavior of the soil should resemble that of benomyl, which also converts to MBC. Accordingly, 2-AB would be anticipated as one of the soil metabolites (1). As with benomyl, the half-life of thiophanate-methyl residues would be expected to range from 3 to 12 months (1). The results of several investigations indicate that MBC and its residues are strongly retained by soils and show little tendency to leach (1, 15, 33). Therefore, application of thiophanate-methyl to soil should not constitute a hazard to water sources because of leaching. Thiophanate-methyl residues should not be taken up by crops during the following season for it should be comparable to benomyl (1), which also yields MBC as the main soil degradation product.

Fate in Air

There are no indications that thiophanate-methyl is volatile or that it constitutes any hazard in air.

Fate in Water

No detectable conversion of thiophanate-methyl to MBC occurred in 14 days in tap water at pH 5.4, but significant conversion took place in solutions of pH 8.3 (51). Solar irradiation markedly accelerates the rate of transformation of thiophanate-methyl in distilled water (4). These studies indicate that thiophanate-methyl transforms rapidly to MBC in water in neutral or alkaline solutions in the light. No conclusions can be drawn regarding stability under acidic conditions in the light.

The relatively long stability of MBC in the soil (1) indicates that it should be relatively stable in water, possibly having a half-life of 3 months or longer. There are indications that decomposition may be hastened by light, particularly under basic conditions (54). MBC is possibly absorbed from water by soil particles. No studies of the long-term stability or the fate of MBC or of thiophanate-methyl in natural bodies of water were found. There is need for additional information concerning these factors.

Summary - Biological and Environmental Fate

The principal conversion product of thiophanate-methyl on plant surfaces and in plant tissue is MBC. Both light and biological activity of plants accelerate conversion of thiophanate-methyl to MBC.

Fungi actively convert thiophanate-methyl to MBC. Fungal breakdown products of MBC include 2-aminobenzimidazole and 5-hydroxy-MBC.

Thiophanate-methyl and its metabolites are rapidly excreted by mice and dogs via urine and feces, or expired as gas. Animal metabolites of thiophanate-methyl include MBC, 5-hydroxy-MBC, dimethyl 4-hydroxy-bis-allophanate, and 5(6)-hydroxy-2-aminobenzimidazole. Metabolism of thiophanate-methyl and excretion of the parent compounds and metabolites are important factors in reducing toxicity to animals. Thiophanate-methyl undergoes transformation to MBC in soil. The conversion rate is more rapid in neutral soils than in acidic soils.

In water, thiophanate-methyl is relatively stable at pH 5.4 but converts to MBC under alkaline conditions. Solar irradiation accelerates the rate of conversion to MBC in distilled water.

Summary of Presumptions Against Thiophanate-methyl

Mutagenicity

that a rebuttable presumption shall arise if a pesticide "induces mutagenic effects, as determined by multi-test evidence."

On the basis of scientific studies and information summarized in the Position Document, the Environmental Protection Agency (Agency) has concluded that this risk index has been exceeded by all registrations and applications for registration of pesticide products containing thiophanate-methyl, and that a rebuttable presumption against new or continued registration of such products has therefore arisen.

Population Reductions in Non-target Organisms

40 CFR 162.11(a)(3)(ii)(C) provides that a rebuttable presumption shall arise if a pesticide "can reasonably be anticipated to result in significant local, regional, or national population reductions in non-target organisms."

On the basis of scientific studies and information summarized in the Position Document, the Agency has concluded that the risk index for population reductions in non-target organisms has been exceeded by registrations and applications for registration of pesticide products containing thiophanate-methyl which are for outdoor use, and that a rebuttable presumption against new or continued registration of such products has therefore arisen.

Biological Effects Related to Exposure

Antimitotic Action

Vonk and Kaars Sijpesteijn in 1971 (51) concluded that the biological action of thiophanate-methyl was mediated via the conversion product MBC. Appreciable scientific evidence collected since 1971 fully supports their conclusions regarding the role of MBC in the action of thiophanate-methyl. When one considers the action of thiophanate-methyl at the cellular level, therefore, it is the MBC conversion product that is of primary interest.

The toxicity of MBC in fungi is based on its interference with the mitotic process (8, 14). Specifically, MBC has been shown to combine with fungal tubulin or tubulin-like protein in Aspergillus nidulans (9). Tubulin is a protein subunit that polymerizes to form microtubular structures, which are involved in various cellular functions. Microtubules function in the process of mitosis whereby chromosome separation and nuclear division are accomplished. Although the exact molecular interaction of MBC with tubulin has not been resolved, the toxic action of MBC in higher organisms involves interference with the structure or function of the mitotic spindle. All of the nuclear effects of MBC thus far recognized in higher organisms, including mammals, appear to be based on antimitotic action (8, 10, 14, 17, 34, 36). Since antimitotic action is the only recognizable "cellular" effect of MBC in mammals, a threshold level for this type of action can be assumed (36). For mice, this level falls between 50 and 100 mg/kg for doses applied by gavage (36). A blood level of 8 μg/ml was regarded as a threshold level of MBC (36). The no-observable-effect level of 50 mg/kg of MBC by gavage corresponds to the 90 mg/kg of thiophanate-methyl needed to produce an equivalent amount of MBC. It is doubtful whether thiophanate-methyl readily converts to MBC in the acidic environment of the stomach. A dose of 90 mg/kg could, nevertheless, be assumed as a no-effect level. The no-observable-effect levels for antimitotic action are judged to be of the same order of magnitude as those regarded as no-observable-effect levels for teratogenesis and reduction of spermatogenesis for benomyl in the EPA-Benomyl Position Document 1. Accordingly, these levels have been used as a basis for calculating safety margins that prevail for potential exposure to thiophanate-methyl.

Applicator exposure estimations for thiophanate-methyl are based on those
developed for benomyl in the USDA-Benomyl Assessment Document. In the assessment of benomyl, application rates of 0.5 pound/acre of active ingredient were used as a basis for exposure calculations. An application rate of 0.7 pound of active ingredient per acre of thiophanate-methyl was used as a basis for exposure calculations in this report. On the basis of MBC-generating capacity, 0.5 pound of benomyl is equivalent to 0.7 pound of thiophanate-methyl. Therefore, the safety margins developed for inhalation exposure of applicators to benomyl are regarded as also applicable for thiophanate-methyl. These safety margins for field applicators are shown in table 1. The data in table 1 indicate that thiophanate-methyl acquired by the inhalation route is not hazardous to field applicators.

Tests for dermal absorption of thiophanate-methyl were made by applying a paste of the compound at the rate of 1000 mg/kg (ai) to a 5x6 inch clipped area of the back of rabbits and covering the area with gauze and parafilm (28). The applied material contained adequate $^{14}$C-labeled thiophanate-methyl to permit detection of a concentration of 0.25 p/m or greater in the blood. No radioactivity could be detected in the blood 24 and 72 hours after application. Gas chromatographic analyses of blood after 6 days of continuous exposure showed that MBC levels in the blood were less than 0.01 p/m, which is a concentration less than 1/100,000 of the applied dermal dose (28). These tests indicate that dermal absorption of thiophanate-methyl is no more than 0.001 percent. Absorption of this amount

Table 1.--Calculated safety margins for inhaled doses of thiophanate-methyl by applicators spraying 0.7 pound per acre of active ingredient for 4 hours. Values are adopted from those calculated for application of 0.5 pound of benomyl (ai) per acre under the same conditions.

<table>
<thead>
<tr>
<th>Activity</th>
<th>Safety margin</th>
</tr>
</thead>
<tbody>
<tr>
<td>Operating power air-blast machine spraying orchard</td>
<td>15,000</td>
</tr>
<tr>
<td>High-pressure power handgun spraying fruit trees in nursery</td>
<td>37,500</td>
</tr>
<tr>
<td>Driving tractor pulling high-pressure handgun sprayer in orchard</td>
<td>37,500</td>
</tr>
<tr>
<td>Operating power air-blast machine spraying fruit orchard</td>
<td>15,000</td>
</tr>
<tr>
<td>Chemical thinning apple blossoms by power air-blast machine</td>
<td>7,500</td>
</tr>
<tr>
<td>High-pressure power handgun spraying orchard cover crop</td>
<td>25,000</td>
</tr>
<tr>
<td>Operating power air-blast machine spraying fruit orchard</td>
<td>25,000</td>
</tr>
<tr>
<td>High-pressure power handgun from ground position near portable tower sprayer-citrus groves.</td>
<td>6,818</td>
</tr>
<tr>
<td>Operating tractor-mounted boom ground sprayer in row crops</td>
<td>10,714</td>
</tr>
</tbody>
</table>

1/ Benomyl exposure values were based on the mean exposure values determined by Wolfe and others (53) for applicators exposed to various pesticides. Application rates in data of Wolfe and others adjusted to 0.5 lb (ai) per acre for making comparisons with benomyl. Exposure values and safety margins calculated for benomyl are presented in the USDA-Benomyl Assessment Document.

2/ 0.7 pound of thiophanate-methyl equivalent to 0.5 pound of benomyl in potential for generating MBC.

3/ These activities are listed in table 2 of Wolfe and others (53) in the following order: 4, 6, 7, 8, 11, 12, 21, 24, and 28.

4/ Ratio of 7.5 mg/kg no-observable-effect level of benomyl on spermatogenesis in rats to mg/kg/4-hour applicator exposure to benomyl. The 7.5 mg/kg value is cited in the EPA-Benomyl Position Document 1.
Table 2.—Calculated safety margins for doses of thiophanate-methyl acquired via respiratory and dermal exposure\(^1\) by home garden applicators while spraying or dusting 0.7 pound per acre of active ingredient for 1 hour. Respiratory doses and dermal deposits are based on those calculated for application of 0.5 pound of benomyl (ai)\(^2,3\)/

<table>
<thead>
<tr>
<th>Activity 4/</th>
<th>Safety margin for respiratory dose plus 0.001 pct of dermal deposit 5/</th>
</tr>
</thead>
<tbody>
<tr>
<td>Operating power air-blast machine spraying orchard</td>
<td>390,625</td>
</tr>
<tr>
<td>High-pressure power handgun spraying fruit trees in nursery</td>
<td>1,041,666</td>
</tr>
<tr>
<td>Operating power air-blast machine spraying fruit orchard</td>
<td>367,647</td>
</tr>
<tr>
<td>High-pressure power handgun spraying orchard cover crop for mouse control.</td>
<td>694,444</td>
</tr>
<tr>
<td>Operating power duster applying pesticide to pole beans</td>
<td>14,204</td>
</tr>
<tr>
<td>High-pressure power handgun spraying from ground position near portable tower sprayer-citrus groves.</td>
<td>135,869</td>
</tr>
</tbody>
</table>

1/ Measurements indicate that dermal absorption of thiophanate-methyl is less than 0.001 percent (37).
2/ Benomyl exposure values were based on the mean exposure values determined by Wolfe and others (53) for applicators exposed to various pesticides. Application rates in data of Wolfe and others adjusted to 0.5 lb (ai) per acre for making comparisons with benomyl. Exposure values and safety margins calculated for benomyl are presented in the USDA-Benomyl Assessment Document.
3/ 0.7 pound of thiophanate-methyl equivalent to 0.5 pound of benomyl in potential for generating MBC.
4/ These activities are listed in table 2 of Wolfe and others (53) in the following order: 4, 6, 8, 12, 16, and 24.
5/ Ratio of 62.5 mg/kg no-observable-teratogenic-effect level of benomyl in rats to mg/kg/h applicator exposure. Ratios are applicable to thiophanate-methyl or benomyl on the basis of MBC-generating capacity; 0.5 pound of benomyl equivalent to 0.7 pound of thiophanate-methyl. The 62.5 mg/kg value is cited in the EPA-Benomyl Position Document 1.

would not change the general magnitude of the applicator's safety margins shown in table 1. The smallest safety margin (activity 24, table 1) would be decreased from 6,818 to 4,166 when 0.001 percent of the dermal deposit, calculated from the values of Wolfe and others (53), is absorbed per hour for a 4-hour period.

Data for home garden applicator exposure (table 2) were based on those developed for benomyl in the USDA-Benomyl Assessment Document except that a value of 0.001 percent was used for absorption of dermal deposits of thiophanate-methyl (28) instead of the 10 percent dermal absorption value assumed for benomyl. In the present calculations, 0.7 lb (ai) per acre of thiophanate-methyl was considered to be equivalent to 0.5 lb (ai) per acre of benomyl.

The data in table 2 show very large safety margins for home garden applicators applying thiophanate-methyl and indicate that the amounts of compound acquired through inhalation and dermal absorption do not constitute a hazard.

Summary - Antimitotic Action

Antimitotic activity is well established as the mode of action of MBC. The basis for this type of activity is distinctly different from that of point
mutation activity. Antimitotic activity is the only type of action that has been acceptably demonstrated for MBC in mammalian systems. Threshold limits can be established for antimitotic activity. The limits are of the same order of magnitude as those established for teratogenicity and reduction in spermatogenic activity cited for benomyl in the EPA-Benomyl Position Document 1. Applicator safety margins for antimitotic activity of thiophanate-methyl are very favorable. These range from 6,818 to 37,500 for field applicators and from 14,204 to 1,041,666 for home garden applicators (tables 1 and 2).

Population Reductions in Non-target Organisms

Toxicity to Earthworms

Thiophanate-methyl, MBC, and benomyl are repellent to earthworm feeding (41). Thiophanate-methyl and benomyl were reported to reduce the earthworm populations in apple orchards in England (40, 41). Both fungicides undergo transformation in soil to MBC, which is the main residue of these two compounds (1, 13). Action of both compounds in soil is evidently mediated via MBC; therefore, their performance should be similar in regard to effects on earthworms. Accordingly, the experience with both thiophanate-methyl and benomyl is considered in making an assessment of the potential impact of thiophanate-methyl on earthworms.

A drench of soil in pots with 7.75 or 1.55 kg/ha of benomyl (6.9 and 1.4 lb (ai)/acre) resulted in respective earthworm kills of 100 percent for 7.75 kg/ha and 60 percent for 1.55 kg/ha 14 days after treatment (41). Stringer and Lyons (40) found that 11 applications of benomyl per year or a total of 3.64 kg/ha (3.2 lb (ai)/acre) during 1972 to a commercial orchard at Biddestone, England led to marked reduction of four of six species of earthworms in samples taken in January 1973. Other tests made at the Long Ashton Experiment Station showed that seven sprays of benomyl per year for 2 years, or an annual application rate of 1.96 kg/ha (1.7 lb (ai)/acre), led to a marked reduction in the population of several species of earthworms (40).

On the other hand, earthworm populations were not reduced in soil at harvest time on October 2 in wheat fields previously sprayed three times with 0.50 kg/ha of benomyl (once each in April, May, and June) for a total application of 1.50 kg/ha (1.34 lb (ai)/acre) (26). Earthworms subsequently cultured for 13 months in a mixture of soil and straw from the treated plots reproduced normally. Weight losses of straw, buried at harvest time (October 2, 1973) and measured on July 1, 1974, did not differ in control samples from those of the 1.50 kg/ha benomyl treatments.

Samplings made 21 days after application of 7.8 kg/ha (6.9 lb (ai)/acre) to pasture showed that earthworm populations were reduced about 95 percent (43). Application of 36 g/m² (32 lb (ai)/acre) of benomyl to Flanagan silt loam by pressure injection at the Illinois Natural History Survey Arboretum in May of 1974 led to a marked reduction in numbers of earthworms in July, August, and September (3). Counts made in August 1974 on plots similarly treated with this unusually high level of benomyl in 1973, 1972, 1971 and 1970 (18 g/m² in 1970) showed normal populations of worms. These tests demonstrate that although earthworm populations are reduced by benomyl, they return to normal within a year and remain at that level thereafter. Stringer and Lyons (40) also found recovery of earthworm populations in apple orchards after benomyl sprays were discontinued. Within 2 years, populations of all species had completely recovered except for those of Lumbricus terrestris and Allolobophora chlorotica, which were significantly lower than normal.

The experience with the MBC-generating compounds thiophanate-methyl and benomyl indicates that application of the fungicides at sufficiently high
rates could reduce earthworm populations; however, no evidence was found that practical use of these fungicides has led to a lowering of plant vigor or productivity because of an adverse effect on earthworm populations.

In most agricultural applications, benzimidazole fungicides are applied at an annual rate that is equivalent to 1 pound or less of benomyl (ai) per acre per year. Experience indicates that the fungicides would have little or no adverse effects on earthworms in these areas (26).

Although it is widely believed that earthworms are beneficial organisms, it is difficult to assess to what extent an orchard would suffer from the absence of, or the reduction in, earthworm populations due to the use of fungicides (40). The nutrient status of apple trees appeared to be unaffected in orchards in which earthworms were almost totally lacking because of heavy use of copper fungicides (40). It has been observed that vegetative vigor and crop yield were as good in black currant fields lacking earthworms as in black currant fields with high earthworm populations (40). Although it is evident that earthworms are beneficial in improving soil conditioning, it has not been proved that they are essential (40). Benomyl is known to be active against plant-parasitic nematodes in the soil (22). The benefits derived from reduction in numbers of these parasites must be taken into consideration.

Any adverse effects on earthworm populations that might result from the practical use of thiophanate-methyl and benomyl would be confined to the site of application because the degradation product, MBC, shows practically no tendency to move in soil away from the area of fungicide application (1, 15, 33). A return of earthworm populations to normal would also be expected to occur within a year or two following discontinued use of the fungicides (3, 40).

Summary - Toxicity to Earthworms

Experience indicates that thiophanate-methyl and other MBC-generating compounds at sufficiently high concentrations can reduce earthworm populations.

The amount of MBC-generating fungicides applied annually to most agricultural areas in the United States is equivalent to less than 1.34 pounds of benomyl (ai)/acre, a level that has no adverse effects on earthworms in wheat fields.

There is no evidence that the use of thiophanate-methyl has led to a lowering either of plant vigor or productivity because of adverse effects on earthworms.

Any adverse effects on earthworms that might result from practical use of thiophanate-methyl should be confined to the area of application, since its main degradation products show little or no tendency to move in soil away from the site of application.

In tests where high levels of an MBC-generating compound (benomyl) reduced earthworm populations, there was recovery of populations upon discontinued use of the fungicide.

Importance of Thiophanate-methyl to Agriculture

Thiophanate-methyl was first introduced in the United States in 1973. It is a broad-spectrum fungicide similar to benomyl. The fungitoxic agent of both benomyl and thiophanate-methyl is MBC. Thiophanate-methyl is effective at low rates, from 1 to 8 oz of active ingredient (ai) per thousand square feet.

Thiophanate-methyl is one of the first major fungicides with systemic activity inside plant tissues. This important characteristic improves disease control, prevents excessive loss of the fungicide from heavy rainfall, and controls fungal infections after they
have become established. Thiophanate-methyl allows more flexibility in timing of applications; turf managers frequently wait until a disease is present before beginning treatment. Owing to its systemic activity, thiophanate-methyl is applied on a 14- to 21-day interval rather than on a 7- to 10-day interval, such as is used with contact-type fungicides. If thiophanate-methyl were not registered for use, turfgrass managers would be forced to apply fungicides more frequently, resulting in increased labor and energy costs.

Current registrations for thiophanate-methyl include turfgrass and ornamentals. For ornamental disease control, thiophanate-methyl is used in combination with Terrazole® and sold as Banrot®. Banrot® contains 25 percent thiophanate-methyl and 15 percent Terrazole®. Banrot® is used exclusively as a soil drench.

Although no products containing thiophanate-methyl are registered for use on food crops, applications are being reviewed for use on stone fruits and strawberries.

The economic impact of thiophanate-methyl will be more thoroughly covered in Part 2 of this report. In the following sections, the assessment team has attempted to give an overview of the use of thiophanate-methyl on turf and ornamentals.

Turfgrass

Turfgrass is a perennial crop. Once established, usually from seed in the North, it remains on that site for years. The one exception to this is sod, which is usually also started from seed and then moved to a site after the turf has become mature and knitted together. Then the turf is watered, fertilized, mowed, and treated for pests on a regular schedule or on an as-needed basis, depending on the maintenance level.

Normal means of evaluating agricultural commodities cannot be applied to turf, except for sod, since it is actually sold and therefore can be assigned a dollar value. The other portions of the turfgrass industry have to be evaluated by different criteria. The three basic methods of evaluation according to Beard (2) are (a) the initial capital investment required to develop and establish the turf; (b) the annual cost for maintaining that turf; and (c) the turfgrass acreages. In addition, turf has other values that cannot be measured in dollars and cents. It is difficult to place a dollar value on beautification, contributions to physical and mental health, dust suppression, noise abatement, and soil erosion; yet these are important to our well being and happiness now and will become more important as we become more overpopulated and more urbanized.

The turgrass acreage in the United States in 1965 was estimated to be over 20 million acres and the annual maintenance cost was estimated at $4.3 billion (25). There is little doubt, considering inflation since 1965, that this figure has greatly increased and is probably closer to $10 billion today, especially when new homes, schools, park areas, and golf courses that have been built since 1965 are taken into consideration. The cost on an individual State basis can be seen in Table 3. Table 4 is a breakdown of maintenance cost for turf in Michigan. The cost of maintaining turf in the United States is an indication of the importance of turf to the American public.
The fact that the majority of this cost is for residential lawn care (tables 4 and 5) illustrates the importance that the average American homeowner places on his home lawn. These valuable lawns could be destroyed by diseases if adequate means of disease control were not available for use.

Thiophanate-methyl is labeled for control of five major turfgrass diseases (listed in table 6 along with the rate and approximate number of treatments). Approximately 45,000 pounds of active ingredient thiophanate-methyl are used per season to control these turfgrass diseases, and loss of the compound could cause severe problems for the turfgrass industry.

Table 3.—Estimate of the total annual turfgrass maintenance costs for 7 States

<table>
<thead>
<tr>
<th>State</th>
<th>Total annual turfgrass maintenance cost</th>
<th>Year estimate was made</th>
</tr>
</thead>
<tbody>
<tr>
<td>Florida</td>
<td>$120,700,000</td>
<td>1960</td>
</tr>
<tr>
<td>Michigan</td>
<td>552,741,545</td>
<td>1973</td>
</tr>
<tr>
<td>New Jersey</td>
<td>95,000,000</td>
<td>1960</td>
</tr>
<tr>
<td>New York</td>
<td>142,000,000</td>
<td>1961</td>
</tr>
<tr>
<td>Oklahoma</td>
<td>72,020,900</td>
<td>1963</td>
</tr>
<tr>
<td>Pennsylvania</td>
<td>565,261,896</td>
<td>1966</td>
</tr>
<tr>
<td>Texas</td>
<td>211,568,126</td>
<td>1964</td>
</tr>
</tbody>
</table>

Table 4.—Extent and cost of maintaining turfgrass areas in Michigan

<table>
<thead>
<tr>
<th>Turfgrass areas</th>
<th>Number of units</th>
<th>Acreage</th>
<th>Annual maintenance cost per unit</th>
<th>Annual maintenance cost per acre</th>
<th>Total annual maintenance cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Home lawns</td>
<td>2,242,518</td>
<td>0.25</td>
<td>560,629</td>
<td>$104.60</td>
<td>$418.40</td>
</tr>
<tr>
<td>2. Apartments</td>
<td>712,051</td>
<td>.4</td>
<td>284,821</td>
<td>260.00</td>
<td>650.00</td>
</tr>
<tr>
<td>3. Golf courses:</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>18 Hole</td>
<td>269</td>
<td>146.0</td>
<td>39,274</td>
<td>82,599.50</td>
<td>565.75</td>
</tr>
<tr>
<td>9 Hole</td>
<td>195</td>
<td>68.0</td>
<td>13,260</td>
<td>27,834.44</td>
<td>409.33</td>
</tr>
<tr>
<td>4. Industrial</td>
<td>133,112</td>
<td>.3</td>
<td>39,934</td>
<td>156.00</td>
<td>520.00</td>
</tr>
<tr>
<td>5. Cemeteries</td>
<td>8,626</td>
<td>10.8</td>
<td>93,500</td>
<td>3,780.00</td>
<td>350.00</td>
</tr>
<tr>
<td>6. Resorts, motels, hotels, and camps</td>
<td>9,672</td>
<td>2.5</td>
<td>24,180</td>
<td>1,015.00</td>
<td>406.00</td>
</tr>
<tr>
<td>7. Roadsides: (^3/)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>State and Federal</td>
<td>1,500</td>
<td>30 A/mi</td>
<td>45,000</td>
<td>233.10</td>
<td>7.77</td>
</tr>
<tr>
<td>Primary</td>
<td>7,700</td>
<td>8 A/mi</td>
<td>61,600</td>
<td>93.36</td>
<td>11.67</td>
</tr>
<tr>
<td>County</td>
<td>88,013</td>
<td>5 A/mi</td>
<td>440,065</td>
<td>56.00</td>
<td>11.20</td>
</tr>
<tr>
<td>8. Schools:</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Grade and High</td>
<td>4,933</td>
<td>3.5</td>
<td>17,758</td>
<td>662.06</td>
<td>189.16</td>
</tr>
<tr>
<td>College</td>
<td>102</td>
<td>253.0</td>
<td>25,778</td>
<td>51,865.00</td>
<td>205.00</td>
</tr>
<tr>
<td>9. Institutional:</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>City, County, State. Churches</td>
<td>10,509</td>
<td>1.5</td>
<td>15,764</td>
<td>307.50</td>
<td>205.00</td>
</tr>
<tr>
<td>10. Parks</td>
<td>560</td>
<td>83.8</td>
<td>46,920</td>
<td>21,117.60</td>
<td>252.00</td>
</tr>
<tr>
<td>11. Airfields</td>
<td>306</td>
<td>835.8</td>
<td>255,757</td>
<td>29,361.65</td>
<td>35.13</td>
</tr>
<tr>
<td>12. Military grounds</td>
<td>60</td>
<td>386.7</td>
<td>23,200</td>
<td>42,537.00</td>
<td>110.00</td>
</tr>
<tr>
<td>Total</td>
<td>2,281,167</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

1/ Table compiled by James B. Beard.
2/ Values and acreages based on 1973 data.
3/ Report units in miles and maintenance cost in cost per mile.
Table 5.—Estimated percentage distribution of expenditures in 1965 for turfgrass maintenance by turfgrass specialty in the United States

<table>
<thead>
<tr>
<th>Turfgrass use category</th>
<th>Percent of total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lawns - residential</td>
<td>69.4</td>
</tr>
<tr>
<td>Roadsides</td>
<td>10.9</td>
</tr>
<tr>
<td>Cemeteries</td>
<td>8.4</td>
</tr>
<tr>
<td>Golf courses</td>
<td>5.5</td>
</tr>
<tr>
<td>Parks - municipal</td>
<td>1.4</td>
</tr>
<tr>
<td>Schools - public</td>
<td>.9</td>
</tr>
<tr>
<td>Airfields</td>
<td>.8</td>
</tr>
<tr>
<td>Lawns - commercial</td>
<td>.6</td>
</tr>
<tr>
<td>Churches</td>
<td>.6</td>
</tr>
<tr>
<td>Colleges and universities</td>
<td>.4</td>
</tr>
<tr>
<td>Miscellaneous</td>
<td>1.1</td>
</tr>
</tbody>
</table>

Table 6.—Diseases controlled by benomyl and thiophanate-methyl; rate and average number of treatments

<table>
<thead>
<tr>
<th>Disease</th>
<th>Rate</th>
<th>Avg no. of treatments</th>
<th>Effi-</th>
<th>Avg no. of treatments</th>
<th>Effi-</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(oz/</td>
<td>1,000 ments per ft²</td>
<td>cacy</td>
<td>1,000 ments per ft²</td>
<td>cacy</td>
</tr>
<tr>
<td>Dollar spot</td>
<td>G</td>
<td>1</td>
<td>1</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>Brown patch</td>
<td>G</td>
<td>2-4</td>
<td>2</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>Fusarium patch</td>
<td>G</td>
<td>2-4</td>
<td>2</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>Fusarium blight</td>
<td>G</td>
<td>5-8</td>
<td>2</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>Stripe smut</td>
<td>G</td>
<td>4-8</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
</tbody>
</table>

1/ G = good control.

Ornamentals

Thiophanate-methyl is widely used as a fungicide for control of soilborne diseases of ornamental plants. It is the major ingredient of Banrot®, a product developed by the Mallinckrodt Chemical Works.

Banrot contains 25 percent thiophanate-methyl (Topsin®-M®) and 15 percent Terrazole® (Truban®). This combination of fungicides provides a broad spectrum of control for such soilborne pathogens as Pythium, Phytophthora, Rhizoctonia, Thielaviopsis, and Fusarium. Water suspensions are commonly used as a soil drench at the time of seeding or transplanting, as well as a periodic drench throughout the growing period.

Probably the most important users of Banrot® on ornamental plants are the small-volume growers who produce a wide variety of plant species. The broad spectrum of control and relative safety of this combination of fungicides prevent extensive plant loss.

Alternatives to Banrot® include a combination of Terrazole® and benomyl (benomyl is currently under RPAR), Dexon®, and Terradon® (PCNB - also under RPAR). Although Dexon® is not currently an RPAR candidate, it would not completely substitute for Banrot® because of its inability to control Rhizoctonia sp.

Although thiophanate-methyl is not registered in the United States on ornamental crops, except in combination with Terrazole®, its use as a constituent of Banrot® constitutes approximately 10 percent (4,000-5,000 lb) of the total market. Although this is a minor use, it is a very critical one for the production of certain ornamental plants.

Summary - Importance of Thiophanate-methyl to Agriculture

Thiophanate-methyl is an important fungicide for plant disease control on turf and ornamentals. Approximately 50,000 pounds of thiophanate-methyl are used annually in the United States; of this amount, approximately 45,000 pounds are used on turf and 5,000 pounds on ornamentals.

Thiophanate-methyl is used to control five major turfgrass diseases. Owing to its unique systemic properties, this fungicide is applied at lower rates and less frequently than alternate contact-type fungicides. In many instances, turfgrass managers wait until diseases are actually present before initiating control programs; thus, actual fungicide use is reduced.
Thiophanate-methyl is widely used as a drench for control of soilborne diseases. It is used exclusively in combination with Terrazole® and sold as Banrot®. The most important use on ornamentals is by small-volume growers who produce a wide variety of ornamental plant species.

PART 2
AN ANALYSIS OF CURRENT THIOPHANATE-METHYL USES, THEIR BENEFITS, THE ROLE OF ALTERNATIVES, IMPACTS TO AGRICULTURE FROM CHANGES IN THIOPHANATE-METHYL USE PATTERNS, AND APPLICATOR EXPOSURE

Introduction

In this section, Part 2: An analysis of current thiophanate-methyl uses, their benefits, the role of alternatives, impacts to agriculture from changes in thiophanate-methyl use patterns, and applicator exposure, special emphasis is given to the benefits of thiophanate-methyl.

Ornamentals

Thiophanate-methyl (TPM), incorporated in Banrot®, is widely used for the control of soilborne diseases of ornamental plants. Banrot® is a wettable powder formulation containing 25 percent TPM (Topsin®-M) and 15 percent Terrazole® (Truban®). Banrot® is registered for control of Pythium sp., Phytophthora sp., Rhizoctonia sp., Thielaviopsis sp., and Fusarium sp. TPM is effective against the last three genera.

Banrot® is registered for treatment of the following crops:

1. Bedding plants - asters, balsam, celosia, marigold, petunia, salvia, snapdragon, verbena, and zinnia.
2. Foliage plants - aglaonema, peperomia, and philodendron.
3. Containers and bedgrown plants - chrysanthemum, geranium, boxwood, pittosporum, and poinsettias.

The use of TPM, as a constituent in Banrot®, represents an annual sale of approximately 5,000 pounds in the ornamentals market. Although the volume of use is relatively small, it is critical for the control of the diseases for which it is used.

The value of TPM to the ornamentals industry lies in the fact that it effectively controls diseases that would otherwise produce high-volume losses in very high-value crops. In addition, alternative chemicals would not completely substitute for the control achieved by Banrot®. Many compounds that one might consider as partial replacements are themselves subject to RPAR action, or they are phytotoxic.

Banrot® is used as a drench for treating nursery and greenhouse plantings. Solutions are applied at low pressure as high-volume low concentration coarse sprays, and as a result there is little possibility of significant exposure to the applicator. In addition, application rates, as prescribed on the label, are low. Treatments of growing media in greenhouses and nurseries call for 1.2 to 7.5 oz al/1,000 ft² of TPM, depending upon the depth and composition of the medium. Applicator exposure and environmental exposure are also reduced because TPM is generally only applied once or twice in the production cycle of the crop. Thus, on a yearly basis, Banrot® may be applied from 3 to 12 times a year.

Under normal cultural practices in the commercial production of ornamentals, artificial mixes are used that contain little or no soil. As a result, the possibility of reduction of earthworm populations does not exist.
Alternatives

No other single registered alternative other than benomyl controls as broad a spectrum of soil diseases as does TPM. The systemic nature of TPM increases its control potential while reducing the amount of chemical needed by decreasing the number of applications. This in turn reduces environmental and applicator exposure and reduces energy and labor costs to the grower since TPM in the soil is taken up by the plant to control some foliar diseases without a separate application to the foliage.

Compared with other chemicals labeled for control of soilborne diseases, Banrot® controls for longer periods of time with relatively smaller amounts of active ingredient (21), as illustrated below.

<table>
<thead>
<tr>
<th>Chemical</th>
<th>Pounds active ingredient per application/100 gal*</th>
<th>Period of control (weeks)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Banrot®</td>
<td>0.2</td>
<td>4-16</td>
</tr>
<tr>
<td>Benomyl</td>
<td>0.5</td>
<td>2-14</td>
</tr>
<tr>
<td>Captan</td>
<td>0.5</td>
<td>1-2</td>
</tr>
<tr>
<td>PCNB**</td>
<td>0.75</td>
<td>-</td>
</tr>
<tr>
<td>Botran®</td>
<td>1.12</td>
<td>3-4</td>
</tr>
</tbody>
</table>

* One application equals ai in 100 gallons for drenching 400 to 800 ft².
** One application per crop because of phytotoxicity.

The greatest benefits derived from the use of TPM in Banrot® are related to the high cash value of the crops involved and to the need for complete control. Partial control results in inferior appearance and may reduce the value of the crop by 80 to 100 percent. LeClerg (19) estimated that 5.5 percent of the wholesale value of woody ornamentals, floral, foliage, and bedding plants are lost to root rot diseases. Of this total loss, diseases caused by Rhizoctonia sp., Thielaviopsis sp., and Fusarium sp., and controlled by the TPM component of Banrot®, account for 36 percent. Although the exact wholesale value of all individual crops is not available, the dollar savings resulting from disease control can be estimated by determining the wholesale value of key ornamental crops or classes of crops. Based on 1976 figures (44), the savings in wholesale value of bedding plants, foliage plants, chrysanthemums, geraniums, and poinsettias resulting from the use of Banrot® may be estimated at $4.6 million annually (table 7).

Benomyl

This is the only registered alternative to TPM with as broad a spectrum of disease control. Fungicide and Nematicide Tests report conflicting results for control of Rhizoctonia rot on poinsettias. Cole and others (7) reported no control with Banrot® but excellent control with Benlate®. Powell (31) measured the severity of Rhizoctonia root rot and reported that both chemicals gave equal control. Benomyl is preferred for control of Rhizoctonia root rot of poinsettia because approximately twice as much TPM as benomyl is needed for equal control (32). On foliage and bedding plants, TPM and benomyl both give good control of soil pathogens (18). Benomyl is recommended at 0.5 lb ai/100 gal water applied at 1 to 2 qt/ft² treatments repeated at 2- to 4-week intervals. Banrot® is recommended at 1.5 to 3.0 oz ai per 100 gal water at 4- to 12-week intervals. Benomyl costs $16.00/lb and does not control the Pythium or Phytophthora water molds. Banrot® ($31.25/lb (ai)) is a combination of the active ingredients that do control the Pythium-Phytophthora water molds, which generally cause greater economic losses than Rhizoctonia sp., Thielaviopsis sp., and Fusarium sp. by a ratio of almost 2:1.

PCNB (Terraclor®)

Control of Rhizoctonia sp. is equal to or better than TPM; however, better overall control of other soil pathogens was achieved with TPM (18). As a soil drench, 0.63 lb ai of PCNB is mixed with 100 gallons of water to treat 333 ft² of bench or bed area. Applications are recommended at 3- to 4-week intervals.
Table 7.—Major ornamental crops treated with thiophanate-methyl (TPM): Production area, units sold, wholesale value,\(^{1}\) percent of crop treated with TPM, diseases, and alternative chemicals, 1976

<table>
<thead>
<tr>
<th>Host</th>
<th>Production area (million ft(^2))</th>
<th>Number of units sold (millions)</th>
<th>Value of sales at wholesale (millions)</th>
<th>Percent of crop treated with TPM</th>
<th>Disease</th>
<th>Alternative chemicals (^{2})</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bedding plants</td>
<td>31.9</td>
<td>20.8</td>
<td>62.8</td>
<td>25</td>
<td>Crown and root rot.</td>
<td>captain, benomyl, PCNB (Terraclor(^{\circ}))</td>
</tr>
<tr>
<td>Foliage plants</td>
<td>116.3</td>
<td>----</td>
<td>235.8</td>
<td>75</td>
<td>Root rot</td>
<td>benomyl</td>
</tr>
<tr>
<td>Chrysanthemum</td>
<td>17.6</td>
<td>25.8</td>
<td>52.9</td>
<td>20</td>
<td>Stem and crown rot.</td>
<td>benomyl, DCNA (Botran(^{\circ})), PCNB</td>
</tr>
<tr>
<td>Geranium</td>
<td>14.8</td>
<td>46.1</td>
<td>30.4</td>
<td>20</td>
<td>Root rot</td>
<td>benomyl, DCNA (Botran(^{\circ}))</td>
</tr>
<tr>
<td>Poinsettias</td>
<td>21.6</td>
<td>14.9</td>
<td>35.5</td>
<td>85</td>
<td>Root, stem, and crown rot.</td>
<td>benomyl, PCNB (Terraclor(^{\circ}))</td>
</tr>
</tbody>
</table>

\(^{1}\) Source: (44).
\(^{2}\) Chemicals with Federal labels only (State labels excluded).

Cost of PCNB is $1.25/lb ai; however, it has the limitation that it is phytotoxic to many plants and cannot be reapplied a second time.

**DCNA (Botran\(^{\circ}\))**

DCNA does not effectively control soilborne pathogens. In addition, some phytotoxicity results from its use.

**Captan**

Captan is registered for control of soilborne fungi and is recommended at equal to or one quarter the amounts of active ingredient (45); however, captan is not considered to be as effective as thiophanate-methyl in disease control (29, 30, 52).

**Turfgrass Diseases Controlled by Thiophanate-methyl**

**Dollar Spot**

Dollar spot attacks turf in all areas of the United States except for the arid regions of the West. On golf courses it is the most commonly occurring disease.

**Symptoms**

The disease is characterized by round, bleached to straw-colored spots, ranging in size from that of a quarter up to a silver dollar, from whence the disease got its name. The spots appear as sunken areas, especially in turf mowed at 1/2 inch in length or less.
As the disease progresses, individual spots may coalesce and destroy the turf in large undefined areas. If the fresh spots are observed in the morning while the grass is still wet, the grayish-white fluffy mycelium of the fungus can be seen. The disease is spread mechanically, primarily by mowers and other maintenance equipment carrying infected plant tissue. Infected plant tissue is also carried by golf shoes and carts. Because of this method of transmission, when the disease is controlled only on the greens, its recurrence will usually first be noticed on the side of the green from which the traffic approaches from the infected areas and fairway.

Occurrence

Dollar spot occurs at temperatures between 60° and 90°F. There appear to be two strains of the causal organism of the disease and they are distinguished by temperature specificity: One strain occurs during cool weather when the temperature is below 75°F; the other strain is favored by temperatures greater than 80°F. Development of the disease is favored by high humidity, warm days, and cool nights.

Non fungicidal Control

Maintaining high nitrogen fertility levels and removal of guttation water are the two cultural means of reducing disease severity. On nitrogen, one school of thought says, "more infection will occur at higher nitrogen fertility but the damage will be less severe." The other says, "that at low fertility, while there may be fewer actual spots, they will be larger and cause more permanent damage." From a practical point of view, it is necessary to keep the nitrogen levels up during periods of severe dollar spot development to reduce the severity and make the fungicide program more effective. "Removing the dew" to reduce dollar spot severity is also a common cultural practice on golf course greens. These practices are not adequate to prevent extensive loss from the disease. Therefore, chemical fungicides are required.

If dollar spot is not controlled with fungicides, it can be severe enough to destroy the majority of the turf on a golf course in a matter of a month to 6 weeks. Loss of turf would make playing golf impossible, with a resulting revenue loss, and it could eventually lead to the bankruptcy of the golf course. For an 18-hole golf course, the expense of reseeding the greens, tees, and fairways to desirable species would cost over $3,000 in seed alone, not to mention the more major cost of machinery, labor, fertilizer, and herbicides. Furthermore, it would be some time after reseeding before the golf course would be playable and further substantial losses in revenue would occur.

Alternatives

The alternatives to TPM for dollar spot control are given in table 8. When they are applied on a 10- to 14-day schedule, they give control comparable to TPM, but on a 1-month schedule only thiophanate and benomyl give equivalent control (46, 47). Only 1 oz/1,000 ft² is required for month-long control with TPM and its alternatives, thiophanate and benomyl. The other alternatives (except for the cadmiums), cycloheximide, cycloheximide-thiram, chlorothalonil, anilazine, PCNB, and cycloheximide-PCNB, all require 2 to 6 oz/1,000 ft² per treatment to be effective. Therefore, where TPM and the alternatives thiophanate and benomyl are being used less fungicide is being added to the environment. The common names, chemical names, and trade names for fungicides and fungicide mixtures used on turf are given in tables 9 and 10.

Thiophanate-methyl and the alternatives thiophanate and benomyl are the cheapest fungicides to use when the length of time they give effective control is taken into consideration because alternatives require multiple applications to give equivalent control (table 11). The exception is cadmium chloride, which is cheaper even at multiple applications. It should be noted that although thiophanate could be substituted directly for TPM, there is
Table 8.—Turfgrass diseases controlled by thiophanate-methyl products, the hosts they occur on, and effective alternatives to them

<table>
<thead>
<tr>
<th>Disease and causal organism</th>
<th>Hosts</th>
<th>Effective alternatives to thiophanate-methyl</th>
</tr>
</thead>
<tbody>
<tr>
<td>Brown patch</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rhizoctonia solani</td>
<td>Annual bluegrass</td>
<td>Chlorothalonil</td>
</tr>
<tr>
<td></td>
<td>Bahiagrass</td>
<td>Cycloheximide</td>
</tr>
<tr>
<td></td>
<td>Bermudagrass</td>
<td>Cycloheximide-PCNB</td>
</tr>
<tr>
<td></td>
<td>Centipedegrass</td>
<td>Cycloheximide-thiram</td>
</tr>
<tr>
<td></td>
<td>Colonial bentgrass</td>
<td>Thiophanate</td>
</tr>
<tr>
<td></td>
<td>Creeping bentgrass</td>
<td>Benomyl</td>
</tr>
<tr>
<td></td>
<td>Fine leaf fescues</td>
<td>Thiophanate-thiram</td>
</tr>
<tr>
<td></td>
<td>Kentucky bluegrass</td>
<td>Thiram</td>
</tr>
<tr>
<td></td>
<td>Meadow fescue</td>
<td>Mancozeb</td>
</tr>
<tr>
<td></td>
<td>Perennial ryegrass</td>
<td>PCNB</td>
</tr>
<tr>
<td></td>
<td>St. Augustinegrass</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Tall fescue</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Velvet bentgrass</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Zoysiagrass</td>
<td></td>
</tr>
<tr>
<td>Dollar spot</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sclerotinia homoeocarpa</td>
<td>Annual bluegrass</td>
<td>Chlorothalonil</td>
</tr>
<tr>
<td></td>
<td>Bahiagrass</td>
<td>Anilazine</td>
</tr>
<tr>
<td></td>
<td>Bermudagrass</td>
<td>Cycloheximide</td>
</tr>
<tr>
<td></td>
<td>Centipedegrass</td>
<td>Cycloheximide-thiram</td>
</tr>
<tr>
<td></td>
<td>Colonial bentgrass</td>
<td>Cycloheximide-PCNB</td>
</tr>
<tr>
<td></td>
<td>Creeping bentgrass</td>
<td>Thiophanate</td>
</tr>
<tr>
<td></td>
<td>Fine leaf fescues</td>
<td>Benomyl</td>
</tr>
<tr>
<td></td>
<td>Kentucky bluegrass</td>
<td>Thiophanate-thiram</td>
</tr>
<tr>
<td></td>
<td>Perennial ryegrass</td>
<td>Thiram</td>
</tr>
<tr>
<td></td>
<td>St. Augustinegrass</td>
<td>Thiabendazole</td>
</tr>
<tr>
<td></td>
<td>Zoysiagrass</td>
<td>Cadmium compounds</td>
</tr>
<tr>
<td></td>
<td></td>
<td>PCNB</td>
</tr>
<tr>
<td>Fusarium patch</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fusarium nivale</td>
<td>Annual bluegrass</td>
<td>The mercuries</td>
</tr>
<tr>
<td></td>
<td>Colonial bentgrass</td>
<td>Mancozeb</td>
</tr>
<tr>
<td></td>
<td>Creeping bentgrass</td>
<td>Thiophanate</td>
</tr>
<tr>
<td></td>
<td>Fine leaf fescues</td>
<td>Benomyl</td>
</tr>
<tr>
<td></td>
<td>Kentucky bluegrass</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Perennial ryegrass</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Tall fescue</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Velvet bentgrass</td>
<td></td>
</tr>
<tr>
<td>Fusarium blight</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fusarium roseum</td>
<td>Kentucky bluegrass</td>
<td>Thiophanate</td>
</tr>
<tr>
<td>Fusarium tricinctum</td>
<td>Centipedegrass</td>
<td>Benomyl</td>
</tr>
<tr>
<td>Stripe smut</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ustilago striiformis</td>
<td>Kentucky bluegrass</td>
<td>Thiophanate</td>
</tr>
<tr>
<td></td>
<td>Creeping bentgrass</td>
<td>Benomyl</td>
</tr>
<tr>
<td>Red thread</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Corticium fuciforme</td>
<td>Kentucky bluegrass</td>
<td>Cadmium compounds</td>
</tr>
<tr>
<td></td>
<td>Creeping bentgrass</td>
<td></td>
</tr>
<tr>
<td>Copper spot</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Gloeocercospora sorghi</td>
<td>Kentucky bluegrass</td>
<td>Cadmium compounds</td>
</tr>
<tr>
<td></td>
<td>Creeping bentgrass</td>
<td></td>
</tr>
<tr>
<td>Common name</td>
<td>Chemical name or mixture</td>
<td>Trade name</td>
</tr>
<tr>
<td>-------------------</td>
<td>------------------------------------------------------------------------------------------</td>
<td>------------------------------------------------</td>
</tr>
<tr>
<td>Anilazine</td>
<td>2,4-dichloro-6-(o-chloroanilino)-s-triazine</td>
<td>Dyrene, Proturf Fungicide III</td>
</tr>
<tr>
<td>Benomyl</td>
<td>methyl 1-(butylcarbamoyl)-2-benimidazolecarbamate</td>
<td>Tersan 1991, Proturf Fertilizer + DSB fungicide</td>
</tr>
<tr>
<td>Cadmium compounds</td>
<td>cadmium chloride</td>
<td>Caddy</td>
</tr>
<tr>
<td></td>
<td>cadmium chloride (8.3 pct) plus thiram (75 pct)</td>
<td>Cad-trete</td>
</tr>
<tr>
<td></td>
<td>cadmium sebacate 5 pct, potassium chromate 5 pct, malachite green 1 pct, auramine 0.5 pct, thiram 16 pct</td>
<td>Kromad</td>
</tr>
<tr>
<td></td>
<td>cadmium succinate 60 pct (29 pct cadmium)</td>
<td>Cadminate</td>
</tr>
<tr>
<td>Captan</td>
<td>N-{[(trichloromethyl)thio]-4-cyclohexene-1,2-dicarboximide}</td>
<td>Orthocide</td>
</tr>
<tr>
<td>Chloroneb</td>
<td>1,4-dichloro-2,5-dimethoxybenzene</td>
<td>Captain 50W, Captain 75W, Tersan SP, Proturf Fungicide II</td>
</tr>
<tr>
<td>Cycloheximide</td>
<td>3-[2-(3,5-dimethyl-2-oxycyclohexyl)-2-hydroxyethyl]glutarimide</td>
<td>Acti-dione TGF</td>
</tr>
<tr>
<td>Chlorothalonil</td>
<td>2,4,5,6-tetrachloroisophthalonitrile</td>
<td>Daconil 2787, Proturf 101V</td>
</tr>
<tr>
<td>Maneb</td>
<td>manganous ethylenebis[dithiocarbamate]</td>
<td>Manzate</td>
</tr>
<tr>
<td>Mancozeb</td>
<td>coordination product of zinc ion and manganous ethylenebis[dithiocarbamate]</td>
<td>Fore</td>
</tr>
<tr>
<td>Maneb plus zinc sulfate</td>
<td>manganous ethylenebis[dithiocarbamate] plus zinc sulfate</td>
<td>Tersan LSR</td>
</tr>
<tr>
<td>Mercury compounds</td>
<td>inorganic mercuric and mercurous chloride</td>
<td>Calo Clor, Calo Gran</td>
</tr>
<tr>
<td>PCNB</td>
<td>pentachloronitrobenzene</td>
<td>Terraclor 75, Scotts F + F II</td>
</tr>
<tr>
<td>PMA</td>
<td>phenylmercury acetate</td>
<td>PMA, PMAS, Puraturf No. 10 Phenmad</td>
</tr>
<tr>
<td>PMAS</td>
<td>phenylmercury acetate</td>
<td></td>
</tr>
<tr>
<td>Thiophanate</td>
<td>diethyl [(1,2-phenylene)bis(iminocarbonothioyl)]= bis[carbamate]</td>
<td>Cleary's 3336</td>
</tr>
<tr>
<td>Thiophanate-methyl</td>
<td>dimethyl [(1,2-phenylene)bis(iminocarbonothioyl)]= bis[carbamate]</td>
<td>Fungo, Spot Kleen, Scotts Systemic Fungicide</td>
</tr>
<tr>
<td>Thiram</td>
<td>bis(dimethylthiocarbamoyl) disulfide</td>
<td>Tersan 75, Spot-Treat, Thiramad</td>
</tr>
<tr>
<td>Dinocap</td>
<td>2-(1-methylheptyl)-4,6-dinitrophenyl crotonate</td>
<td>Karathane, Mildex</td>
</tr>
<tr>
<td>Terrazole</td>
<td>5-ethoxy-3-(trichloromethyl)-1,2,4-thiadiazole</td>
<td>Koban</td>
</tr>
<tr>
<td>Thiabendazole</td>
<td>2-(4-thiazoyl)benzimidazole</td>
<td>Mertect 160, Tobaz</td>
</tr>
</tbody>
</table>
Table 10.—Fungicide mixtures

<table>
<thead>
<tr>
<th>Trade name</th>
<th>Generic make-up of mixture</th>
</tr>
</thead>
<tbody>
<tr>
<td>Acti-dione thiram</td>
<td>Cycloheximide + thiram.</td>
</tr>
<tr>
<td>Acti-dione RZ</td>
<td>Cycloheximide + PCNB.</td>
</tr>
<tr>
<td>Bromosan</td>
<td>Thiophanate + thiram.</td>
</tr>
<tr>
<td>Scotts Fertilizer</td>
<td>PMA + thiram</td>
</tr>
</tbody>
</table>

not enough thiophanate available to meet the needs if both benomyl and TPM registrations are canceled.

RPAR's have been issued against PCNB and cadmium products; this means that PCNB, cycloheximide-PCNB, and cadmium may not be available depending on the outcome of their rebuttals. Without benomyl, thiophanate, TPM, and cycloheximide-PCNB the chemical, labor, and energy costs of controlling dollar spot could double for a turfgrass manager.

Brown Patch

Symptoms

The disease is characterized by circular brown patches ranging in size from a few inches up to several feet in diameter. The infected leaves first appear water-soaked and dark, eventually drying, becoming withered and dark brown. Brown to black sclerotia, small seedlike masses composed of mycelium, are sometimes found beneath the leaf sheath or on the stolons. When high humidity is present a so-called "smoke ring," which consists of the mycelium of the fungus, surrounds the outer margins of the diseased area. The "smoke ring" will disappear as the foliage dries.

The turfgrass areas destroyed by brown patch or other diseases are usually invaded by broadleaf weeds or weedy grasses. Most of the broadleaf weeds and annual grass can be controlled with selective herbicides, but the perennial weedy grasses cannot—they require a complete renovation. If the disease is widespread, the entire turf area will have to be replaced at considerable cost to the homeowner or professional turf person.

Occurrence

*Rhizoctonia solani*, the causal organism of brown patch, survives periods of extreme heat or cold as sclerotia or as mycelium in plant debris. It can also survive as a saprophyte in the turf thatch. When the soil temperatures rise into the 60's the sclerotia begin to germinate and the fungus grows. The fungus grows in a circular pattern, as most fungi do, but apparently does not parasitize the grass plant until the air temperature rises to the mid-80's with high humidity and nighttime temperatures that remain in the 70's or higher. At lower temperatures, *R. solani* is a weak parasite growing as a saprophyte or causing minute infections; serious infection does not take place as the lower temperature is conducive to healthy grass growth. It is only after grass plants undergo heat stress and begin to go through high temperatures that growth stoppage occurs. The balance then switches in favor of the fungus, resulting in disease development. *R. solani* usually infects roots first, then stolons, and finally leaves. It can enter the grass plant through the cut ends of the grass blades, through stomates, or by direct penetration.

Nonfungicidal Control

Two major cultural practices that help to reduce the severity of brown patch are maintaining low levels of nitrogen during periods when brown patch may be a problem and removing guttation water as soon as possible in the morning. The cultural practices will help to reduce the severity of disease, but they will not give a satisfactory level of control to prevent severe turf loss. For acceptable levels of control, fungicides are necessary.
Table 11.--Fungicide cost comparison for commercial turfgrass use

<table>
<thead>
<tr>
<th>Fungicide</th>
<th>Cost/lb</th>
<th>Cost/oz</th>
<th>Rate/1,000 ft²</th>
<th>Cost/1,000 ft²</th>
<th>Cost/acre ²</th>
</tr>
</thead>
<tbody>
<tr>
<td>Anilazine (Dyrene)</td>
<td>2.83</td>
<td>0.18</td>
<td>4</td>
<td>0.71</td>
<td>30.63</td>
</tr>
<tr>
<td>Benomyl (Tersan 1991)</td>
<td>10.05</td>
<td>0.63</td>
<td>1</td>
<td>0.63</td>
<td>27.00</td>
</tr>
<tr>
<td>Cadmium succinate</td>
<td>14.95</td>
<td>0.93</td>
<td>1/2</td>
<td>0.47</td>
<td>20.21</td>
</tr>
<tr>
<td>Cadmium chloride</td>
<td>16.50/gal</td>
<td>0.12</td>
<td>1</td>
<td>0.12</td>
<td>5.16</td>
</tr>
<tr>
<td>Chloroneb (Tersan SP)</td>
<td>6.02</td>
<td>0.38</td>
<td>9</td>
<td>3.38</td>
<td>145.00</td>
</tr>
<tr>
<td>Chlorothalonil (Daconil 2787)</td>
<td>3.50</td>
<td>0.21</td>
<td>4</td>
<td>0.84</td>
<td>36.21</td>
</tr>
<tr>
<td>Cycloheximide (Acti-dione TGF)</td>
<td>7.60</td>
<td>0.47</td>
<td>1</td>
<td>0.47</td>
<td>20.50</td>
</tr>
<tr>
<td>Cycloheximide and PCNB (Acti-dione RZ)</td>
<td>5.04</td>
<td>0.32</td>
<td>1/2</td>
<td>0.161</td>
<td>6.78</td>
</tr>
<tr>
<td>Cycloheximide-thiram (Acti-dione Thiram)</td>
<td>4.90</td>
<td>0.31</td>
<td>2</td>
<td>0.61</td>
<td>26.33</td>
</tr>
<tr>
<td>Mancozeb (Tersan LSR)</td>
<td>1.70</td>
<td>0.11</td>
<td>4</td>
<td>0.52</td>
<td>22.36</td>
</tr>
<tr>
<td>Mercuro and Mercuric Chloride (WP)</td>
<td>16.99</td>
<td>1.06</td>
<td>3</td>
<td>3.09</td>
<td>132.87</td>
</tr>
<tr>
<td>Mercuro and Mercuric Chloride (G)</td>
<td>1.22</td>
<td></td>
<td>(6 lb)</td>
<td>7.32</td>
<td>314.76</td>
</tr>
<tr>
<td>PMAS 10 pct</td>
<td>9.33</td>
<td>0.50</td>
<td>1</td>
<td>0.50</td>
<td>21.50</td>
</tr>
<tr>
<td>PCNB (Terraclor)</td>
<td>2.10</td>
<td>0.13</td>
<td>4</td>
<td>0.52</td>
<td>22.36</td>
</tr>
<tr>
<td>Proturf F + F ³/ II (PCNB)</td>
<td></td>
<td></td>
<td>2.00</td>
<td>86.00</td>
<td></td>
</tr>
<tr>
<td>Thiophanate</td>
<td>9.93</td>
<td>0.58</td>
<td>1</td>
<td>0.58</td>
<td>25.08</td>
</tr>
<tr>
<td>Thiophanate-methyl (Fungo)</td>
<td>9.95</td>
<td>0.62</td>
<td>1</td>
<td>0.62</td>
<td>26.74</td>
</tr>
<tr>
<td>Thiram (Tersan 75)</td>
<td>2.03</td>
<td>0.13</td>
<td>4</td>
<td>0.52</td>
<td>22.36</td>
</tr>
</tbody>
</table>

¹/ Costs were rounded off for all treatments.
²/ Cost/acre is based on 43,000 ft²/acre.
³/ Also contains fertilizer, which adds to the cost.
Alternatives to thiophanate-methyl for control of brown patch are given in table 8. Chlorothalonil, cycloheximide, cycloheximide-thiram, cycloheximide-PCNB, PCNB, mancozeb, thiophanate, benomyl, and thiram all give control equivalent to TPM. TPM gives effective control of brown patch at a 2 oz/1,000 ft² rate. The product cost of TPM at 2 oz/1,000 ft² is equivalent to the alternatives since one application will give control for one month compared with two applications required of the other fungicides to give control over the same period. If three applications of the alternatives were required, as sometimes happens, TPM would be cheaper and the energy and labor costs would be two to three times greater. Only thiophanate and benomyl give equivalent duration of control at equivalent cost, and only cycloheximide-PCNB would cost less even with multiple applications (table 11).

Less fungicide enters the environment when TPM, thiophanate, and benomyl are used compared with the alternatives, even though the costs may be the same. RPAR's have been issued against the PCNB products and mancozeb, making their use as alternatives questionable pending the outcome of their reviews. It is doubtful whether enough thiophanate would be produced to fill the demand if registration of both benomyl and thiophanate-methyl were canceled.

Fusarium Patch

Fusarium patch disease is important in many northern areas that experience cool, wet springs or falls or that have snow cover in the winter months. In the Pacific Northwest, Fusarium patch is the most important turfgrass disease. This is mainly due to the extended periods of cool, wet weather without snow cover that are experienced there. In annual bluegrass, creeping bentgrass, velvet bentgrass, colonial bentgrass, and perennial ryegrass, the fungus can enter the crown and result in complete loss of the grass plants. Fusarium nivale, the causal organism, is one of a complex of several fungal organisms that cause snow mold in turf. Some of these are not controlled by thiophanate-methyl or benomyl.

Symptoms

The disease occurs without snow cover as reddish-brown spots ranging in size from less than an inch to about 8 inches in diameter, although large spots are occasionally found. When the disease occurs under snow, the circular spots are usually 2 to 3 inches up to 1 to 2 feet in diameter, and are a tan to whitish-gray or reddish-brown color. If the spots are seen shortly after the snow has melted, they will often have the pink mycelium of the fungus present in the margins, from whence the disease got its common name, pink snow mold.

Occurrence

The fungus can survive as mycelia and conidia in the thatch. It will grow actively on the grass residue. Infection takes place when the temperatures are below 60°F, especially if accompanied by wet weather. The disease can occur under snow cover at temperatures just above freezing.

Nonfungicidal Control

High nitrogen fertility, which makes turfgrass lush and vigorous, will increase susceptibility to Fusarium patch. It will also make control with fungicides more difficult. Although avoiding such nitrogen fertility practices will reduce disease severity, fungicides are necessary to prevent turfgrass from being lost to Fusarium patch.

There are no true Fusarium patch-resistant creeping bentgrass cultivars. All cultivars require chemical treatment to prevent disease development. Annual bluegrass also requires chemical treatment. Kentucky bluegrass and annual bluegrass appear to be more susceptible to Fusarium patch than creeping bentgrass. Fusarium patch has been observed to select out the annual bluegrass
patches in golf course greens, leaving the creeping bentgrass alone.

Alternatives

The alternatives to thiophanate-methyl for the control of Fusarium patch are given in table 8. They are mancozeb, thiophanate, benomyl, and the mercuries. They all give equivalent control of Fusarium patch where multiple applications can be made. The mercury fungicides give the best control in areas where snow cover remains on the ground for a month or longer and multiple applications cannot be made. On the basis of a single application, the costs of benomyl, thiophanate, thiophanate-methyl, mancozeb, and phenyl mercury acetate solution are equivalent to, but much cheaper than, the mercurous and mercuric chloride fungicides. The most critical point is that thiophanate alone could not meet the demand if benomyl and thiophanate-methyl had their registrations canceled. Moreover, all of the other alternatives have serious limitations. One alternative, mancozeb, is in the RPAR process and its availability as an alternative is questionable, leaving the mercuries as the other alternatives. Removing benomyl, TPM, and mancozeb would leave the mercuries and thiophanate as the only effective alternatives for control of Fusarium patch. In addition, Fusarium patch is only one of several diseases that occur in the snow mold complex, which compounds the problem of control for this serious loss of turf in winter.

Fusarium Blight

Fusarium blight is one of the most destructive diseases of Kentucky bluegrass on golf courses and home lawns. Large acreages of valuable sod are lost to this disease every year.

Symptoms

The disease appears as circular spots ranging in size from 6 to 24 inches in diameter. The center of these spots appears as healthy grass surrounded by a band of dead or dying turf. This symptom is commonly referred to as a "frog eye." Under severe conditions, however, or on some of the more susceptible varieties like Pennstar, Flyking, and Nugget, the entire circle of grass will be killed. In areas of temperatures greater than 90°F and high humidity, the disease can be seen as a foliar blight. In the more northern areas and in California the disease occurs as a root and crown rot.

Plants infected with Fusarium blight have shortened root systems that are poorly developed. Even when the grass begins to recover in these spots, the roots and shoots remain stunted. In these areas, the spots first appear as wilted turf (dark blue to purple), and if the turf is not treated it will turn straw-colored to light tan.

On centipedegrass, the primary symptoms on the plant are blighting at the cut end of the blades and mid-blade discoloration, which is sometimes accompanied by tissue collapse. The root systems of infected plants are brown.

Occurrence

The fungus can overwinter in the thatch and in infected plants. Fusarium sp. is also a good saprophyte and is often found in plant debris. In the more southern region where Fusarium blight occurs, the high temperature and humidity stress appear to be conducive to disease development. The fungus can infect the grass plant crowns. Plants whose crowns are infected usually die.

On centipedegrass, most of the injury occurs in the early spring. The centipede either fails to initiate new growth or the new growth soon deteriorates. It has both a leaf blight and root rot stage.

Nonfungicidal Control

High nitrogen fertility early in the season will increase severity of Fusarium blight. In areas where disease is a problem, fertilizing in early fall and the dormant season is advisable,
with light but frequent applications through summer.

Moisture stress is the key to development of symptoms in the North. Watering recommendations for healthy turf usually state "water once a week to a depth of 6 inches to encourage deep root development," but for turf infected with Fusarium blight this is not a good recommendation. What is needed in Fusarium blight-infected turf is light, frequent watering to keep the top inch or half inch of the root zone moist. Because of the shortened root system, even with the top inch or half inch of soil being moist, the infected plants may still wilt and die on days when the temperatures are above 80°F. Minimal turf loss on these days can be obtained by syringing during the warmest part of the day.

Resistant Cultivars

The following cultivars appear to be resistant at this time, although they are certainly not immune: Adelphi, Majestic, Parade, Vantage, and Touchdown; however, these cultivars have not been widely grown for a long enough period to know if they are really resistant or if they will become susceptible as new races of Fusarium roseum develop.

Stripe Smut

Stripe smut and Fusarium blight are the most destructive diseases in Helmithosporium sp.-resistant Kentucky bluegrass cultivars. Stripe smut is a systemic perennial, which means that once a plant becomes infected it will remain so for life. Also, all plants arising from that mother plant will be infected. A smut-infected plant is always in a weakened condition compared with a healthy plant and, consequently, any additional stress will result in death. The most common form of stress is drought, and it is not unusual to see loss of entire lawns that are heavily infected with stripe smut when people go on vacation in the summer and neglect to have someone water their lawns.

Symptoms

From a distance, an infected turf area will appear clumpy. This is the result of the stripe smut organism causing a more upright growth of the infected bluegrass plant. Stripe smut is a disease that tends to kill individual plants, leaving bare spots that contribute to the clumpy appearance. The smut-infected plants do not tiller as profusely as healthy plants, and consequently bare areas are not readily filled in; this results in grass and broadleaf weeds moving into these bare areas.

Light yellow blades of grass are the first symptoms to appear. As the disease advances, the leaf blades begin to curl and have black stripes running parallel up and down the length of the blades, from which a black soot-like dust can be rubbed off. This soot-like dust is the spores of the stripe smut fungus. Older infected blades will be twisted, curled, and shredded from the tips down.

Occurrence

The stripe smut fungus overwinters as mycelium in the crown of an infected plant and in other vegetative parts of an infected plant. It can also overwinter for many seasons as teliospores in the soil. Infection of seedlings can occur through the coleoptiles or through auxiliary crown buds or rhi-zome nodes.

Stripe smut symptoms occur most commonly in the spring and fall during periods of wet, cool weather when the day temperatures are below 70°F. The symptoms gradually disappear as the temperatures become warmer. Although the symptoms are most evident during periods of cool weather, very little turf is lost. Most of the infected turf is lost during the hot, dry weather of the summer when the grass is under heat and drought stress or in open winters when the plants are subject to desiccation and cold-temperature stress.
Stripe smut is a systemic disease that is perennial in the grass plant. Systemic means that the fungus is internal and can spread throughout the vascular system (veins) of the plant. The striping effect of the grass blades is due to the fungus growing only in the veins. Perennial means that once a grass plant is infected it will remain so for life. Although visual symptoms may not always be present, this simply means that the grass is resistant to the prevalent stripe smut races of today, most of which are specific for 'Merion' and 'Windsor'. The possibility for developing new races that can attack other cultivars occurs prior to every new infection.

The diseases controlled by thiophanate-methyl, rates/1,000 ft², and average number of treatments applied in a season are listed in table 6, part 1.

Nonfungicidal Control

Cultural practices will help to reduce disease severity. They consist of applying minimum amounts of nitrogen during the summer months and no more than 1/2 lb nitrogen/application/month. A stripe smut-infected turf will die if allowed to become dry. Unlike a healthy Kentucky bluegrass turf, which will enter dormancy if not watered and recover when water is applied, a stripe smut-infected lawn will not recover.

Resistant Cultivars

There are several Kentucky bluegrass cultivars available today that are believed to be resistant to stripe smut; however, this resistance is probably only temporary because of the numerous races that the stripe smut fungus has the potential to produce. Once a Kentucky bluegrass becomes widely grown, a race of the stripe smut fungus that can attack it will probably develop.

Alternatives for Fusarium Blight and Stripe Smut

The only alternative to thiophanate-methyl for the control of Fusarium blight and stripe smut are thiophanate and benomyl (46, 48, 49, 50). Since thiophanate is similar to thiophanate-methyl and benomyl, similar rates are used and costs are approximately the same. It is highly unlikely, however, that enough thiophanate would be made available to meet the demand for the control of these two diseases if the registrations of thiophanate-methyl and benomyl were canceled, not to mention the demand for the treatment of dollar spot, brown patch, and Fusarium patch.

Applicator Exposure

Ornamentals

Approximately 5,000 pounds of thiophanate-methyl are used annually on ornamentals in the United States. It is sold exclusively as a component of Banrot® and is available as a 25 percent wettable powder. Banrot® is sold in 2-pound multi-walled foil-lined paper bags. Rates vary according to the crop to be treated. For bedding plants, 1 to 2 oz (ai) are mixed with 100 gallons of water and applied at 1 gal/8 ft². For bench planting of tropical foliage plants and bed-grown plants, 1.5 to 7.2 oz (ai) are mixed with 100 gallons of water and applied to 400 ft². For container- and bed-grown herbaceous and woody plants, 1.5 to 7.2 oz (ai) are mixed with 100 gallons of water for 400 ft² or a sufficient amount to saturate the soil mix. Banrot® is used only as a soil drench and is applied as a coarse spray to soil through a water breaker or hose nozzle or by mechanical injection with a proportioner into the irrigation water for each container through Chapin tubing. Banrot® is applied to the medium at seeding or transplanting. Retreatment is recommended at 4- to 12-week intervals if disease occurs. Since TPM is a systemic fungicide with therapeutic activity, routine treatment may not be necessary and additional applications may be initiated when disease symptoms appear. Applications are made year-round, and from 4 to 10 applications may be made. Treatment of a 400 ft² bed requires approximately 5 minutes. Eight worker-hours are
required for a two-person crew to treat one acre; however, in applications of Banrot® most operations do not involve more than 2 hours per week. Most applicators are commercial; less than 2 percent of thiophanate-methyl is applied by homeowners. There are approximately 3,500 commercial applicators involved in the use of Banrot®. In the mixing process, the required amount of fungicide is dumped into a pre-mix tank partially filled with water. The concentrated slurry is agitated and diluted to the required volume. This concentrate is dispensed either by mechanical injection or by water aspirator into the irrigation or drench water and applied to the growth media.

Protective equipment worn by applicators includes coveralls, respirators, goggles, rubber gloves, and boots.

Turfgrass

Approximately 45,000 pounds of thiophanate-methyl are used annually for turfgrass disease control. It is available as a wettable powder of 20, 50, and 70 percent active ingredient. TPM is available in 2-pound multi-wall foil-lined paper bags. All applications are made with ground sprayers equipped either with booms, cluster jets, or handguns for spot treatment of small areas. Homeowners usually use hose-on applicators. Applications are usually made from March through September and approximately 1 to 4 applications are made during the year. When applications are made to large areas, such as golf courses, large ground sprayers equipped with booms will cover an acre of ground in approximately 10 minutes. Handguns on 50- to 200-gallon sprayers will cover 10,000 ft² in approximately 5 minutes. When thiophanate-methyl is applied to home lawns with a hose-on type sprayer a private applicator can cover 5,000 ft² in less than 30 minutes (Benomyl assessment team Report II).

Approximately 80 percent of the thiophanate-methyl sold for use on turf is applied by 2,500 commercial applicators. Twenty percent is applied by homeowners or private applicators.

Protective clothing and equipment will vary with the type of applicator applying thiophanate-methyl. Commercial applicators generally use rubber boots, gloves, face mask, and coveralls. Homeowners may wear some type of protective equipment, but most wear normal work clothes.
REFERENCES

19. LeClerg, E. L. Crop losses due to plant diseases in the United


