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Control of Deciduous Tree Fruit Diseases: A Succ

During the 19th century, fruit disease control was hampered by lack of knowledge, inefficient fungicides, and primitive spray equipment. Research and extension workers in state Agricultural Experiment Stations and the U.S. Department of Agriculture then led the way with a long series of improvements that make up one of the great success stories of plant pathology.

Beginning with the introduction of lime sulfur as an apple foliage and fruit fungicide, improvements were made nearly every year as numerous investigators sought more information on diseases and methods of control. By 1960, we had the knowledge, fungicides, and equipment to prevent epidemics of the major fungal diseases of deciduous fruit trees. Many growers were obtaining excellent control year after year. The nature of the battle then changed significantly. The cost of the fungicide program became the chief item in the list of fruit industry losses due to fungal diseases. Fungicide usage was reduced in an attempt to lower costs. Tolerance to dodine, benomyl, and some related compounds was discovered in the fungi that cause several important diseases, limiting the use of these fungicides and discouraging the development of others. Government regulation of fungicide usage created some vexing problems. In spite of these circumstances, efficiency has improved to the point where good disease control is the rule rather than the exception, and many fruit growers are using only 50–60% of the amount of fungicide recommended in the standard spray programs of two decades ago.

Further increases in efficiency are not expected to come easily. Pest management programs, which require precise evaluation of the factors affecting fungicide usage, increase the need for research and place special stresses on the Cooperative Extension Service, which already suffers from manpower and budget shortages.

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Fungicide spray coverage is likely to be poor on large, thick apple trees.

Lime Sulfur

In 1908, Cordley described his research with lime sulfur as a foliage and fruit fungicide for the control of apple scab caused by *Venturia inaequalis* (Cke.) Wint. (2). For the first time, a highly effective scab fungicide was available for use in production of moderate crops of apples free from the fruit russeting caused by Bordeaux mixture. Continued research led to improved spray timing, better spray equipment, and the use of lime sulfur on stone fruits. Unfortunately, it soon became apparent that the fungicide caused serious tree injury and crop reduction when used in a series of applications. Its use was halted about 1945 when lead arsenate lost its effectiveness in the control of codling moth on apples and was replaced by organic insecticides incompatible with highly alkaline lime sulfur solutions.

Elemental Sulfur Fungicides

Efforts to improve elemental sulfur products, application equipment, and schedules were intensified soon after it became evident that lime sulfur was not an ideal fruit fungicide. Sulfur dusts were used on many farms to supplement

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sprays. The elemental sulfur fungicides were improved until a few had an average particle size of 3–6 μm and gave fair disease control if applications were timed to precede infection periods. However, some growers still lost 10% or more of their apple crop to scab and other diseases nearly every year. Losses of peaches and other stone fruits during the harvesting and marketing period tended to limit sales and prices. Sulfur injury was common and appeared to be a limiting factor in yields of such apple cultivars as Delicious and Stayman. The use of sulfur on fruit was reduced 90–95% after the introduction of organic fungicides.

Mills' Method of Timing Fungicide Applications

From about 1930 until the mid-1940s, a major goal in apple disease research was to either improve lime sulfur or replace it with elemental sulfur fungicides. Dry wettable sulfur, sulfur paste, and sulfur dust are protectant fungicides that must be applied before infection to obtain control. Since weather forecasts are imperfect, timing the application proved difficult. In desperation, growers began to spray or dust in the rain whenever necessary to provide protection during an infection period. Mills developed a system of forecasting apple scab infection in orchards with an abundance of ascosporic inoculum (2). His system was based on the number of hours of wetness at various temperatures required for infection. With information on temperature and the time when rainfall began, Mills could warn growers that scab infection was expected and that a protectant fungicide must be applied by a specified time. Roosje (4) and Moore (1) found, contrary to Mills' belief, that the wet period required for infection by conidia was as long as that required for infection by ascospores. Soenen et al (5) found that Mills' system predicted infection when none occurred in 27% of cases. Jones et al (1) found that the system failed to predict some infection periods unless relative humidity was taken into consideration. Rapid progress is being made in developing a microcomputer-based instrument that can be used on individual farms to identify scab infection periods and predict disease severity (1).

In orchards where inoculum is abundant, any disease control program requiring fungicide application by a specified time during or shortly after a rain period inevitably results in crises where crops are lost or a fungicide must be applied in the rain, at night, on weekends, and so on. There is no room for laxity or compromise.

After-Infection Control

Work by Szkolnik (7), Roosje (4), and many others has shown that lime sulfur and several of the organic fungicides give varying levels of apple scab control when applied after periods of wetness sufficiently long to allow abundant infections on unsprayed trees. Some of the most effective fungicides either are experimental or have been eliminated as unsafe. Benomyl, captan, dodine, maneb, and metiram are listed as effective when applied after wet periods of 18 hr at 60 F or 24 hr at 50 F. Since 10 hr of wetting are required for infection at 60 F and 15 hr at 50 F, these fungicides give control if applied up to 8 or 9 hr after the time required for infection.

After-infection control of cherry leaf spot has been obtained with cycloheximide and with some experimental fungicides, but these are either phytotoxic or unavailable for commercial use. Peach brown rot, caused by *Monilinia fructicola* (Wint.) Honey, has been controlled by benomyl applied after a wet period of 15 hr at 72 F. Under the same conditions, dichlone gave 85% and captan 47% control (6).

This work significantly increased our ability to control apple scab and peach brown rot by allowing more flexibility in timing fungicide applications.

New Fungicides

Several proprietary copper fungicides have been developed but are not widely used on deciduous fruit trees.

Ferbam was the first effective, noninjurious organic fungicide for control of the rust diseases of deciduous fruit trees, and the dithiocarbamates are still the exclusive choice of pathologists for rust control on apples. None effectively controls powdery mildew, caused by *Podosphaera leucotricha* (E. and E.) Salm., and their efficacy in apple scab control is only moderate. Yet, metiram and mancozeb are widely used on apples in fungicide mixtures designed to control scab, powdery mildew, and the rust diseases. Zineb is one of the most effective fungicides for the control of sooty blotch (*Gloeodes pomigena* [Schw.] Colby) and fly speck (*Zygophiala jamaicensis* Mason) on apples and of black knot (*Dibotryon morbosum* [Schw.] T. and S.) on plums.

Other organic fungicides have proved very useful. Captan provided a new standard for control of several fruit diseases, with improved fruit finish and freedom from unsightly residues and obvious tree injury. Dinocap is moderately effective against mildew, has some acaricidal properties, and is preferred in some pest management programs. Folpet is the choice for control of leaf spot on tart cherries and fruit rots on apples. Dodine is highly effective in controlling apple and pear scab if the causal fungi have not developed tolerance to it. Captafol has the unique ability to control apple scab during the prebloom period with only one spray. Glyodin was used to break the cycle of annual epidemics of cherry leaf spot in Pennsylvania but had undesirable fruit effects and was replaced by folpet, captafol, captan, benomyl, and dodine.

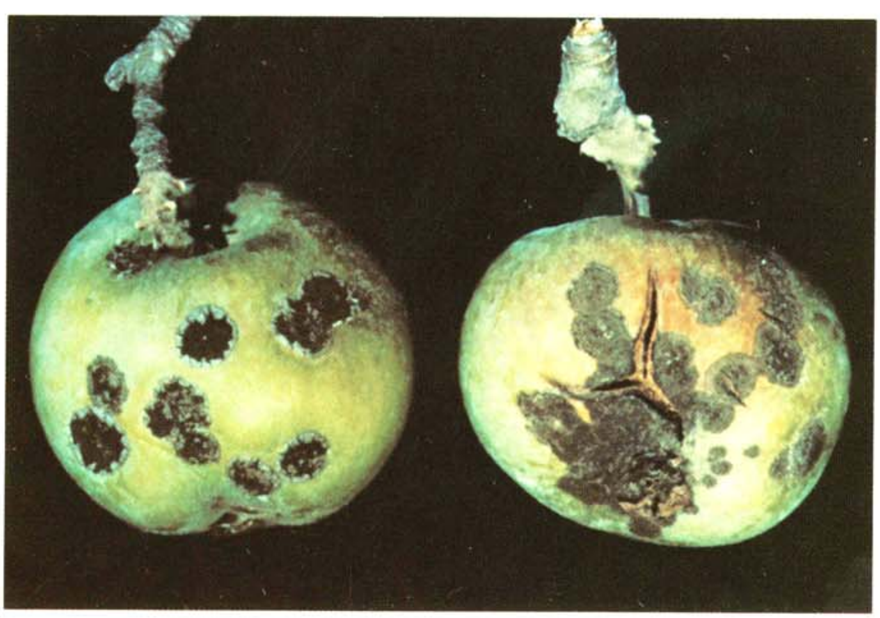
Benomyl is an excellent fungicide for control of brown rot of peaches and nectarines and is one of the better fungicides for control of scab, sooty blotch, and fly speck on apples. It is moderately effective against powdery mildew but is unsatisfactory for control of the rust diseases. The causal agents of several important diseases have developed a tolerance to benomyl and related fungicides.

Improved Equipment

The airblast sprayer represented a great step forward in fruit production. Another was the development of concentrate or low-volume sprays applied by airblast equipment at 20–100 gal per acre. A third was the development of a method of using large airblast sprayers to apply pesticides from alternate row middles at twice the normal frequency (2).

The advantages of using airblast sprayers to apply concentrates in full-coverage (complete) or alternate-middle (half) sprays are: 1) rapid coverage, 2) less water, 3) usually less equipment for pumping, storing, and hauling water, 4) less labor, 5) less pesticide, and 6) reduced costs in most orchards. The disadvantages are: 1) greater degree of skill to calibrate the sprayer and determine the amount of pesticide per tank and per acre, 2) greater care to avoid rust particles and other debris in spray water, 3) difficulty in convincing people that a large airblast sprayer may be required to efficiently apply a small amount of fungicide per acre, and 4) temptation to allow the interval between alternate-middle sprays to fluctuate from 7 to 14 days and thus jeopardize the success of the program.

Apple scab on leaves, pedicels, fruits, and sepals.



Apple scab lesions caused by *Venturia inaequalis* (Cke.) Wint.

Factors Affecting Control

Although these major improvements have been integrated into many fruit disease control programs, recent surveys have shown that the level of disease control often is not related to the amount of fungicide used. Also, suggested changes have been implemented most rapidly by growers who have ready access to sources of information. Management of the disease control program is both a challenge and perhaps our greatest opportunity for improvement.

Management would be improved by a simple method of judging the severity of the problems in each orchard and of suggesting appropriate responses. For such a method to succeed, it will be necessary to reconsider some data, develop new ways of presenting data to growers (eg, presenting fungicide rates and comparative efficacy in tabular form), and be more willing to state that a control recommendation is only for a specified set of conditions. More detailed research will be required on some points.

About 5 yr ago, I prepared a tentative apple disease management program. The factors affecting the level of disease control obtained with each pound of fungicide were listed under nine categories, with values assigned to sections within the categories. Our knowledge is limited in considering the categories or factors as interrelated parts that control the final outcome. Yet, the general scheme appears to be promising as a guide to research, extension, and orchard management.

Factor 1: Cultivar susceptibility to disease. There are large differences in the susceptibility of apple cultivars to such diseases as scab, powdery mildew, and the rusts. For example, in southern Pennsylvania, Rome Beauty is apt to be severely affected by scab, powdery mildew, and cedar-apple rust (*Gymnosporangium juniperi-virginianae* Schw.). Golden Delicious is much less affected by scab, mildew is serious only where the inoculum level is very high, and cedar-apple rust occurs only as occasional lesions. Delicious occupies a position between Golden Delicious and Rome Beauty in susceptibility to scab, usually having only slightly more scab than Golden Delicious. It is little affected by powdery mildew or cedar-apple rust but is one of the most susceptible cultivars to quince rust (*G. clavipes* Cke. and Pk.).

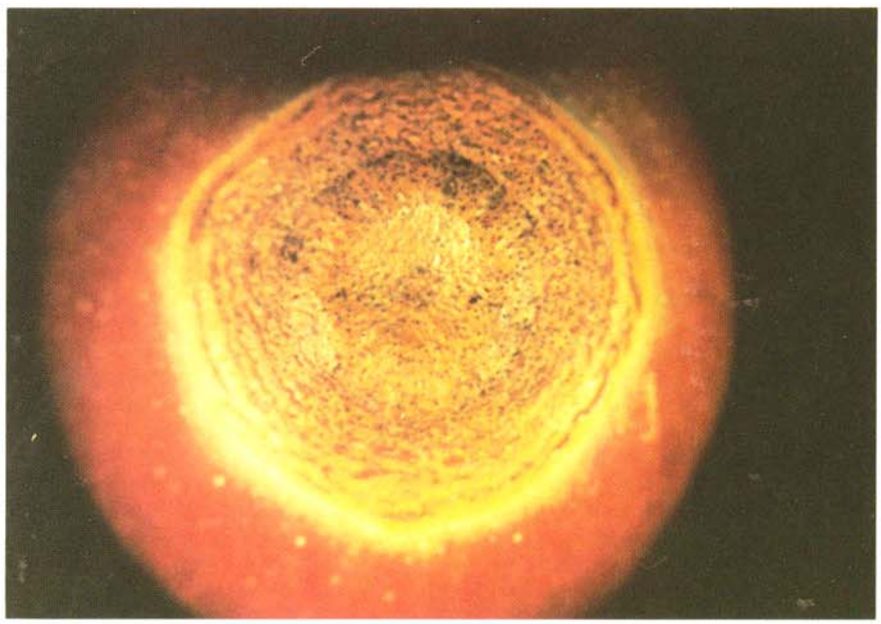
More work is required to develop a reliable rating of cultivar susceptibility to major diseases. Some of the large differences appear to be beyond question. Much of our concern, however, is with cultivars that show a significant level of resistance where conditions for disease spread are less than ideal. We want to know whether resistance is sufficient to affect fungicide requirements. A reasonable conclusion is that cultivar susceptibility to disease should be measured in the orchard on trees sprayed with inadequate amounts of fungicide. The amount of inoculum from nearby trees should be considered. Comparison of the susceptibility of a cultivar to that of a standard such as Rome Beauty would be helpful.

Factor 2: Size of fungal population or amount of available inoculum. Severe scab infection one year is apt to be followed the next year by early development of large numbers of ascospores, early infection, poor fungicide performance, and continued need for large amounts of fungicide. Palmiter (3) tested fungicides in three orchards where the percentage of overwintered leaves bearing perithecia of the scab fungus varied from 1 to 5, from 20 to 40, and from 70 to 95, respectively. Scab control with Magnetic-70 Sulfur Paste 5-100 in the three orchards was 99, 86, and 52%, respectively. When scab infection occurs early in the growing season, control during the summer often requires using fungicides, such as benomyl and dodine, that reduce both spore numbers and spore germination.

The amount of *Venturia* inoculum appears to be significantly lower in the Cumberland-Shenandoah Valley region than in the McIntosh orchards of Michigan, New York, and New England. Also, because the maturation of ascospores is moderately delayed in commercial orchards, most growers have ample opportunity to apply one or two sprays before scab infection occurs. Such differences are important in determining the success or failure of disease control programs based on low amounts of fungicide applied at regular intervals.

For management purposes, I rate orchards according to the amount of scab on the leaves in the fall and the proximity of abandoned trees. Spore development in the spring is measured using leaf samples from a few orchards where scab was abundant the previous year. Any treatment to reduce ascospore development must be considered in the rating.

Cherry leaf spot caused by *Coccomyces hiemalis* Higgins.



Cedar-apple rust caused by *Gymnosporangium juniperi-virginianae* Schw.

Factor 3: Rainfall and temperature. The infection process of numerous fungi, including those that cause apple scab, cherry leaf spot, and brown rot of stone fruits, requires water for spore discharge, germination, and entry of the germ tube into the plant. The amount of apple scab often is correlated with the amount of rainfall. The spread of powdery mildew does not require rainfall but may be favored by weather conditions that encourage rapid tree growth.

Four types of spray programs suggest varying degrees of emphasis on rainfall, temperature, and scab infection periods. With the first type, infection periods are studied very closely with the objective of preventing all infection and ending fungicide applications after about six sprays. Such a program is feasible only where late-season diseases are unimportant. A second and widely used type of program is where most sprays are applied at intervals of 7–14 days and data on scab infection periods are used for valuable background information. In a third type of program, captafol is used at the green-tip stage of tree growth at a rate high enough to give scab control until pink or petal-fall. This program appears impractical in most cases in Pennsylvania because

Table 1. Effects of application method, spray interval, and fungicide rate on control of apple scab and powdery mildew

Treatment[y]	Fungicide rate (%)	Apple scab Leaves (%)	Apple scab Control (%)	Powdery mildew Leaves (%)	Powdery mildew Control (%)
No fungicide		88.5		54.0	
Complete sprays at 7-day intervals	80	27.1 a[z]	69	19.8 a[z]	63
Complete sprays at 10-day intervals	80	38.3 bc	57	25.1 abc	54
Complete sprays at 14-day intervals	80	50.6 d	43	28.2 bc	48
Alternate-middle sprays at 7-day intervals	80	35.9 b	62	21.8 ab	60
Alternate-middle sprays at 7-day intervals	65	41.3 bcd	53	29.1 bc	46
Alternate-middle sprays at 7-day intervals	50	50.0 d	44	32.0 c	41

[y]Basic formula was 6 lb of captan plus 1.5 lb of dinocap per acre every 14 days. All treatments at 80% rate received the same amount of fungicide per day.
[z]Values followed by different letters are significantly different ($P = 0.05$) according to Duncan's multiple range test.

of high fungicide cost, possible phytotoxicity, and the need for prebloom sprays to control powdery mildew, the rust diseases, mites, and insects. In the fourth type of program, detailed information on scab infection periods is not critical except in timing the first fungicide application and in deciding on exceptional measures for exceptional conditions. Alternate-middle sprays are applied with large airblast sprayers at 7-day intervals on trees pruned to a height of 18–20 ft. This program is especially suitable for orchards where levels of fungus inoculum are low; two alternate-middle or half sprays can be applied before the first scab infection period, and the interval between sprays can be shortened in cases of unusually long (5–7 days) rain periods or lengthened under conditions unfavorable for disease spread.

Factor 4: Tree growth, including pruning and nutritional status. A close correlation can be expected between the increase in the number of leaves on terminal shoots and the increase in disease on those shoots. Young leaves are most susceptible to scab and powdery mildew. Unpruned trees are difficult to spray adequately. Rapid growth on large, vase-shaped trees may make adequate spray coverage in the top half of the trees almost impossible.

Under this factor, I rate orchards on the bases of tree shape, degree of pruning, amount of terminal growth, and the time when leaf growth is expected to cease in the summer or fall.

Factor 5: Spray equipment. Most, if not all, airblast sprayers provide spray coverage and deposit that decrease with height on the tree. Normally, the amount of fungicide on the tree at 4–7 ft is at least twice that at 18–20 ft and four times that at 28–30 ft. Up to fivefold differences can occur between the top center of the tree and the outer 3 ft nearest the sprayer. Both coverage and deposit have been improved significantly by sprayers able to blow the spray several feet above the tree tops against a wind of 5–10 miles per hour. Differences among sprayers are therefore important in determining both the degree of coverage of the leaves and fruit and the amount of deposit obtained with a given amount of fungicide. Operational procedures, such as the ground speed or rate of travel, also are important.

Unfortunately, we cannot provide an adequate set of engineering specifications for airblast spray equipment used under a wide range of orchard conditions. We can, however, classify both sprayers and trees into categories that can be rated or assigned mathematical values. Experience in judging the ability of sprayers to provide good coverage and deposit can be gained quickly through trials with sprays containing hydrated lime or other chemical that leaves a visible residue on foliage.

Factor 6: Spray timing. From Pennsylvania to Georgia, fungicide applications on apples are required during a period of about 18–20 wk between April and September. All the sprays may be important in scab control. Powdery mildew control on susceptible cultivars must be considered in at least eight sprays, and under severe conditions fungicide application every 5–7 days may be required. Control of cedar-apple and quince rusts may require 3–5 fungicide applications beginning no later than early bloom. All the sprays after bloom may be important to control sooty blotch, fly speck, and fruit rots, especially the cover sprays applied after May 15–20. Most fungicide applications are timed according to tree development, number of days between applications, and requirements of insect and mite control programs. Special attention is paid, however, to the fungi when conditions are especially favorable for their development.

When all conditions are favorable for rapid increase in disease, spray timing is apt to be the most important factor affecting disease development. When conditions are unfavorable, especially where most sprays are applied at intervals of 7–14 days, a rating system can be based on whether adequate protection was provided before the first scab infection period and on the interval between sprays. Increasing the interval between sprays is a favorite grower method of trying to reduce costs.

Factor 7: Application method. Traditionally, sprays have been applied from each row middle (two sides of each tree) to provide a complete spray on each spray date. Lewis and Hickey (2) described the alternate-middle method of applying sprays. The idea is that many current pesticides are ill-suited to long intervals between sprays and are more effective when applied from alternate sides of the tree at half the normal interval with airblast sprayers capable of covering more than 50%, often 90–95%, of the trees. For example, I conducted an experiment on Stayman apples in which alternate-middle and complete sprays of captan and dinocap were applied at fixed intervals and the fungicide rate was calculated on the basis of a given amount of each fungicide per day. Application method, spray interval, and fungicide rate were important factors in the level of control obtained with a constant amount of fungicide per day (Table 1).

My preference for Pennsylvania growers is alternate-middle sprays using concentrates at 7-day intervals. The rating is less favorable as the spray interval increases or a change is made to complete sprays using concentrates or to complete sprays with the fungicides at the rates usually suggested for dilute or high-volume sprays.

Factor 8: Fungicides. Fungicides can be rated on ability to control various diseases, modes of action, phytotoxicity, and so on. The availability of highly effective fungicides is one of the major reasons why the amount of fungus inoculum has been decreased in many orchards in the Cumberland-Shenandoah Valley to a point where we can consider reductions in fungicide usage. Fungicides of low efficacy frequently fail to give adequate control in commercial orchards where it is difficult to keep all factors affecting control at an optimum level. Partial failure one year may result in increased difficulty in control the following year.

Factor 9: Fungicide rate or dosage. The amount of fungicide needed for disease control on apples varies with conditions. In some orchards, the full amount of fungicide permitted by the label is needed. In others the amount of fungicide used on an annual basis can be reduced by 20–50% compared with the old standard of the amount required in 400 gal of dilute spray per acre in each of 10 or 11 sprays per year. Such reductions depend on the problems and their severity, the information available to the orchard manager, and his skill in managing all the factors affecting disease control.

In some localities, a reduction in pesticide usage in early and middle season sprays has been accompanied by an extra spray application near the end of the season. No progress is being made unless lower fungicide rates provide dependable control without increasing the number of applications, the application costs, and the hazard from residues at harvest.

Problems, Needs, and Goals

Plant pathologists can be proud of the progress made toward eliminating epidemics of leaf and fruit disease caused by fungi on the pome and stone fruits. Our knowledge of the fungi and the diseases is at a record level. Many growers are producing crop after crop of fruit nearly free from injury caused by such diseases as apple scab, cherry leaf spot, and brown rot of stone fruits. Yet, many problems with these and other diseases remain unsolved. As we change our goals, we find that some of the variables affecting disease development and control by fungicides require closer study.

A reduction in pesticide usage is one of the important goals of current research and extension programs. Growers share this interest because of costs and other considerations. Changes in fungicides, application equipment, and application methods have improved disease control, reduced fungus inoculum to a low point in many orchards, and allowed a reduction in the use of fungicides. Pest management programs have shown the value of providing the grower with up-to-date information and have encouraged the development of new ideas for research, for rapid transfer of information, and for greater attention to the needs of each orchard. All these things are helpful, but we must not leap to the conclusion that all fruit growers can reduce fungicide usage within a short time. Conditions vary greatly among orchards and among fruit-growing districts. Recommendations and restrictions for fungicides must recognize those variations.

It seems unlikely that new fruit fungicides will significantly alter the current situation within the next few years. There is a continued need for new products, however, especially for after-infection control and to replace products no longer used because of fungal tolerance or regulatory action. Much of the work with fungicides should be directed toward more efficient use of them.

The renewed interest in fruit breeding is encouraging. Few people have recognized disease resistance as an important factor in breeding new cultivars. It is unusual to find an orchard where disease resistance was considered a governing factor in selection and arrangement of cultivars. Therefore, fungicide recommendations usually must fit the needs of the most disease-susceptible cultivar in the orchard.

There is a great deal of interest in the work being done to improve the Mills method of predicting apple scab infection. Electronic instruments located in each orchard could provide accurate weather data and predict special conditions. It remains to be seen what effect this will have in areas where growers are accustomed to achieving scab control without precise timing of fungicide applications and in areas where such diseases as powdery mildew and sooty blotch require a seasonal fungicide program.

The apple disease management program I prepared about 5 yr ago was intended to emphasize that several factors in addition to dosage are involved in the level of disease control obtained with each pound of fungicide. Also, I wanted to develop an overall approach to the control problem where several diseases are important and to construct an outline that could be used by an extension specialist or grower to rate individual orchard operations and emphasize any weakness contained therein. Such consideration of individual operations seems essential if the amount of fungicide used is to be tailored to the severity of the disease problem. Detailed ratings under each factor can be based on the opinion of specialists within each state.

There is a need for more research on disease development and control under conditions where disease spread is slow. Available data indicate that low levels of inoculum, moderate levels of resistance in the cultivar, marginal infection periods, improved spray timing, and improved methods of fungicide application are complementary in achieving control. If so, additional data will increase our ability to make recommendations for specific conditions anywhere within a wide geographic area.

Undue stress on reducing fungicide rates can be counterproductive. If reductions in fungicide usage and development of tolerance to some of our most useful fungicides reach a point where control failures become common, then our credibility may be lost at a time when disease problems and fungicide needs are increasing.

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