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Control of Apple Powdery Mildew in the Mid-Atlantic Region

Apple powdery mildew, caused by *Podosphaera leucotricha* (Ell. & Ev.) Salm., has become a persistent disease problem on susceptible cultivars in the mid-Atlantic region (Delaware, Maryland, New Jersey, Pennsylvania, Virginia, West Virginia) of the eastern United States since organic fungicides replaced sulfur fungicides for control of scab, rusts, and other apple diseases during the late 1940s and early 1950s. Although mildew had been recognized as a problem in Virginia in the early 1930s, the disease was only casually mentioned in the 1934–1953 annual reports of A. B. Groves, fruit pathologist at the Winchester Fruit Research Laboratory. The disease was not mentioned at all in the Virginia Spray Bulletins of those years.

Severity of the powdery mildew disease and need for control measures are related to susceptibility of and intended market for the cultivar. The Delicious cultivar composes about 35% of the plantings in the mid-Atlantic region and usually does not require specific mildew control measures. About 20% of the plantings in the region contain Jonathan, Rome Beauty, Stayman, and the minor cultivars Idared, Paulared, and Granny Smith, highly susceptible cultivars that need special attention to avoid mildew problems (1). The remaining 45% of apple plantings in the region contain moderately susceptible cultivars, such as Golden Delicious, Winesap, York Imperial, and several minor cultivars. Disease severity on these cultivars depends on disease potential and susceptibility of adjacent trees in a planting.

Although a significant portion of the

mid-Atlantic production acreage is affected by powdery mildew, this disease is only one of 10 or more fungal diseases that are potential threats to apple production in the region. Other fungal diseases that commonly affect many of the commercial cultivars in the region include scab (*Venturia inaequalis* (Cke.) Wint.), cedar apple rust (*Gymnosporangium juniperi-virginianae* Schw.), quince rust (*G. clavipes* Cke. & Pk.), Brooks or Phoma fruit spot (*Mycosphaerella pomi* (Pass.) Lindau), sooty blotch (*Gloeodes pomigena* (Schw.) Colby), flyspeck (*Zygothiala jamaicensis* Mason), black rot (*Physalospora obtusa* (Schw.) Cke.), bot or white rot (*Botryosphaeria dothidea* (Moug. ex Fr.) Ces. et de Not.), and bitter rot (*Glomerella cingulata* (Stonem.) Spauld. & Schrenk) (8). The relative prominence of these diseases varies with annual precipitation and temperature patterns. With the exception of scab in the northern areas, most of these diseases are more prevalent in the mid-Atlantic region than in the northern and western apple production regions of the United States.

Symptoms and Disease Cycle

Symptoms of powdery mildew include whitish lesions on curled or longitudinally folded leaves (Figs. 1 and 2), stunted whitish gray twig growth (Figs. 2 and 3), and fruit russetting (Fig. 4). Economic damage occurs in the form of aborted blossoms (Fig. 5), reduced fruit finish quality, reduced vigor and yield of bearing trees, and stunting and poor form of young, nonbearing trees (2).

The apple powdery mildew fungus overwinters as mycelium in dormant blossom and shoot buds produced and infected the previous growing season. Conidia, the primary inoculum, are produced and released from the unfolding leaves as they emerge from infected buds (4,5). Conidia germinate in high relative

humidity at 10–25 C (optimum 19–22 C) (2,3). Germination does not occur in free moisture. The early-season powdery mildew epiphytic is regulated more closely by temperature than by humidity. Abundant sporulation from overwintering shoots and secondary lesions on young foliage leads to a rapid buildup in inoculum. Secondary infection cycles may continue until susceptible tissue is no longer available. Since leaves are most susceptible soon after emergence (3,4), infection of new leaves may occur as long as shoot growth continues. Fruit infection occurs near the time of blossoming. Infection of overwintering buds occurs soon after bud initiation (4). Cleistothecia are produced on heavily infected shoots and leaves in midsummer but are not considered an inoculum source because the ascospores they contain fail to germinate readily (3).

Heavily infected shoots and buds are low in vigor and lack winterhardiness, resulting in a reduction of primary inoculum at temperatures below –20 C (6,12). This phenomenon has been observed in other areas with lower winter temperatures than those commonly experienced in the mid-Atlantic region and is believed to be partially responsible for fluctuations in mildew incidence over a period of years.

General Control Strategy

Mildew control strategy is based on reduction of primary inoculum and protection from secondary inoculum. Primary inoculum is reduced by removing infected terminal shoots during the winter pruning operation (4,8,12). Foliage and fruit are protected from secondary inoculum by fungicide sprays applied from the tight cluster stage until terminal shoot growth stops in mid-summer. As many as eight or more protectant sprays may be required for trees of highly susceptible, vigorous

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Fig. 1. Shoot with secondary powdery mildew infection.

cultivars throughout the period of susceptibility. Terminal shoot growth may stop prematurely when a dry period occurs in early summer, then resume after a favorable rainfall. In such years, late-season mildew protection is required to prevent late infection and heavy inoculum carry-over.

Standard fungicides. Fungicides currently used for mildew control in the mid-Atlantic region include sulfur, dinocap, benomyl, and thiophanate-methyl. The grower's choice of fungicide is frequently determined as much by the fungicide's efficacy against other diseases, compatibility with other pesticides, phytotoxicity factors, or price as by its effectiveness in mildew control.

All the fungicides cited provide effective mildew protection when applied at frequent intervals. Benomyl and thiophanate-methyl are more frequently used for early-season mildew control because they provide antispore activity and postinfection activity against scab and

are compatible with spray oil, which is used as an early-season insecticide. These fungicides are also used when mid- and late-season mildew sprays are needed because they are less phytotoxic than sulfur and have fewer preharvest restrictions than dinocap. Dinocap is used during the early cover spray period as part of the Dikar formulation (dinocap + mancozeb), which provides broad-spectrum disease control and is adaptable to integrated pest management programs for mite suppression. Sulfur usage is limited by incompatibility with oil and phytotoxicity to some cultivars; however, sulfur is the least expensive fungicide and is often used at low rates in combination with other fungicides where disease is light to moderate.

Application schedule. Routine mildew control is usually achieved by mixing mildewcides in spray mixtures applied for control of other diseases and insects. Over the years, standard and experimental compounds have been tested under conditions for determining their adaptability to the overall spray program. Frequently, the compounds tested show promising mildew activity at relatively low rates but at higher rates fail to achieve the control desired under extended spray intervals typical of the grower's dry-weather spray schedule. Altering spray intervals has given more satisfying results. Groves et al (7) demonstrated that dinocap controlled mildew more effectively when applied frequently at lower rates than when applied for extended intervals at higher rates.

In a recent experiment involving combinations of dinocap and benomyl applied as Dikar 76.7W and Benlate 50W, respectively, no benefit was achieved by doubling the rate applied on 14-day spray intervals (Table 1). Better

Table 1. Effect of application interval and fungicide concentration on control of powdery mildew by dinocap-benomyl combinations on Jonathan apple

Treatment rate ^a (mg a.i./L)		Treatment interval (days)	Mildew incidence (%)	
Dinocap	Benomyl		Leaves ^b	Fruit ^c
112.8	75.0	14	15 b	19 b
56.4	37.5	14	12 b	9 ab
56.4	37.5	7	5 a	12 ab
28.2	18.8	3-4	3 a	6 a
No fungicide		...	99 c	48 c

^a Applied as spray tank mixes of Dikar 76.7W (4.7% dinocap, 72% mancozeb) + Benlate 50W.

^b Counts of all leaves on 10 terminal shoots from each of four replicate trees. Mean separation by Duncan's multiple range test ($P = 0.05$).

^c Counts of 50 fruit from each of four replications. Mean separation by Duncan's multiple range test ($P = 0.10$).



Fig. 2. Shoot with primary powdery mildew infection (right) compared with healthy shoot (left).



Fig. 3. Healthy shoot (left) compared with overwintering mildew-infected terminal shoots.

mildew control was obtained by reducing both the amount of material applied and the length of the application interval; the total amount of material applied throughout the season was the same. Although application costs may become prohibitive at the shorter time intervals, control in severe disease situations is better.

The timing of applications in a typical protective spray schedule for broad-spectrum disease and insect control is 7-day intervals from the green tip to petal fall stages (excluding insecticides during bloom) and 14-day intervals during the cover spray period, if both sides of the tree are sprayed on the same dates. If the materials are applied from only one side of the tree on each application date (half-spray), as in the alternate middle system of spraying described by Lewis and Hickey (11), intervals between half-sprays are reduced to 5 days before petal fall and 10 days for cover sprays.

The benefits of the alternate middle system of application have been demonstrated for control of powdery mildew (Table 2) and other diseases (10,11). Where tree size and sprayer capability are matched, spraying from only one side gives adequate coverage on 80–90% of trees. This permits better utilization of short residual pesticides, since applications from alternate sides are made at shorter intervals than sprays applied from both sides on the same date. Reducing the total number of complete sprays needed may lower pesticide and application costs by as much as one-third.

Timing of sprays. The importance of early-season sprays in controlling powdery mildew was demonstrated in a 2-year test conducted on mature Jonathan apple trees at Winchester (Table 3). A significant increase in the amount of leaf infection when the first spray was delayed until bloom was noted in 1975 but not in 1974. Fruit infection was reduced by an application before bloom in 1974 and before pink in 1975. Yields in 1976 of trees treated for mildew in 1974 and 1975 were three to four times those of trees not protected from mildew (Table 3).

In tests in the same orchard in 1978 and 1979 there was no benefit to trees from applications at the 1-cm green bud stage (8 April 1978 and 7 April 1979) compared with those left unprotected until the tight cluster (17 April 1978) or pink (20 April 1979) stage. In this orchard in 1979, treatments in another test (Table 1) were not applied until 23 April (40% bloom), yet frequent applications after that date still achieved good mildew control on leaves and fruit (13). A reliable means of predicting mildew occurrence is needed to permit reduction of the amount of fungicides in seasons when infection does not occur until bloom and to avert potential losses with earlier fungicide applications in seasons of earlier fruit

Table 2. Effect of application method and fungicide rate on control of powdery mildew on Rome Beauty apple

Treatment ^a	Dinocap rate/spray (g a.i./ha) ^b	Leaves infected (%) ^c
Complete sprays, 7–14 day intervals	263	16 b
Alternate-middle sprays, 5–10 day intervals	132	3 a
Complete sprays, 7–14 day intervals	132	13 b
Alternate-middle sprays, 5–10 day intervals	66	15 b
No mildew fungicide ^d	...	47 c

^a Applied at 5- or 7-day intervals in prebloom sprays and 10- or 14-day intervals in postbloom sprays.

^b Applied as Dikar 76.7W (4.7% dinocap, 72% mancozeb).

^c Based on leaves on 20 terminal shoots from each of four five-tree replicates. Mean separation by Duncan's multiple range test ($P = 0.05$).

^d Captan 80W (3.4 kg/ha) applied.

Table 3. Effect of application timing on mildew incidence and yield of Jonathan apple trees

Phenological bud stage at time of first spray ^a	Total sprays		Mildew incidence (%) ^b				Fruit yield (kg/tree) 1976
			Leaves infected		Fruit infected		
	1974	1975	1974	1975	1974	1975	
No fungicide	0	0	79 b	82 c	33 bc	90 c	26 b
1-cm green ^c	8	12	14 a	16 a	16 a	29 a	95 a
Pink	7	10	15 a	17 a	21 ab	43 b	91 a
Bloom	6	8	17 a	35 b	48 c	54 b	77 a

^a Each spray contained pyrazophos 30EC (0.62 ml) + mancozeb 80W (2.4 g/L).

^b Based on leaves on 20 terminal shoots and 50–100 fruits from each of five replicate trees. Mean separation by Duncan's multiple range test ($P = 0.05$).

^c Applied at open cluster stage in 1974.



Fig. 4. Jonathan fruit with russeting caused by powdery mildew infection.



Fig. 5. Apple blossom cluster with primary powdery mildew infection.

infection. In many years, however, the need for scab fungicides and insecticides would preclude attempting to save the cost of application during this time period.

Potential for Improved Control

Mildew control could be improved. Solution of the powdery mildew problem in the mid-Atlantic region is related to several factors.

Cultivar susceptibility. The powdery mildew problem is closely related to cultivar susceptibility. Orchards could be designed with greater attention to the pesticide requirements of the cultivars included and, once planted, could be maintained accordingly. Improvements in this area would reduce the need for

separate pesticide applications to portions of a planting. The main difficulty is that some of the mildew-susceptible cultivars have been planted as pollenizers (12). Their proximity to less susceptible cultivars as a pollen source also assures their proximity as a mildew inoculum source.

Economics of control vs. losses. Additional research on the value of certain mildew control practices is desirable. Any increase in control practices may represent an additional cost the grower is inclined to avoid. Economic data on the value of primary inoculum reduction by pruning or the value of additional early-season or late-season applications are needed in determining the number of applications

and the type of fungicide needed for control.

Grower understanding of the differences between powdery mildew and wet-weather diseases. One hindrance to achieving effective control of mildew is the grower's fear of wet-weather diseases, such as scab, rusts, and fruit rots, and the lack of awareness that powdery mildew increases rapidly during rainfree periods. Many growers are concerned about spray coverage and timing during wet weather but consider periods of dry weather as opportunities to save money on the spray bill as long as insect pests are under control. Growers are more aware of diminishing pesticide residues through rainfall wash-off than they are of the effects of photodegradation, microbial decomposition, and dilution by increased leaf area through growth. Losses to mildew are not as likely to affect the fruit

directly as are scab and the summer rot diseases and thus receive less attention.

Development of more effective fungicides. Ideal characteristics of a mildew fungicide in the mid-Atlantic region would include: 1) curative, antispore activity, 2) systemic translocation to unprotected shoot growth during dry weather, 3) residual activity and redistribution during wet weather, and 4) broad-spectrum activity to assure economic attractiveness. Although this list may be too idealistic, sterol-inhibiting fungicides such as Vangard (CGA-64251), Rubigan (fenarimol), Baycor (bitertanol), and Bayleton (triadimefon) possess several of these attributes. These products now have experimental use permits on apple, and their continued development represents potential for improved powdery mildew control. Some of these compounds

have excellent activity against powdery mildew (9), scab, and apple rust diseases (14). This spectrum of activity at unusually low field rates is unprecedented.

If the broad-spectrum, sterol-inhibiting fungicides prove economically competitive with currently registered fungicides for control of scab and rusts, we could see a reversal of the situation that contributed to the flare-up of apple powdery mildew in the 1950s. Further exploration of the benefits of these and other new materials and encouragement of growers in their judicious use will be one of the challenges for research and extension fruit pathologists in the coming decade.

Acknowledgments

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