Organic Small Fruit Disease Management Guidelines

Integrated Management of Strawberry Diseases

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Introduction

Disease management strategies are very similar for both organic and conventional small fruit production systems in the Midwest. In both systems it is important to develop and use an integrated disease management program that integrates as many disease control methods as possible, the more the better. Major components of the disease management program include: **use of specific cultural practices; developing knowledge of the pathogen and disease biology, use of disease resistant cultivars, and timely application of organically approved fungicides or biological control agents or products when needed.** These guidelines have been written for caneberries (raspberry and blackberry), strawberry, blueberry and grape. Specific information is provided for each crop in its respective chapter. Most disease control methods or strategies are identical for both conventional and organic production systems. Perhaps the greatest difference between organic and conventional production systems is that organic growers are not permitted to use synthetic "conventional" fungicides. If disease control materials are required in the organic system, growers are limited to the use of "inorganic" fungicides such as sulfur (elemental sulfur and lime-sulfur) or copper fungicides (Bordeaux mixture and fixed copper products). In addition, there are several new "alternative" disease control materials and biological control products that are currently available and are cleared for use in organic production.

There are several problems associated with the use of these inorganic fungicides and "alternative" products in small fruit disease control programs. Among the most important are 1) **Phytoxicity**, which is the potential to cause damage to foliage, fruit set and fruit finish (this is a concern primarily with copper and sulfur fungicides); and 2) **their limited spectrum of fungicide activity**, which means they may not be capable of providing simultaneous control of the wide range of fungal pathogens that can cause economic damage to the crop. For example, sulfur is highly effective for controlling powdery mildew on most fruit crops, but provides little or no control of most other diseases.

In a climate like the Midwest, environmental conditions during the growing season are generally very conducive (warm and wet) to the development of several important diseases, insect pests and weeds. Limitations in relation to which pesticides may or may not be used, present the organic grower with some unique and very demanding challenges. Whereas the use of various cultural practices and disease resistance will be the "back bone" of the organic disease management program, the limited use of organically approved pesticides or biocontrol agents will probably be required at times.

Integrated Management of Strawberry Diseases

The objective of an integrated disease management program is to provide a commercially acceptable level of disease control on a consistent (year-to-year) basis. This is accomplished by developing a program that integrates all available control methods into one program. An effective disease management program for strawberries must emphasize the integrated use of specific cultural practices, knowledge of the pathogen and disease biology, disease resistant cultivars and timely applications of organically approved fungicides or biological control agents, when needed. In order to reduce the use of fungicides to an absolute minimum, the use of disease resistance cultivars and various cultural practices must be strongly emphasized. Many strawberry varieties adapted to the Midwest have good resistance to a number of important diseases (Table 1). This is generally not the case with other small fruit crops. In Strawberry, the use of disease resistant varieties is especially important for organic production.

Identifying and Understanding the Major Strawberry Diseases

It is important for growers to be able to recognize the major strawberry diseases. Proper disease identification is critical to making the correct disease management decisions. In addition, growers should develop a basic understanding of pathogen biology and disease cycles for the major strawberry diseases. The more you know about the disease, the better equipped you will be to make sound and effective management decisions. The following literature contains color photographs of disease symptoms on strawberries, as well as information on pathogen biology and disease development:

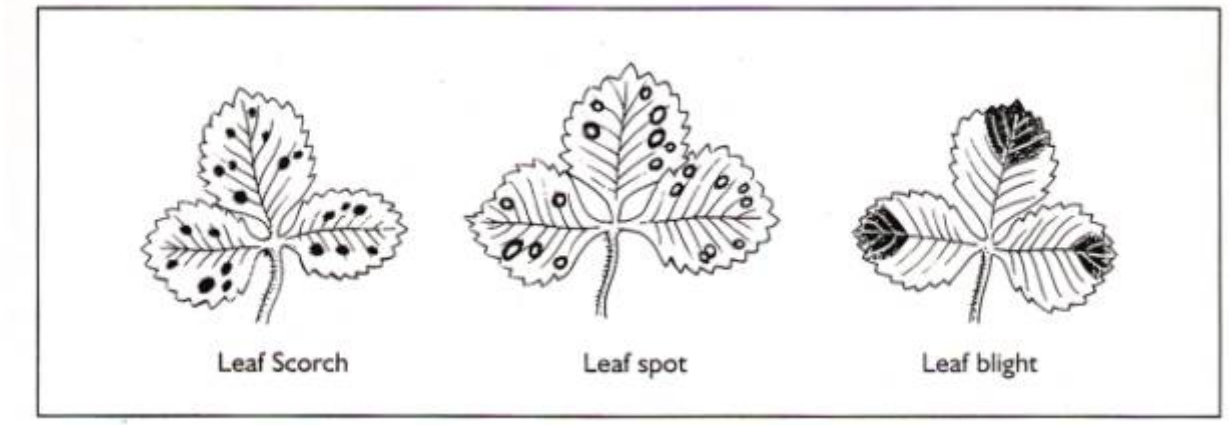
Strawberry Production Guide - This is a very comprehensive book covering most phases of strawberry production. It can be purchased from: Northeast Regional Agricultural Engineering Service, 152 Riley-Robb Hall, Cooperative Extension, Ithaca, NY 14853. Phone: 607-255-7654.

Compendium of Strawberry Diseases - Published by the American Phytopathological Society, 3340 Pilot Knob Rd., St. Paul, Minnesota 55121. Phone: 612-454-7250 (1-800-328-7560). This is the most comprehensive book on strawberry diseases available. All commercial growers should have a copy.

Foliar Diseases

There are three major leaf diseases of strawberries in the Midwest. They are leaf spot, leaf scorch, and leaf blight (Figure 1). All three diseases can occur singly or together on the same plant or even on the same leaf. All three are caused by fungi. Under favorable environmental conditions, these three diseases can cause serious reductions in strawberry yields. They damage the strawberry plant by causing premature leaf death, reduction in fruit quality, a general weakening of the plant, and (in some situations) plant death. In order to maximize strawberry production, these leaf diseases must be recognized and controlled. Fortunately, several varieties have good resistance to leaf spot and leaf scorch (Table 1).

(Figure 1) Leaf spot and leaf scorch usually appear first in early to mid-spring. Leaf blight is more common during the summer and early fall.



Leaf Spot

Symptoms

Leaf spot is caused by the fungus *Mycosphaerella fragariae*. The leaf spot fungus can infect leaves, fruit, petioles, runners, fruit stalks, and berry caps or calyxes. The most obvious symptoms of the disease are small, round spots. These spots develop on the upper surface of the leaf and at first are dark purple to reddish-purple (Figure 2). They range in size from 1/8 to 1/4 inch in diameter. With time, the centers of the spots become tan or gray and eventually almost white; while their margins remain dark purple. Later in the season, tan or bluish areas form on the underleaf surface. Symptoms on other plant parts, except fruit, are almost identical to those on the upper leaf surface. On fruits, superficial black spots may form during moist weather

(Figure 3). The spots form on ripe berries and around groups of seeds. They are about 1/4 inch in diameter, and usually there are only one or two spots per fruit. However, some fruits may be more severely infected.

(Figure 2) Strawberry leaf spot symptoms on leaflet.

(Figure 3) Black seed disease on strawberry fruit. This disease is caused by the same fungus that causes strawberry leaf spot.

Disease Development

This fungus can produce two types of spores that infect newly-emerging leaves in spring. First, older infected leaves that remain alive during winter may give rise to conidia (spores) that are spread to new foliage by splashing water or by handling infected plants. Another type of spore (ascospore) is produced in speck-sized black perithecia, which form at the edges of the leaf spots during autumn. In the spring, these ascospores are forcibly ejected from perithecia and are carried by wind or water to new leaf tissue.

Infection by both types of spores occurs through the underleaf surface. Temperatures between 65 and 75 F are optimum for infection and disease development. Infections may occur throughout the growing season, except during hot, dry weather. Young, expanding leaves are the most susceptible to infection.

Leaf Scorch

Symptoms

Leaf scorch is caused by the fungus *Diplocarpon earliana*. The leaf scorch fungus can infect leaves, petioles, runners, fruit stalks and caps of strawberry plants. Leaf scorch symptoms are very similar to the early stages of leaf spot. Round to angular or irregular dark-purple spots up to 1/4 inch in diameter are scattered over the upper leaf surface (Figure 4). As spots enlarge, they resemble small drops of tar. This tar-like appearance is caused by the formation of large numbers of minute, black, fungal fruiting bodies (acervuli). The centers of the spots remain dark purple. This distinguishes the disease from leaf spot where the center turns white. If many infections occur on the same leaf, the entire leaf becomes reddish or light purple. Severely infected leaves dry up and appear scorched. Similar, but elongated, spots may appear on other affected plant parts. Lesions may girdle fruit stalks causing flowers and young fruit to die. Infections on green berries are rare, appearing as red-to-brown discolorations or a flecking on the fruit surface. The leaf scorch fungus can infect strawberry leaves at all stages of development.

(Figure 4) Leaf scorch on strawberry. First symptoms are individual red spots.

Disease Development

The fungus overwinters on infected leaves that survive the winter. In the spring, conidia are produced on both leaf surfaces in speck-sized, black acervuli. The fungus also produces ascospores in the early spring within disk-shaped apothecia (fungal fruiting structures) that appear as black dots in old lesions on the lower surface of diseased leaves that died during winter. In the presence of moisture, ascospores germinate within 24 hours and infect the plant through the lower leaf surface. After symptom development, conidia are produced on the leaf spots in large numbers throughout the growing season. Therefore, repeated infections occur whenever weather conditions are favorable. Conidia are spread mainly by splashing water.

Leaf Blight (Phomopsis Leaf Blight)

Symptoms

Leaf blight is caused by the fungus *Phomopsis obscurans*. Leaf blight is found most commonly on plants after harvest. The disease is distinctively different from both leaf spot and leaf scorch. The enlarging leaf spots of this disease are round to elliptical or angular and a quarter of an inch to an inch in diameter (Figure 5). Spots are initially reddish-purple. Later, they develop a darker brown or reddish-brown center surrounded by a light-brown area with a purple border. Similar spots may sometimes develop on the fruit caps. Usually, only one to six lesions develop on a leaflet. Often the infected area becomes V-shaped with the widest part of the "V" at the leaf margin. New lesions appear throughout the summer and fall if weather conditions are favorable.

Older leaves become blighted and may die in large numbers. This disease is usually more destructive on slow growing or weak plants. The same fungus can cause an enlarging, soft, pale-pink rot at the stem end of the fruit. Information on resistance to leaf blight in currently used varieties is limited. If growers encounter a high level of disease on certain varieties, these varieties should be avoided.

(Figure 5) Phomopsis leaf blight on strawberry.

Disease Development

This fungus produces spores (conidia) in speck-sized, black pycnidia (fungal fruiting bodies) embedded in the centers of older leaf lesions. Conidia ooze out of pycnidia during damp weather when temperatures are high. Conidia are splashed to new leaf tissue where they germinate in the presence of free water to initiate new infections on leaves and fruit. The fungus overwinters on either infected leaves that survive the winter or in dead tissue on old infected leaves.

Powdery Mildew

Powdery mildew is caused by the fungus *Sphaerotheca macularis*. Generally the disease is not a serious problem in the Midwest; however, under the proper environmental conditions and on highly susceptible varieties, the disease can become serious. Disease resistance is available in several varieties. Growers are encouraged to avoid highly susceptible varieties.

Symptoms

Foliage symptoms usually are the most obvious. An upward curling of leaf edges usually is the first symptom seen. Dry, purplish or brownish patches develop on the lower surface of infected leaves and reddish discoloration may develop on the upper surface (Figure 6). Patches of white, powdery fungus mycelium may appear on the undersides of leaves as the disease progresses (Figure 7).

(Figure 6)Reddish-purple discoloration of leaf often associated with powdery mildew infection

(Figure 7) Patches of white fungus growth on strawberry infected with powdery mildew.

Disease Development

The fungus that causes strawberry powdery mildew infects only wild and cultivated strawberries. This pathogen can not survive in the absence of living host tissue. It apparently overwinters in infected leaves. Spores are carried by wind to infect new growth in the spring. Development and spread of powdery mildew is favored by moderate to high humidity and temperatures of about 60 to 80 F (15 to 27 C). Unlike most other fungi that cause plant disease, powdery mildew does not require free water for spores to germinate and infect. In dry years, when most other diseases are not a problem, powdery mildew can be very serious.

Angular Leaf Spot (Bacterial Blight)

Angular leaf spot or bacterial blight of strawberries is caused by the bacterium *Xanthomonas fragariae*. In the Midwest, it is the only reported strawberry disease that is caused by a bacterium. The disease was first reported in Minnesota in 1960, and has since been found in other regions of the United States. It appears to be spreading rapidly to many strawberry-growing areas of the world with the importation of planting material. Although the disease has not been a major problem in the Midwest, it can become serious and does represent a potential threat to production. Copper fungicides have been recommended for control of bacterial blight with varying degrees of success when applied in a protectant program. Once the disease is established in the planting there is little or nothing that can be done to control it. Hot, dry weather is the best cure for the disease. Cultivars differ in their susceptibility to the disease.

None are completely resistant, but Cavendish, Annapolis, Allstar, Honeoye, and Kent are all highly susceptible.

Symptoms

Typical symptoms of angular leaf spot appear initially as minute, water-soaked lesions on the lower leaf surface (Figure 8). These lesions enlarge to become angular spots, usually delineated by small veins. An important distinguishing characteristic of this disease is that lesions are translucent when viewed with transmitted light, but dark green when viewed with reflected light (Figure 9).

(Figure 8) Angular leaf spot (bacterial blight) symptoms on lower leaf surface. Note the “water-soaked Espots.

(Figure 9) Angular leaf spot (bacterial blight) symptoms on upper leaf surface. Note the translucent, yellow spots.

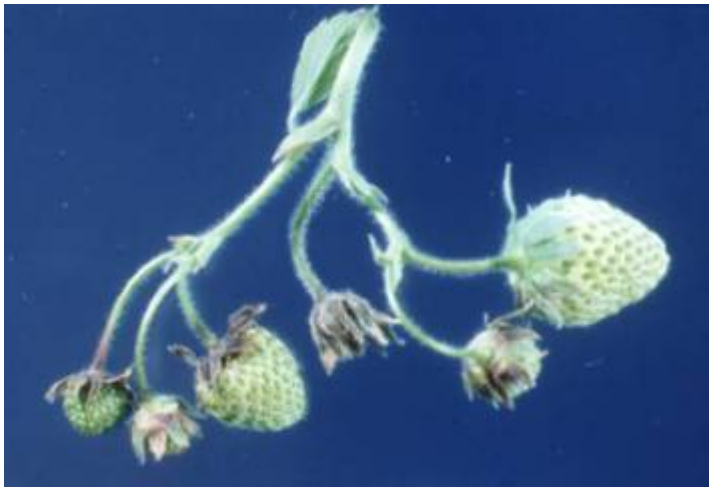
Under moist conditions, lesions often have a viscous bacterial exudate on the lower leaf surface. When it dries, the exudate forms a whitish, scaly film. This exudate or film is an additional characteristic that is useful in the identification of angular leaf spot.

Lesions may coalesce to cover large portions of the leaf. Eventually, lesions become visible on the upper leaf surface as irregular, reddish-brown spots, which are necrotic and opaque to transmitted light. A chlorotic halo may surround the lesion. At this stage, symptoms may be difficult to distinguish from those of common leaf spot and leaf scorch.

Heavily infected leaves may die, especially if major veins are infected. Occasionally, under natural conditions, infection follows the major veins, resulting in veinal water-soaking that may or may not spread to the interveinal regions.

Infection by *X. fragariae* may become systemic. The pathogen can infect all plant parts except fruits and roots and, in some cases, even the fruits have been infected, apparently only in the tissue adjacent to an infected calyx (fruit cap). Calyx infection can be serious. Infected tissues turn black resulting in unattractive fruit (Figure 10).

(Figure 10) Angular leaf spot (bacterial blight) symptoms on strawberry calyx. Note the brown discoloration and drying.



Disease Development

Inoculum for the primary infection of new growth in the spring comes from infected dead leaves where the pathogen overwintered. *X. fragariae* may survive for extended periods in dry leaves or in infected leaves buried in the soil. Spread is primarily from infected leaf debris or infected crowns.

Bacteria that exude from lesions under high-moisture conditions may provide secondary inoculum. Bacteria may be disseminated to uninfected plants or leaves by splashing water, such as rain or overhead irrigation. *X. fragariae* gains entrance into host tissue either passively through wounds or actively as motile cells that swim into natural plant openings by means of drops of dew, gutation fluid, rain, or irrigation water.

Very little is known about the epidemiology of angular leaf spot. Development of the disease is favored by moderate to cool daytime temperatures around 68 F (20 C), low nighttime temperature (near or just below freezing) and high relative humidity. Long periods of precipitation, sprinkler irrigation to protect plants from freezing, or heavy dews in the spring also favor the disease. Young leaf tissue or leaves on healthy, vigorous plants are more likely to become infected than those on diseased or environmentally stressed plants.

Strawberry Root Diseases

Red Stele

Red stele is caused by the soil-borne fungus *Phytophthora fragariae*. Many commercial strawberry cultivars are susceptible to the red stele fungus; however, many varieties have good resistance to several races of the red stele fungus (Table 1). The use of disease resistant varieties and selection of sites with good soil drainage are the key methods of control. This root rot disease has become a serious problem facing strawberry production in the northern two-thirds of the United States. The disease is most destructive in heavy clay soils that are saturated with water during cool weather. Once it becomes established in the field, the red stele fungus can survive in soil up to 13 years. Normally, the disease is prevalent only in the lower or poorly drained areas of the planting; however, it may become fairly well distributed over the entire field, especially during a cool, wet spring. The red stele fungus may become active at a soil temperature of 40 F. However, the optimum soil temperature for growth and disease development is between 55-60 F. Under favorable conditions of high soil moisture and cool temperatures, plants will show typical disease symptoms within 10 days after infection.

Symptoms

When plants start wilting and dying in the more poorly-drained portions of the strawberry field, the cause is very likely red stele disease (Figure 11). Infected plants are stunted, lose their shiny green luster, and produce few runners. Younger leaves often have a metallic bluish-green cast. Older leaves turn prematurely yellow or red. With the first hot, dry weather of early summer, diseased plants wilt rapidly and die. Diseased plants have very few new roots compared to healthy plants that have thick, bushy white roots with many secondary feeder roots (Figure 12). Infected strawberry roots usually appear gray, while the new roots of a healthy plant are yellowish-white.

(Figure 11) Plants dying from red stele root rot.

(Figure 12) Root system from a red stele infected strawberry plant.

The best way to identify the disease is to carefully dig up a wilted plant and peel off the outside portion of several roots. The inside or central portion of the root is known as the stele. If the stele is pink to brick red or brownish red, the plant has the red stele disease (Figure 13). The stele of

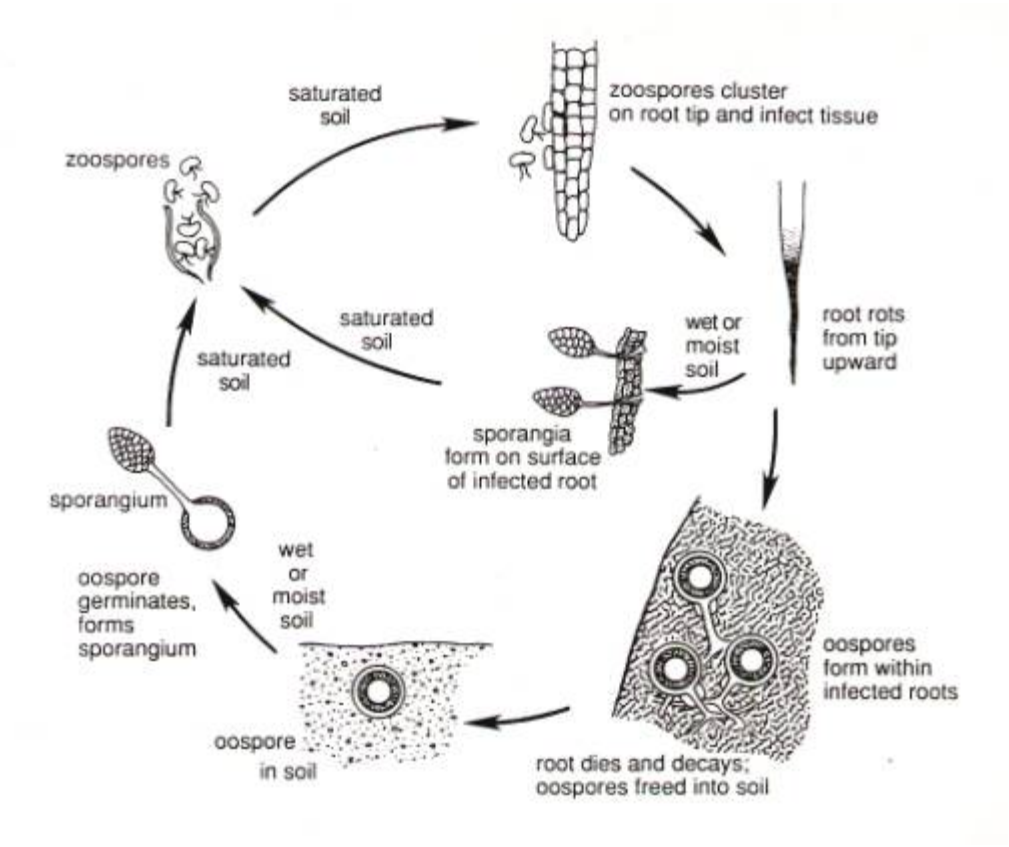
normal plants is yellowish-white. The red color may show only near the dead tip of the root or it may extend the length of the root. The red stele is best seen in the spring up to the time of fruiting. No other disease of strawberry produces this symptom.

(Figure 13) Longitudinal section of a healthy (right) and red stele infected (left) strawberry root.

Disease Development

The red stele fungus is introduced into new planting sites mainly through the distribution of infected plants. The fungus can be spread within a field or area by anything that carries or moves infested soil (implements, shoes, water, etc.). Once in the field, spores (oospores) of the fungus produce large numbers of smaller spores (zoospores). Zoospores are motile and swim about when soil moisture is high. Zoospores invade the tips of young fleshy roots. Once in the roots, the fungus grows and destroys the water and food conducting tissues resulting in wilting and plant death (Figure 14). As soil temperatures rise, the fungus forms large numbers of oospores in the stele of infected plants. These oospores survive periods of hot, dry, and freezing weather for several years in the soil.

Figure 14: Red stele disease cycle. Disease cycle of Red Stele Root Rot on strawberry. We wish to thank the New York State Agriculture Experiment Station for use of this figure. Figure taken from the Small Fruit IPM Disease Identification Sheet No.2



Verticillium Wilt

Verticillium wilt, caused by the soil-borne fungus *Verticillium albo-atrum*, can be a major factor limiting production. When a plant is severely infected, the probability of it surviving to produce a crop is greatly reduced. The Verticillium fungus can infect nearly 300 different host plants, including many fruits, vegetables, trees, shrubs, and flowers as well as numerous weeds and some field crops. Once it becomes established in the field or garden, it may remain alive for 25 years or longer. Several varieties have resistance to Verticillium wilt. The use of resistant varieties and proper site selection and crop rotation to avoid infested soil are the key methods of control.

Cool, overcast weather interspersed with warm, bright days is most favorable for development of Verticillium wilt. Optimal conditions for infection and disease development occur when soil temperatures are 70 to 75 F.

Many soils in the Midwest contain the Verticillium wilt fungus. The fungus can be introduced into uninfested soil on seeds, tools, farm machinery, and from the soil and roots of transplants.

Symptoms

The first symptoms of Verticillium wilt in new strawberry plantings often appear about the time runners begin to form. In older plantings, symptoms usually appear just before picking time. Symptoms on above-ground plant parts may differ with the susceptibility of the cultivar affected. In addition, above-ground symptoms are difficult to differentiate from those caused by other root infecting fungi. Isolation from diseased tissue and culturing the fungus in the laboratory are necessary for positive disease identification.

On infected strawberry plants, the outer and older leaves drop, wilt, turn dry, and become reddish-yellow or dark brown at the margins and between veins (Figure 15). Few new leaves develop and those that do tend to be stunted and may wilt and curl up along the midvein. Severely infected plants may appear stunted and flattened with small yellowish leaves. Brownish-to-bluish black streaks or blotches may appear on the runners or petioles. New roots that grow from the crown are often dwarfed with blackened tips. Brownish streaks may occur within the decaying crown and roots. If the disease is serious, large numbers of plants may wilt and die rapidly (Figure 16). When the disease is not so serious, an occasional plant or several plants scattered over the entire planting may wilt and die.

(Figure 15) Strawberry plant dying from verticillium wilt. Note the outer leaves die first

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(Figure 16) Strawberry field showing symptoms of verticillium wilt.

Disease Development

The fungus overwinters in soil or plant debris as dormant mycelium or black speck-sized bodies (microsclerotia). These microsclerotia can remain viable in the soil for many years. Under favorable environmental conditions, they germinate and produce thread-like fungal structures (hyphae). Hyphae can penetrate root hairs directly or through breaks or wounds in the rootlets. Once inside the root, the fungus invades and destroys the water-conducting tissue. Destruction of water-conducting tissue results in reduced water uptake by the plant; thus, plants wilt and wither. As fungal colonies get older, they produce microsclerotia in infected host tissue and the disease cycle is completed.

Black Root Rot

Black root rot is the general name for several root disorders which produce similar symptoms. The disorders are not clearly understood and are generally referred to as a root rot complex. Although the exact cause of the black root rot is not known, one or more of the following is thought to be responsible: soil fungi (such as *Rhizoctonia* and *Fusarium*); nematodes; winter injury; fertilizer burn; soil compaction; herbicide damage; drought; and excess salt, water or improper soil pH. Black root rot has been found in every strawberry-growing area of the United States. Injured plants may be scattered throughout the planting or localized in one or more areas

(Figure 17). A considerable incidence of black root rot has been observed in recent years throughout the Midwest. Once the disease is established (shows up) in the planting, little or nothing can be done to control it.

(Figure 17) Strawberry field showing black root rot symptoms.

To recognize black root rot symptoms, it is necessary to know what a normal root looks like. Newly developed main roots of a normal strawberry plant are pliable and almost white. After several months of growth, they generally become woody and are dark brown to black on the surface. When this dark surface is scraped away, a yellowish-white living core can be seen. Small feeder roots that branch out from the main roots should be white as long as they are active.

Roots affected by black root rot have one or more of the following symptoms: 1) the root system is much smaller than normal; 2) the main roots are spotted with dark patches or zones (Figure 18); 3) the feeder roots are lacking or are spotted with dark patches or zones; 4) all or part of the main root is dead (Figure 19). A cross-section of the dead root shows it blackened throughout. Plants with black root rot are less vigorous than normal plants and produce fewer runner plants. Severely affected plants usually die.

(Figure 18) Strawberry root with black root rot symptoms. Note black discoloration (lesions) on the root.

(Figure 19) Strawberry root system with advanced stages of black root rot. Note the dead, black "Rat-tail" roots.

Strawberry Fruit Rots

Botrytis Fruit Rot (Gray Mold)

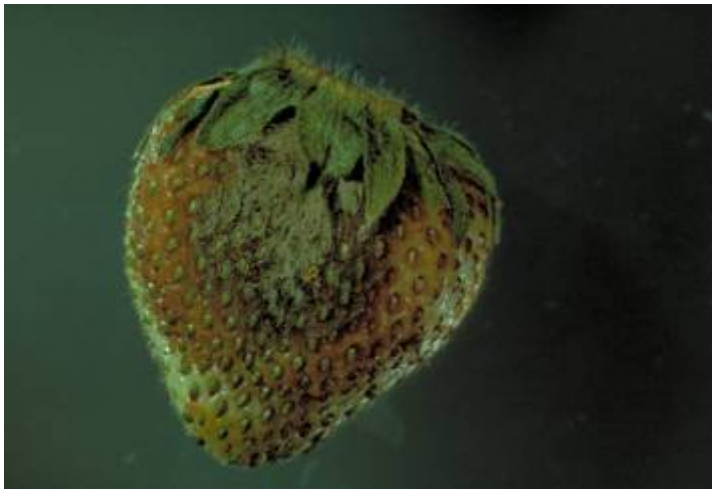
One of the most serious and common fruit rot diseases of strawberry is gray mold. Gray mold is caused by the fungus *Botrytis cinerea*. Under favorable environmental conditions for disease development, serious losses can occur. The gray mold fungus can infect petals, flower stalks (pedicels), fruit caps, and fruit. During wet springs no other disease causes a greater threat to flowers and fruit. The disease is most severe during prolonged rainy and cloudy periods during bloom and harvest. Abundant gray-brown, fluffy, fungal growth on infected tissue is responsible for the disease's name "gray mold".

During wet, cool springs, gray mold will be a major threat to organic strawberry production. In conventional production systems, application of fungicide during bloom generally results in good disease control. Fungicides used in organic systems (sulfur and copper) are not very effective for control of Botrytis. Several biological control products are currently available for Botrytis control; however, their effectiveness under moderate to heavy disease pressure is questionable. Resistance is not available in most varieties; therefore, the use of several cultural practices are the key control methods in organic plantings.

Symptoms

Young blossoms are very susceptible to infection. One to several blossoms in a cluster may show blasting (browning and drying) that may spread down the pedicel. Fruit infections usually appear as soft, light brown, rapidly enlarging areas on the fruit (Figure 20). If it remains on the plant, the berry usually dries up, "mummifies", and becomes covered with a gray, dusty powder (Figure 21). Fruit infection is most severe in well-protected, shaded areas of the plant where the humidity is higher and air movement is reduced. Berries resting on soil or touching another decayed berry or a dead leaf in dense foliage are most commonly affected. The disease may develop on young (green) fruits, but symptoms are more common as they mature. Often, the disease is not detected until berry picking time. During harvest, the handling of infected fruit will spread the fungus to healthy ones. After picking, mature fruits are extremely susceptible to gray mold, especially if bruised or wounded. Under favorable conditions for disease development, healthy berries may become a rotted mass within 48 hours after picking.

(Figure 20) Immature strawberry fruit with symptoms of Botrytis fruit rot (gray mold). Note the symptoms usually develop first on the calyx end of the fruit.

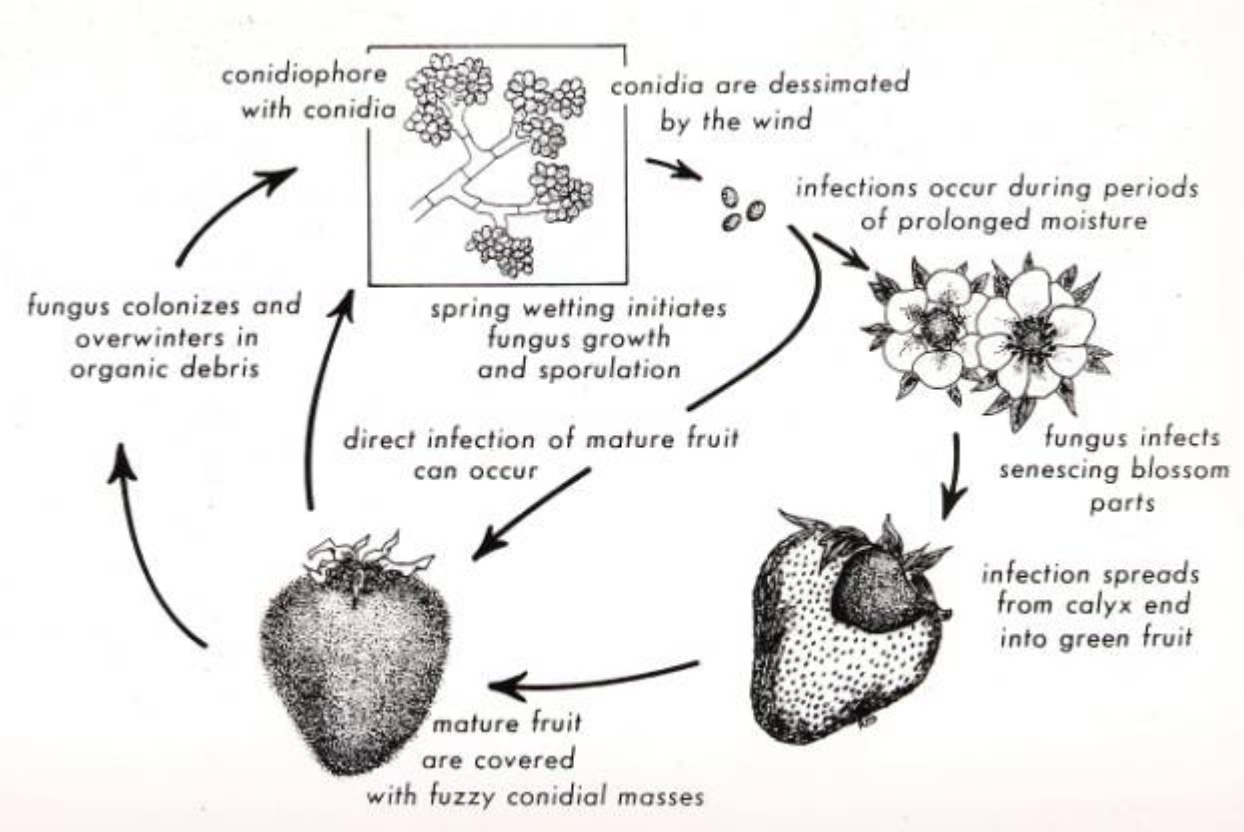


(Figure 21) Botrytis fruit rot (gray mold) on a mature strawberry fruit.

Disease Development

The fungus is capable of infecting a great number of different plants. It overwinters as minute, black, fungal bodies (sclerotia) and/or mycelium in plant debris, such as dead strawberry leaves in the row. In early spring, these fungal bodies produce large numbers of microscopic spores (conidia), which are spread by wind throughout the planting. They are deposited on blossoms and other plant parts where they germinate in a film of moisture. Infection occurs within a few hours (Figure 22).

(Figure 22) Disease cycle of gray mold on strawberry. We wish to thank the New York State Agriculture Experiment Station for the use of this figure. Figure taken from the Small Fruit IPM Disease Identification Sheet No. 1



Disease development is favored by wet conditions accompanied by temperatures between 41 F and 86 F. Conditions that keep flowers and fruit wet, such as rain, dew, or sprinkler irrigation encourage Botrytis rot.

Strawberries are susceptible to Botrytis during bloom and again as fruits ripen. During the blossom blight phase of the disease, the fungus colonizes senescing flower parts, turning the blossoms brown. The fungus usually enters the fruit through flower parts, where it remains inactive (latent) within the tissues of infected green fruits. As the fruit matures, the fungus becomes active and rots the fruit. Thus, while infection actually occurs during bloom, symptoms are usually not observed until harvest. This is important to remember when one considers control. Temperatures between 70 and 80 F and moisture on the foliage from rain, dew, fog, or irrigation are ideal conditions for disease development.

Leather Rot

Leather rot is caused by the soil-borne fungus *Phytophthora cactorum*. Leather rot has been reported in many regions throughout the United States. In many areas, it is considered a minor disease of little economic importance. However, excessive rainfall during May, June, and July can lead to severe fruit losses and quality reduction. In 1981, many commercial growers in the Midwest lost up to 50 percent of their crop to leather rot. The leather rot fungus primarily attacks the fruit but may also infect blossoms. Organic fungicides (sulfur and copper) are not effective for control. The key control methods in organic as well as conventional systems are maintaining a good layer of straw mulch between fruit and the soil, and site selection or improvement for good water drainage (avoid saturated soil).

Symptoms

The leather rot pathogen can infect berries at any stage of development. When the disease is serious, infection of green fruit is common. On green berries, diseased areas may be dark brown or natural green outlined by a brown margin (Figure 23). As the rot spreads, the entire berry becomes brown, maintains a rough texture, and is leathery in appearance. The disease is more difficult to detect on ripe fruit. On fully mature berries, symptoms may range from little color change to discoloration that is brown to dark purple (Figure 24). Generally, infected mature fruit is dull in color and is not shiny or glossy. Infected ripe fruit are usually softer to the touch than healthy fruit. When diseased berries are cut across, a marked darkening of the water-conducting system to each seed can be observed. In later stages of decay, mature fruits also become tough and leathery. Occasionally, a white moldy growth can be observed on the surface of infected fruit. In time, infected fruit dry up to form stiff, shriveled mummies.

(Figure 23) Leather rot symptoms on an immature strawberry fruit.

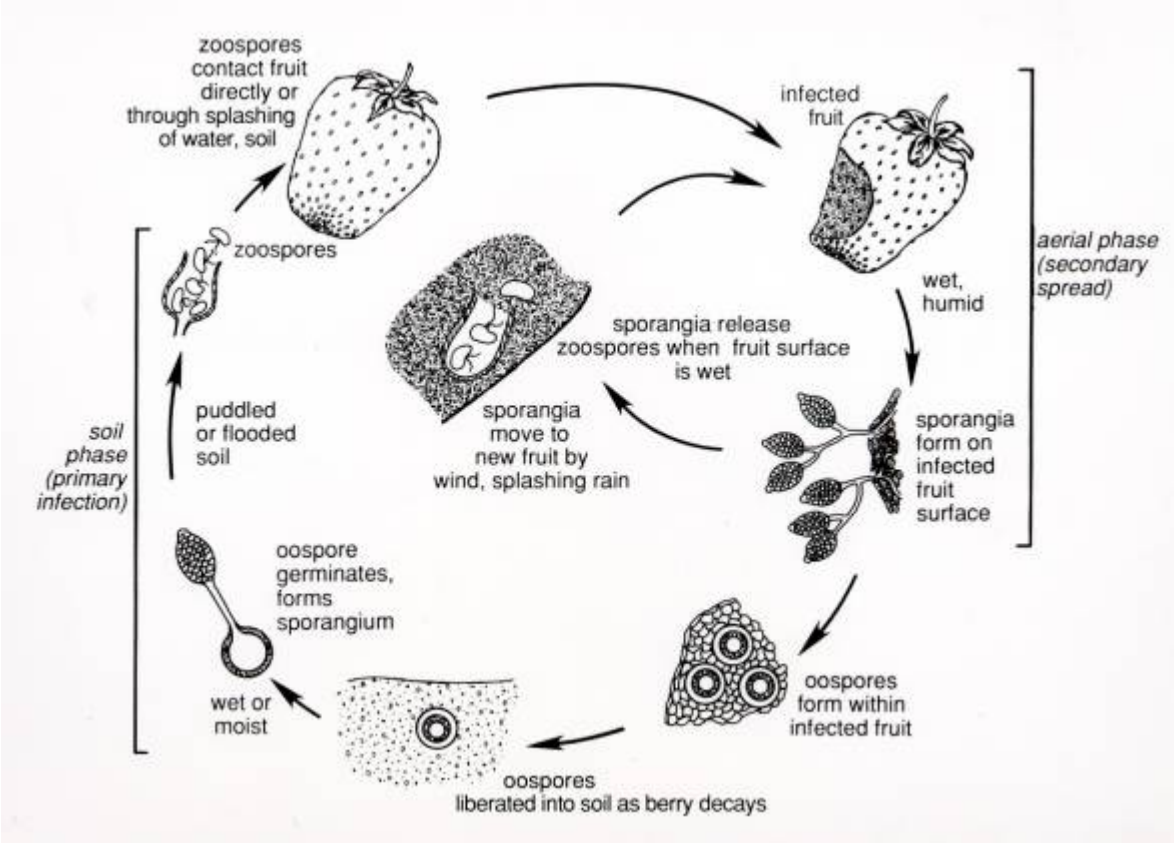
(Figure 24) Leather rot symptoms on a mature strawberry fruit. Note the purplish discoloration.

Berries that are affected by leather rot have a distinctive and very unpleasant odor and taste. Even healthy tissue on a slightly rotted berry is bitter. This presents a special problem to growers in pick-your-own operations. An infected mature berry with little color change may appear normal and be picked and processed with healthy berries. Consumers have complained of bitter tasting jam or jelly made with berries from fields where leather rot was a problem. Leather rot is most commonly observed in poorly-drained areas where there is or has been free-standing water or on berries in direct contact with the soil.

Disease Development

The fungus survives the winter as thick-walled resting spores, called oospores that form within infected fruit as they mummify (Figure 25). These oospores can remain viable in soil for long periods of time. In the spring, oospores germinate in the presence of free water and produce a second type of spore called a sporangium. A third type of spore called a zoospore is produced inside the sporangium. Up to 50 zoospores may be produced inside one sporangium. The zoospores have "tails" and can swim in a film of water. In the presence of free water on the fruit surface, the zoospores germinate and infect the fruit. In later stages of disease development, sporangia are produced on the surface of infected fruit under moist conditions.

(Figure 25) Disease cycle of leather rot on strawberry. We wish to thank the New York State Agriculture Experiment Station for use of this figure. Figure taken from the Small Fruit Crop IPM Disease Identification Sheet No. 4



The disease is spread by splashing or wind-blown water from rain or overhead irrigation. Sporangia and/or zoospores are carried in water from the surface of the infected fruit to healthy fruit where new infections occur. Under the proper environmental conditions, the disease can spread very quickly. A wet period (free water on fruit surface) of two hours is sufficient for infection. The optimum temperatures for infection are between 62 and 77 F. As the length of the wet period increases, the temperature range at which infection can occur becomes much broader. As infected fruit dry up and mummify, they fall to the ground and lie at or slightly below the soil surface. Oospores formed within the mummified fruit enables the fungus to survive the winter and cause new infections the following year, thus, completing the disease cycle.

Strawberry Anthracnose

Anthracnose is a disease that can affect foliage, runners, crowns and fruit. Various forms of anthracnose can be caused by several fungi. In the Midwest, the most common form of the disease is fruit rot, caused by the fungus *Colletotrichum acutatum*. Although the disease is not very common, if it becomes established in the planting, serious losses can occur. Organic fungicides (sulfur and copper) are not effective for control. Midwest varieties with resistance are not available. Once the disease develops on fruit in the planting there is little that can be done to control it. Managing the movement of pickers into and out of infested areas and adjusting irrigation practices can be beneficial in preventing disease spread.

Symptoms

Affected stems are sometimes girdled by lesions, causing individual leaves or entire daughter plants to wilt. Under warm, humid conditions, salmon-colored masses of spores may form on anthracnose lesions.

When crown tissue is infected and becomes decayed, the entire plant may wilt and die. When infected crowns are sliced open, internal tissue is firm and reddish brown. Crown tissue may be uniformly discolored or streaked with brown.

On fruit, symptoms first appear as whitish, water soaked lesions up to 1/8 inch in diameter which turn brown and enlarge within 2 to 3 days to involve most of the fruit (Figure 26). Lesions are covered with salmon-colored spore masses. Infected fruit eventually dry down to form hard, black, shriveled mummies. Fruit can be infected at any stage of development.

(Figure 26) Anthracnose lesion on strawberry fruit.

Disease Development

The disease is probably introduced into new plantings on infected plants. Spore production, spore germination, and infection of strawberry fruits are favored by warm, humid weather and by rain. Spores require free water on the plant surface in order to germinate and infect. Anthracnose fruit rot is considered to be a warm-weather disease with an optimum temperature for disease development near 80 F. Thus, the disease is generally a problem in the Midwest when abnormally high temperatures and rainfall occur during fruit set and harvest. Spores are dispersed primarily by water splash. Once the disease is established in the field, the fungus can overwinter on infected plant debris, primarily old-infected, mummified fruit.

Plant Parasitic Nematodes

Plant parasitic nematodes are microscopic round worms and are common in soils throughout the Midwest. Lesion and root-knot nematodes are probably the most destructive kinds in midwestern plantings. These organisms restrict root growth by feeding directly on roots. This makes plants less efficient at taking up water and minerals from the soil. Nematodes can also cause strawberry roots to be more susceptible to root-rotting fungi. Strawberry plantings in nematode infested soils are not long-lived. Production will decline rapidly after one or two seasons. Nematode damage is most common and most severe in replant situations, because preceding crops increase nematode numbers and high populations of these parasites may be present when the young plants are set. Under these conditions, strawberries never develop strong root systems.

Symptoms

Strawberry plants infested with nematodes are stunted and show symptoms of mineral deficiencies and water stress, particularly as the berries form. Because nematodes are unevenly distributed in the field, damaged plants tend to occur in patches. Heavily infested plantings decline rapidly.

Root-knot nematodes cause the formation of knots or galls on fine roots. Heavy galling may cause abundant adventitious root formation and lead to a "whiskery root" condition. Other types do not form such distinct root symptoms. Infested roots are not well developed. Lateral roots may be few. Roots attacked by lesion nematodes are dark in color.

Causal Organisms

The lesion nematode (*Pratylenchus penetrans*) and the northern root-knot nematode (*Meloidogyne hapla*) are common in the Midwest. The dagger nematode (*Xiphinema americanum*) is frequently found. The dagger nematode is the vector of tomato ring-spot virus, which it can acquire from common weed hosts, such as dandelion. Ring nematodes (*Criconemella spp.*) and lance nematodes (*Hoplolaimus spp.*) are also found in soils in the Midwest. Their effect on strawberries is not known.

Use of Disease Resistant Varieties

In the integrated disease management program, the use of cultivars with disease resistance must be emphasized. Many commercial cultivars have resistance and/or tolerance to *Leaf Spot, Leaf Scorch, Red Stele, Verticillium Wilt and Powdery Mildew*. The more disease resistance within the program, the better. Table 1 lists ratings for disease resistance in several of the more commonly grown cultivars. This type of information is available from a number of sources. Most nurseries should be able to provide information on disease resistance for the cultivars they sell.

Table 1. Disease resistance of Several Strawberry Cultivars Commonly Grown in the Midwest

June Bearing		Disease Resistance[a]				
Cultivar	**Season**	**Verticillium Wilt**	**Red Stele**	**Leaf Diseases[b]**	**Powdery Mildew**	**Comments**
Earliglow	Early	R	R	R	PR	Standard for early cultivars; berry size medium. Excellent flavor, but only moderately productive.
Veestar	Early	T	S	T	PR	Early, productive. Has performed well in Southeast PA, with medium bright berries. Fruit shows some *Botrytis* resistance.
Annapolis	Early	I	R	S	S	Fruit medium-large, firm, and glossy with good flavor. Plants runner freely. Fairly susceptible to *Botrytis*.
Northeaster	Early	R	R	I	S	Very large, early, and firm fruit with aromatic flavor and aroma. King berries slightly rough. Well adapted to heavy soils. In PA, for trial only.
Mohawk	Early	R	R	PR	T	Medium-sized fruit, comparable to Earliglow. Good flavor. Tolerant of *Botrytis*. Has been very variable, as two lines of plant material exist. Plant only small quantities.
Avalon	Early	R	R	T	R	Large berry with good color and flavor, average productivity and vigor. Has performed well in Southeastern PA. For trial only.
Sable	Early	U	R	PR	S	Veestar x Cavendish cross. Productive, well suited to U-pick operations. Available in small quantities. For trial only. Produces dense beds; *Botrytis* control may require more effort than usual.
Evangeline	Early	U	S	U	R	Medium yields of conical, firm berries. Flavor good if fully ripe. Berries produced on stiff, upright stalks. May not runner well. For trial only. Limited quantities available.

June Bearing		Disease Resistance[a]				
Cultivar	**Season**	**Verticillium Wilt**	**Red Stele**	**Leaf Diseases[b]**	**Powdery Mildew**	**Comments**
Honeoye	Early-mid	S	S	PR	T	Large fruit, productive; has performed well in PA, but lack of red stele resistance a concern. Tends to become soft in hot weather. Flavor distinctive, "Perfumy".
Cavendish	Early-mid	I	R	PR	S	Very large firm fruit with good flavor. Very productive (yields 85% of Kent) and moderately vigorous. Tends to ripen unevenly in certain years.
Brunswick	Early-mid	U	R	U	U	Good size and flavor. May perform better in cooler locations. Susceptible to Phytophthora crown rot. For trial.

June Bearing		Disease Resistance[a]				
Cultivar	**Season**	**Verticillium Wilt**	**Red Stele**	**Leaf Diseases[b]**	**Powdery Mildew**	**Comments**
Raritan	Mid	S	S	S	S	Widely planted cultivar in spite of disease susceptibility; first fruits are large, but size decreases more rapidly than most cultivars. Very flavorful.
Guardian	Mid	R	R	R	S	Very productive, firm, large fruit, sometimes rough (uneven) looking. *Botrytis* is generally more prevalent in Guardian. Tends to get a "Long neck" which breaks down and allows easy entry for slugs and sap beetles. Susceptible to Sinbar injury.
Redchief	Mid	PR	R	R	R	Productive, with good color and size. Flavor average. Excellent disease resistance.

Lester	Mid	S	R	R	U	Productive, good-sized berry. Flavor is good, though size tends to "run down" quickly. Fruit if fairly susceptible to *Botrytis*.
Kent	Mid	S	S	S	T	Extremely productive berry with large firm fruit. Tends to yield fruit in middle of rows, resulting in high rot, so keep rows narrow. Flavor average. Susceptible to Sinbar injury.
Settler	Mid	T	U	T	S	Large attractive moderately firm fruit. Very susceptible to Sinbar injury. In PA, for trial only.
DelMarvel	Mid	R	R	R	U	Very vigorous plants, with high production, large, firm, aromatic fruit. In PA, for trial only.
Primetime	Mid	R	R	R	U	Medium-firm berry with mild, lightly aromatic flavor. Good *Botrytis* resistance. In PA, for trial only.
Mira	Mid	U	R	S	R	Glossy, medium-red, tart berries. High yielding in areas north of PA. Good winter hardiness. Vigorous plants. In PA, for trial only.
Eros	Mid	S	R	U	U	'Allstar' hybrid from England, with darker fruit color than 'Allstar'. Large fruit, well-balanced flavor. Available in small quantities. For trial only.
Darselect	Mid	U	U	T	U	Attractive fruit with good color and quality. Vigorous. Available in small quantities for trial.

June Bearing		Disease Resistance[a]				
Cultivar	**Season**	**Verticillium Wilt**	**Red Stele**	**Leaf Diseases[b]**	**Powdery Mildew**	**Comments**
Jewel	Mid-late	S	S	PR	R	Large soft fruit; can be very dark. Tends to soften in hot weather. Very productive, though dense foliage can encourage *Botrytis*.
Allstar	Mid-late	R-T	R	T	T	Productive, elongated, flavorful berries. Lighter color than most berries. Good fruit size. Has become the standard mid-season berry in PA, in spite of light color. Has potential for the annual system on plastic mulch. Susceptible to angular leaf spot.
Seneca	Mid-late	S	S	U	U	Round, large, medium-red, exceptionally firm fruit with firm skin. Plant is vigorous. Flavor mediocre, but firmness of fruit may be useful for shipping market. Has potential for the annual system on plastic mulch.
Lateglow	Mid-late	R	R	T	T	Productive, good size and flavor. First berries extremely large, though size "runs down" over season. Extremely vigorous plant and needs to be controlled.
Latestar	Mid-late	R	R	R	U	Mild flavor, but variable yields and small fruit size. Vigorous plants. Flowers and ripens a few days later than 'Allstar'. In PA, for trial only. Susceptible to gray mold.
Winona	Mid-late	T	R	R	U	Large, firm conical fruit with bright red-orange color and good flavor. Released from Minnesota. May be marginal quality when

						warm. In PA, for trial only.
Mesabi	Mid-late	R	R	R	R	Large, dark-red fruit with good flavor. Winter hardy. Skin tends to become weak in warm weather.
Cabot	Mid-late	U	R	T	U	Huge berries, averaging 20-30 g over season. Berries rough-looking with firm flesh and tender skin. Available in small quantities. Greatest value may be as a "novelty berry" Doesn't runner well. For trial only.

June Bearing		**Disease Resistance[a]**				
Cultivar	**Season**	**Verticillium Wilt**	**Red Stele**	**Leaf Diseases[b]**	**Powdery Mildew**	**Comments**
Delite	Late	R	R	R	U	Large berries, very resistant to disease, average flavor.
Sparkle	Late	S	R	S	S	Flavorful, high-quality, attractive but soft fruit. Tends to grow very thickly. Size decreases rapidly during harvest season.

Day neutral		**Disease Resistance[a]**				
Cultivar		**Verticillium Wilt**	**Red Stele**	**Leaf Diseases[b]**	**Powdery Mildew**	**Comments**
Tribute		PR	R	T	R	Slightly later than 'Tristar' with larger fruit. Flavor not as strong, and plants are more vigorous.
Tristar		R	R	T	R	Bears an early crop, smaller than 'Tribute' flavor is excellent. Flesh and skin firm. Moderate vigor. Size reduced

					when weather too hot.
Everest	U	U	U	U	An alternative for growers who wish to try a day-neutral other than Tribute or Tristar. Recommended for small quantity trials only.

Plastic culture system		Disease Resistant[a]				
Cultivar	**Season**	**Verticillium Wilt**	**Red Stele**	**Foliar Diseases[b]**	**Powdery Mildew**	**comments**
Sweet Charlie	Early	U	U	U	U	Good flavor and size. Yields lower than for Chandler but produces crop for early market. Tends to break dormancy and flower during warm spells in late winter and early spring.
Chandler	Mid	U	S	S	S	Standard berry for this production system. Large, firm berries. Flavor is sweet if allowed to ripen fully, and not over-fertilized with nitrogen.
Camarosa	Mid	U	U	S	S	Large, firm berries. Productive and vigorous in warmer climates. Flavor fair. Cool fall temperatures may negatively affect flower bud initiation.
Marmolada	Mid	R	U	U	U	Requires high nitrogen rates for high yields. Large, glossy, bright red fruit with red flesh. Flavor fair. In PA, for trial only.

[a] I = intermediate, PR = partially resistant, R = resistant, S = susceptible, T = tolerant, U = unknown. [b] Includes leafscorch and leaf spot.

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Cultural Practices For Disease Control in Strawberry Production Systems

The use of any practice that provides an environment within the planting that is less conducive to disease development and spread should be used. The following practices should be carefully considered and implemented in the disease management program.

Use Disease-Free Planting Stock

Always start the planting with healthy, virus-indexed plants obtained from a reputable nursery. Remember that disease-free plants are not necessarily disease resistant: cultivar selection determines disease resistance.

Site Selection

Soil Drainage (Extremely ***Important)***-Select a planting site with good water drainage. Avoid low, poorly-drained wet areas. Good water drainage (both surface and internal drainage) is especially important for control of Leather Rot and Red Stele. Both of these diseases require free water (saturated soil) in order to develop. If there are low areas in the field that have a tendency to remain wet, this is the first place that red stele will develop. Under midwestern growing conditions, any time there is standing water in the field, plants are subject to leather rot infection. Any site in which water tends to remain standing is, at best, only marginally suited for strawberry production and should be avoided. Any practice, such as tiling, ditching, or planting on ridges or raised beds, that aids in removing excessive water from the root zone will be beneficial to the disease management program.

Previous Cropping History

Select a site that does not have a history of Verticillium wilt in any crop. Select a site that does not have a history of red stele or black root rot. To minimize the risk of black root rot, do not replant strawberries immediately after removing an old strawberry planting. In general, it is also not a good practice (due primarily to Verticillium) to plant strawberries immediately after solanaceous or other Verticillium-susceptible crops. These include tomatoes, potatoes, peppers, eggplant, melons, okra, mint, brambles, chrysanthemums, roses, or related crops. If possible, select sites that have not been planted to any of these crops for at least 3 to 5 years. There should be no herbicide residual in the soil from previous crops.

Site Exposure

A site with good air circulation that is fully exposed to direct sunlight should be selected. Avoid shaded areas. Good air movement and sunlight exposure are important to aid in drying fruit and foliage after a rain or irrigation. Any practice that promotes faster drying of fruit or foliage will aid in the control of many different diseases.

Crop Rotation

First Planting of Strawberry - If the land has no recent (5 years or less) history of strawberry production or Verticillium diseases in other crops, soil-borne diseases such as red stele or Verticillium wilt should not be a problem.

Replanting Strawberries - Crop Rotation and Soil Fumigation. If strawberries are to be replanted in the same field, crop rotation must be used or the field should be fumigated. Fumigation is currently not an option in organic production systems. With rotation, the site should be plowed, worked down and planted to a crop that is not susceptible to Verticillium wilt for a minimum of 2 years. Many soil-borne pathogens form specialized survival structures and are capable of surviving for several years in soil, even when strawberries are not present. The longer the site can be rotated away from strawberries prior to replanting, the better.

The combination of crop rotation plus soil fumigation is a sound approach that is used by many conventional growers. However, for organic growers (that can not use soil fumigation), crop rotation alone often provides acceptable control for most soil borne diseases, if the rotation is sufficiently long.

Neither crop rotation nor soil fumigation will reliably provide adequate control of red stele. With red stele, disease resistant varieties and improved soil drainage must be emphasized. Cultivars with resistance to red stele and Verticillium wilt should always be used.

Fertility

Fertility should be based on soil and foliar analysis. Soil should be analyzed and nutrient levels adjusted before planting. The use of excess fertilizer, especially nitrogen, should be avoided. Sufficient fertility is essential to produce a crop, but excess nitrogen results in dense foliage that increases drying time in the planting (stays wet longer) and also results in softer berries that are more susceptible to fruit rots. Avoid the application of nitrogen in the spring prior to harvest on medium to heavy soils. Excessive use of nitrogen has been shown to increase the level of Botrytis fruit rot (gray mold).

Weed Control

Good weed control is essential to successful strawberry production. From the disease control standpoint, weeds in the planting prevent air circulation and result in fruit and foliage staying wet for longer periods. Gray mold, in particular, is a much more serious problem in plantings with poor weed control versus plantings with good weed control. In addition, weeds will reduce production through direct competition for light, nutrients, and moisture with strawberry plants and will make the planting less attractive to pick-your-own customers, especially if you have thistles!

Mulch

Research and grower experience has shown that a good layer of straw mulch is very beneficial for controlling fruit rots, especially leather rot. Bare soil between the rows should be avoided and a good layer of straw mulch is highly recommended. The mulch keeps berries from contacting the soil where the leather rot fungus overwinters. In addition, it also aids in preventing infested soil from splashing onto the berries. Recent research has shown that plastic mulch (a layer of plastic) under the plants and/or between the rows increases splash dispersal of the pathogens that cause anthracnose and leather rot. Especially where fruit rots have been a problem, the use of plastic mulch is not recommended.

Sanitation

Any practice that removes old leaves and other plant debris from the planting is beneficial in reducing the amount of Botrytis inoculum. Leaf removal at renovation is highly recommended.

Irrigation Practices

The application of supplemental water should be timed so that the foliage and fruit will dry as rapidly as possible. For example, irrigating early in the day is better than in the evening. If diseases, such as gray mold, leather rot, anthracnose or bacterial blight, become established in the planting, overhead irrigation should be minimized or avoided.

Control Movement of People and Machinery

Movement of people (pickers) and machinery from a field or area that is infested to a clean or uninfested field should be avoided. Diseases of primary concern are anthracnose, leather rot and angular leaf spot (bacterial blight). Diseases such as these are usually spread over relatively short distances by splash dispersal (rain or irrigation). Movement from one field to another field through the air (wind blown spores) is generally not a problem with these diseases. However, pickers moving from a field where the disease is present to a non-infested field can transport fungal spores or bacteria very efficiently on shoes, hands, and clothing. If people or machinery are used in fields where these diseases are a problem, they should complete work in non-infested fields before moving to infested fields. In addition, any machinery that moves soil from one field to another can introduce soil-borne diseases, such as red stele, Verticillium wilt, leather rot, and nematodes, from infested into non-infested fields.

Harvesting Procedures

a) Pick fruit ***frequently*** and early in the day before the heat of the afternoon (preferably as soon as plants are dry). Picking berries as soon as they are ripe is critical. Overripe berries will cause nothing but problems during and after harvest.

b) Handle berries with care during harvest to avoid bruising. Bruised and damaged berries are extremely susceptible to rot.

c) Train pickers to recognize and avoid berries that have disease symptoms of gray mold and leather rot. If at all possible, have pickers put these berries in a separate container and remove them from the field.

Post Harvest Handling

a) Always handle fruit with care during movement from the field to market to avoid any form of damage.

b) Get the berries out of the sun as soon as possible.

c) Refrigerate berries immediately to 35 to 40°F in order to slow the development of gray mold (Botrytis) and other fruit rots.

d) Market the berries as fast as possible. Encourage your customers to handle, refrigerate, and consume or process the fruit immediately. Remember that even under the best conditions, strawberries are very perishable.

Table 2: Strawberry disease control strategies

- **All possible control strategies must be employed if strawberry diseases are to be controlled.**
- **Key: ++=most important controls; +=helpful controls; -=no controls.**

Disease control	Verticillium Wilt	Red Stele	Black Root Rot	Nematodes	Viruses	Fruit Rot	Leaf Spots	Powdery Mildew
1) Good drainage	-	++	++	-	-	++	+	-
2) No shade	-	+	-	-	-	++	++	-
3) No infested runoff	+	+	+	+	-		-	
4) Rotation	++[a]	++[a]	++[a]	++[a]	-	-	+	-
5) Resistant varieties	++[b]	++[c]	-	-	-	-	++[d]	++
6) Disease -free plants	++	++	++	+	++	-	+	+
7) Adequate plant and Row spacing	-	-	-	-	-	++	++	+
8) Mulch for winter injury and/or fruit rot	-	-	++	-		Leather rot (++)	-	
9) Fruit storage conditions	-	-	-	-	-	++	-	-
10) Renovation	-	-	++	-	-	-	+	+
11) Weed control	+	-	-	+	-	++	++	+

[a]Rotations: Verticillium wilt, black root rot, nematodes are 3 to 5 yrs; red stele is very long.

[b]Resistant to Verticillium wilt: Earliglow· Sunrise· Katskill· Guardian· Midway· Redchief· Surecrop· Selite· Sparkle·

[c]Resistant to some strains of red stele: Earliglow· Redglow· Sunrise· Guardian· Midway· Redchief· Surecrop· Selite· Sparkle·

[d]Resistant to leaf spot: Guardian· Midland· Redchief· Surecrop· Resistant to leaf scorch: Katskill· Guardian· Midland· Redchief· Sunrise· Surecrop·

Fungicides for Use in Organic Production Systems

The following is a brief description of some disease control materials that are commonly or traditionally used in organic production systems. Copper fungicides, elemental sulfur and liquid lime sulfur are the old “standard” fungicides, and have been used for many years in organic production systems.

Note: Prior to using any material in the organic system, it is important that the grower consult his/her organic certification agency or program to be positive that use of the material is permitted.

Copper Fungicides

When different formulations of copper are dissolved in water, copper ions are released into solution. These copper ions are toxic to fungi and bacteria because of their ability to destroy proteins in plant tissues. However, because copper can kill all types of plant tissues, the use of copper fungicides carries the risk of injuring foliage and fruit of most crops. Factors promoting this injury include: 1) the amount of actual copper applied, and 2) cold, wet weather (slow drying conditions) that apparently increases the availability of copper ions and, thus, increases the risk of plant injury. Because of the potential to injure plants and to accumulate in soil, the use of copper fungicides in conventional production systems has largely been replaced with conventional fungicides that are generally safer to plant tissues and often more effective.

Several terms are used when discussing copper as a fungicide. The original material used was copper sulfate (also known as blue vitriol or bluestone). When this material was combined with lime in the French vineyards, the combination became known as Bordeaux mixture.

Bordeaux Mixture

Bordeaux mixture is a mixture of copper sulfate and hydrated lime in water. It has long residual action and has been used for years to control many diseases, including downy mildew and powdery mildew of grape. It can be made (mixed) on site by combining copper sulfate with spray grade lime. It is also commercially available as a dry wettable powder.

Fixed Copper Fungicides

Following the discovery and use of Bordeaux mixture, several relatively insoluble copper compounds or fixed coppers were developed. Fixed copper formulations release less copper ions and are generally less injurious to plant tissues (safer to use) than Bordeaux mixture, but their use is still limited because of their potential to injure plants and lack of compatibility with other pesticides. Some of the more common commercial formulations of fixed copper include C-O-C-S, Kocide 101, Tribasic Copper sulfate, Champ, and Tenn-Copp 5E. There are several fixed copper fungicides registered for use on small fruit.

Sulfur Fungicides

Sulfur is available as liquid lime sulfur and as dry wettable powders or liquid (flowable) formulations of elemental sulfur.

Liquid Lime Sulfur

Liquid lime sulfur can be used at high concentrations as a dormant spray on raspberries and blackberries for control of cane blight, spur blight and anthracnose and on grapes for control of anthracnose. At high concentrations, it should be used only when plants are dormant. It can cause severe damage if applied after green foliage appears. Lime sulfur has a foul odor that many people dislike. It is also registered for use on grapes and caneberries as a more dilute concentration for use during the growing season.

Dry Wettable Sulfurs or Flowable Sulfurs

Sulfur for use as a fungicide is available under many trade names. The microfine wettable sulfurs or flowable sulfurs are usually much less injurious to foliage and fruit than liquid lime sulfur, but their use during hot weather (above 85°F) may result in some leaf burning and fruit damage. Sulfur fungicides are very effective for control of powdery mildew on most fruit crops, but are not highly effective for control of most other fruit crop diseases. Sulfur is very toxic to foliage of certain grape varieties (mainly American grapes) including Concord, Chancellor, DeChaunac and Foch. Sulfur is relatively safe on most other varieties see Table 6, page 68. Applications after the fruit begins to ripen may pose problems during fermentation if the grapes are intended for wine making.

Growers should note that sulfur is lethal to some beneficial insects, spiders and mites. These beneficial insects are natural predators of harmful insects and mites that affect fruit crops. Killing these beneficial insects may increase certain pest problems, especially mites.

Specific comments on fungicide use will be made in the text for each crop where applicable.

"New Alternative" Disease Control Materials for Small Fruit

Many products are currently available or currently being introduced as "biological control agents" or "biopesticides". These include living microorganisms, "natural chemicals such as plant extracts, and "plant activators" that induce resistance in plants to disease. For most of these products, independent evaluations are currently being conducted; however, their effectiveness under moderate to high disease pressure is uncertain. Although many of these new products have great potential for use within organic production systems, their effectiveness needs to be determined in field tests. It is important to remember that registration of these materials for control of a specific disease on a crop is no guarantee that they will provide effective control under moderate to heavy disease pressure. In addition, many products may be effective for only one or a few diseases and most have very limited residual activity (they have to be applied often). It is also important to remember that these are registered pesticides and growers need to be certain that their use is permitted within their organic certification program.

The biological control committee of the American Phytopathological Society has developed a web page for **"Commercial Biocontrol Products Available for Use Against Plant Diseases".** The web page address is: www.oardc.ohio-state.edu/apsbcc/. This web page lists all the products currently available along with information such as registered crops and diseases controlled. It also lists the name of the company that manufacturers or distributes the product along with phone numbers and web site addresses. This site is updated regularly and is a valuable resource for growers interested in these products.

The following are a few of the most common "alternative disease control products currently registered for use on small fruit.

- **AC10** (*Ampelomyces quisqualis*) is a biofungicide registered for control of powdery mildew in grapes, strawberries, blueberries, raspberries, currants, and gooseberries. *A. quisqualis* is a fungus, that parasitizes powdery mildew fungi. Preliminary results in grapes in Michigan show moderate disease control. Adding an adjuvant such as Nufilm (0.02% v/v) enhances its efficacy. Application should start as soon as susceptible tissue becomes available and continue on a 7 to 14 day schedule. A minimum of 2 sequential applications if needed to maintain the population of *A. quisqualis*. The following chemicals cannot be tank-mixed with AQ10: sulfur and potassium salts of fatty acids.
- **Armicarb 100** (potassium bicarbonate=baking powder) is a reduced-risk, protectant (contact) fungicide. Armicarb 100 is registered for control of powdery mildew and other diseases in grapes, blueberries, strawberries, and brambles. Preliminary results in grapes in Michigan indicate moderate control of powdery mildew. Start applications at the first sign of disease and continue on a 7-14 day schedule. The preharvest interval (PHI) on all crops is 0 days.
- **Galltrol** (*Agrobacterium radiobactor* strain 84) is a biological control product for control of crown gall, caused by Agrobacterium tumifaciens on several tree fruit and nut crops. The active ingredient is the bacterium, Agrobacterium radiobactor strain 84. On small fruits it is effective for control of crown gall on raspberry and blueberry. It is not effective for controlling crown gall on grapes. It is purchased as a pure culture grown on agar in petri plates. The bacterial mass from one plate is diluted into one gallon on non-chlorinated water and plants are treated with a pre-plant dip in the solution or as a soil drench.
- **Kaligreen** (potassium bicarbonate = baking powder) is a reduced-risk protectant (contact) fungicide. Kaligreen is registered for control of powdery mildew on grapes, strawberry, brambles (raspberry and blackberry) and blueberry. It provides good control of powdery mildew when applied on a frequent-protectant program of 7 to 10-day intervals. It has little or no efficacy against most other fungal diseases on small fruit. It is formulated as a micro-encapsulated powder that is mixed in water and sprayed directly on the crop. Kaligreen has a preharvest interval (PHI) of 1 day on all small fruit crops.
- **Messenger** (harpin) is a reduced risk product registered for use on grapes, blueberries, cranberries, strawberries, brambles, and currants. The active ingredient is derived from a protein produced by certain bacteria. This protein stimulates natural plant defenses. Messenger has no direct effect on pathogens. The efficacy of this material for disease control or suppression has not been sufficiently confirmed. Messenger has a 0 day PHI.
- **Mycostop** (*Streptomyces griseoviridis* strain K61) is a biocontrol product registered for

use on all fruit crops for control of several important pathogenic fungi that cause seed, root, and stem rot and wilt diseases. The active ingredient is the bacterium, Streptomyces griseoviridis strain K61. It is sold as a powder formulation that is mixed with water and applied as a spray or a drench.

- **Oxidate** (hydrogen dioxide) is a broad-spectrum bactericide/fungicide registered for use in grapes, blueberries, cranberries, strawberries, and brambles. It is a rather corrosive material and works by oxidizing fungal and bacterial cells. The efficacy of the material for disease control has not been sufficiently confirmed on several diseases. In one Ohio fungicide evaluation, it provided no control of grape black rot.
- **Serenade** (*Bacillus subtilis*) is a biocontrol product registered for control of powdery mildew, Botrytis bunch rot and sour rot in grapes. Serenade is also reported to provide some suppression of downy mildew. This product needs further evaluation, but preliminary results show a moderate level of control of Botrytis bunch rot and powdery mildew. Serenade did not control grape black rot in Ohio. Good coverage is important for control. Applications are recommended on a 7-10 day schedule. Serenade has no maximum seasonal application rate and has a 0 day PHI.
- **Trichodex** (*Trichoderma harzianum*) is a biofungicide registered for use on all small fruit crops for control of a wide range of diseases, but primarily for control of Botrytis fruit rot. It is sold as a wettable powder formulation that is mixed with water and sprayed directly onto the plants.
- **Trilogy** (Clarified Hydrophobic Extract of Neem Oil). The label states that Trilogy is a broad spectrum fungicide of certain diseases and controls mites in citrus, deciduous fruits and nuts, vegetable crop, cereal grains and other miscellaneous crops. The label does not state what diseases are controlled on specific crops. Trilogy is registered for use on grapes, strawberry, brambles (raspberry and blackberry), and blueberry. Trilogy is a liquid that is applied for diseases as a 1% solution in sufficient water to achieve complete coverage of the foliage.

As the efficacy of these new materials is tested and validated, they will be included in these guidelines where appropriate.

Efficacy of Disease Control Materials

for Powdery Mildew

Powdery mildew is different from most other plant diseases caused by fungi, because the fungus that causes it lives almost entirely on the surface of infected plant parts. The fungus may penetrate only one cell layer deep into the plant. Thus, it is exposed to eradication following topical treatment with a range of products that do not affect many other pathogenic fungi that colonize deeper into infected plant tissues. Research in New York and other locations has demonstrated that many new and “alternative materials can provide effective control of powdery mildew if applied often enough (7 day schedule) through the growing season. These materials burn out the fungus growing on the surface, but do not provide protection against new infections; thus, repeated applications are important. These materials include: Nutrol (manopotassium phosphate); Kaligreen and Armicarb (potassium bicarbonate-baking soda); oils such as Stylet Oil and Trilogy; and dilute solutions of hydrogen peroxide (Oxidate).

Unfortunately, these materials have little or no effect on many other small fruit diseases. In addition, organic growers need to consult with their certification agency or program to be sure that any material they use is “certified” or acceptable as organic.

Fungicide Use Strategies for Organic Production

Unfortunately, there are not many options to choose from when one considers current fungicide use strategies. The current options are:

1. **Do Not Use Fungicides**

   This is always an option, but may not be a wise decision for commercial grape plantings in the Midwest. This option should not be confused with “organic” production. Grape growers in “organic” production systems will most probably use Sulfur or Copper to some extent for disease control. Sulfur and Copper are fungicides. Growers that choose not to use fungicides must rely completely on cultural practices, disease resistance, or biological control agents or products for disease control. For strawberries, caneberries and blueberries organic fungicides are often of little value against the more common diseases such as Botrytis fruit rot (gray mold); therefore, little or no fungicide will probably be used in organic production of these crops.

2. **Protectant Fungicide Program**

   In a protectant program, fungicides are used as a protective barrier on the plant surface. This chemical barrier prevents the fungus from entering the plant. It works much like paint on a piece of wood to keep out water. Protectant fungicides (such as sulfur and copper) are not systemic and cannot move into plant tissues. Once the fungus penetrates into the plant, protectant fungicides will not control it. As the protective barrier breaks down or new foliage is produced, additional applications are required to maintain the protective barrier.

Protectant fungicide programs have been, and still are very effective; however, they generally result in a fairly intensive use of fungicide. On grapes, protectant fungicides are usually applied on a 7-10 day schedule early in the growing season and on a 10-14 day schedule later in the season. Obviously, maintaining a protective barrier on the plant surface throughout the growing season requires several applications.

Organic Fungicides and Biocontrol products for Strawberry Disease Control

Most organic fungicides and biocontrol agents are not highly effective against the overall disease complex on strawberry. A number of products including sulfur, salts and oils will provide good control of powdery mildew if applied on a 7 to 10 day schedule; however, these materials have little or no activity against most of the other leaf spot or fruit rot diseases. Emphasis for controlling these diseases, as well as powdery mildew, should be placed on the selection and use of disease resistant cultivars (Table 1). If a high level of resistance is not available in adapted varieties, growers should at least avoid the selection of highly susceptible varieties. Copper fungicides have limited use on strawberry. The potential for plant injury using copper fungicides is high on strawberry. In addition, copper fungicides are not highly effective against most of the leaf spot and fruit rot diseases. In order to apply sufficient copper to obtain control, the potential for plant injury is probably unacceptable. Copper fungicides have been recommended and used for control of angular leaf spot (bacterial blight) with varying levels of success. Once the disease is established in the planting, copper fungicides will do little to control it. There are several biocontrol products registered for control of Botrytis fruit rot. Their efficacy under moderate to severe disease pressure needs to be determined.