

# Diseases of Geraniums

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## Introduction

Geraniums are one of the most versatile and widely used flowering plants in the floriculture industry. They are produced as pot plants and bedding plants by the commercial florist. Geranium plants may be used as spring pot plants, in window boxes, in border plantings, and in mass exhibits in outdoor landscape designs. They may be vegetatively propagated from cuttings or apical shoot-tip culture or grown from seed. Extensive use of culture-indexed and virus-indexed cuttings, the use of plants produced from apical shoot-tip culture, and the use of seed-propagated cultivars have reduced the number of disease problems for both the commercial producer and the consumer.

According to the United States Department of Agriculture Crop Reporting Board publication *Floriculture Crops, Production Area and Sales, 1980 and 1981, Intentions for 1982*, geraniums grown for potted plants in the United States in 1981 had a total wholesale value of approximately \$49,518,000. In the northeastern United States the wholesale value of this crop was \$15,479,000, and New York State produced a crop valued at \$5,927,000. Geraniums are also grown from seed in bedding plant production. Although the percentage of geraniums used as bedding plants is not known, it is a significant number in an industry with a wholesale value of \$150,388,000 in the United States in 1981. From this information one can see that geraniums are a commercial crop of considerable value, and disease problems can result in significant economic losses.

The diseases discussed in this bulletin are primarily those that affect the florist, garden, or zonal geranium, *Pelargonium x hortorum*. Some of these pathogens may also affect other species of *Pelargonium* such as the Martha Washington geranium, *Pelargonium domesticum*, and the ivy geranium, *Pelargonium peltatum*, as well as the geranium cultivars propagated from seed. Such cases are noted in the text when their occurrence can be documented.

## Pesticide Legislation

In accordance with recent New York State legislation, pesticides that are highly toxic and those that are persistent and accumulative are placed on a restricted-use list and may be purchased and used only by certified applicators or under the direct supervision of certified applicators. Restricted-use pesticides recommended in this publication are identified throughout by a dagger (†).

The Federal Environmental Pesticide Control Act (FEPCA) was signed into law October 21, 1972. Under this law, all pesticides are to be classified into restricted-use and general-use categories. This law also prescribes that all users of restricted-use pesticides be certified.

In New York State, all commercial applicators of pesticides must be certified, even if they use only general-use (nonrestricted) pesticides. Also, all private applicators who use restricted-use pesticides must be certified. In most situations, private certification is sufficient for greenhouse operators and their employees. If in doubt, check with the Department of Environmental Conservation pesticide inspector for your region.

Classification of pesticides in the restricted-use category may change. Therefore, the chemicals listed in this bulletin under control measures should be taken as examples of compounds that will control the specific disease. These recommendations may not be current. Consult your Cooperative Extension agent if in doubt of their current status.

To avoid confusion, common names of pesticides are used when approved for use on the label by the Office of Pesticides Program of the Environmental Protection Agency (EPA). Otherwise, trade names are used because they also appear on the label. No endorsement of pesticides or other named products is intended, nor is criticism of unnamed products implied.

More-detailed information on the rules and regulations governing the handling and use of these chemicals in New York State can be obtained from the Department of Environmental Conservation, Bureau of Pesticide Management, 50 Wolf Road, Albany, NY 12201.

## Bacterial Diseases

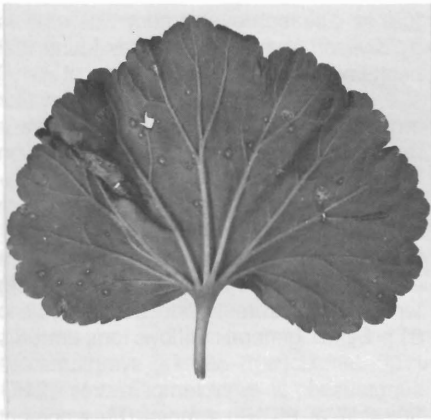


Figure 1. Bacterial blight. Small water-soaked spots developing on the lower leaf surface.



Figure 2. Bacterial blight. Later stage in the development of leaf symptoms showing slightly sunken, well-defined spots. Notice that the leaf has begun to wilt.

### Bacterial Blight *Xanthomonas pelargonii*

#### Importance

Bacterial blight, or bacterial stem rot and leaf spot, is one of the most important diseases of geranium in the United States. Until the introduction of culture-indexed cuttings on a commercial scale, this disease was the limiting factor in the production of cuttings from field-grown geraniums in California. Disease epidemics occurred regularly, and losses of 10 to 100 percent were experienced by plant producers.

The disease is not restricted to California and apparently occurs wherever geraniums are grown. Before the introduction of culture-indexed cuttings, bacterial blight occurred throughout the northeastern United States and often resulted in losses of 50 to 60 percent to local growers. The disease is widespread in the United States, and because geraniums are one of the leading pot-plant crops in this country, bacterial blight is of considerable economic importance. For many growers the control of this disease makes the difference between a loss or a profit in geranium production.

In addition to the United States, bacterial blight occurs throughout the world and has the potential to cause severe losses wherever geraniums are grown. The disease has been reported from Australia, Denmark, England, France, Greece, and West Germany and probably occurs in other countries as well.

#### Symptoms

The bacterium causing this disease attacks leaves, stems, and cuttings of *Pelargonium hortorum* as well as other species of *Pelargonium*. The stem rot stage is the most common symptom seen in commercial greenhouses, and most commercial cultivars of *P. hortorum* are susceptible. The leaf spot symptom is seen less often. This may be because environmental factors are not often favorable for its occurrence or some cultivars are resistant to leaf infection.

**Leaf symptoms.** Two types of symptoms occur on leaves infected with the bacterial blight organism. In one case symptoms first appear as small water-soaked spots on the

underside of the leaf (fig. 1). After a few days, these spots become slightly sunken and well defined. These symptoms are followed by wilting (fig. 2) and death of the affected leaf. Bacteria from the leaf spots may spread down the water-conducting (vascular) tissue in the leaf petiole into the stem and then back up to the top of the plant, eventually causing the death of the plant from the stem rot phase of the disease.

In other cases affected leaves wilt at the margins of the leaf blade, and the leaf petiole initially remains turgid. Infected areas of the leaf rapidly die in angular areas bounded by the veins. This symptom is common in geranium and may be caused by several other factors. But wilting of the affected leaves is always associated with bacterial infections. The affected leaves may drop off immediately or may hang on the plant for a week or more.

**Stem symptoms.** The stem rot phase of this disease is often called black rot. In plants attacked in this manner the water-conducting tissues in stems and branches become brown to black 2 to 4 weeks after the plant is infected. At this time one or more leaves on a branch usually wilt (fig. 3). Later the bacteria spread from the water-conducting tissue, located just under the cortex, inward to the pith and outward to the cortex, causing a brown to black discoloration in the stem. At this stage the exterior of the stem is gray and dull in appearance, and defoliation of the plant continues until only the tips of the branches



Figure 3. Bacterial blight. Early symptoms of the stem rot phase on the cultivar *Irene*. Notice the leaves wilting on the left side of the plant.



Figure 4. Bacterial blight. Continued development of the stem rot phase on the cultivar Irene. Notice that more leaves are wilting and there is a black lesion (arrow) on the stem.



Figure 5. Bacterial blight. Continued defoliation and development of stem lesions on the cultivar Springfield White.



Figure 6. Bacterial blight. Blackened and shriveled areas (arrows) on stems of geranium resulting from infection by *Xanthomonas pelargonii*.

have leaves (figs. 4, 5). The stem rapidly blackens and shrivels into a dry rot, leaving the stem fibers and epidermis intact but destroying the rest of the stem tissue. At this time affected plants consist of almost completely defoliated, blackened branches with only a few tufts of leaves on the tips (fig. 6). The roots are blackened, but not decayed. Occasionally a plant will recover partially and produce new healthy appearing branches. In a few months these branches also will die.

**Cutting symptoms.** Infected cuttings fail to root and slowly rot from the base upward. The leaves wilt and often show typical wilt symptoms as described previously. A few weeks after such cuttings are placed in a rooting medium, the stems become a dull black-brown as with typical stem rot, and the cuttings die.

#### Pathogen

This disease is caused by the bacterium *Xanthomonas pelargonii*. The pathogen was reported to cause a bacterial leaf spot of geranium in the eastern United States in 1923. At that time the bacterium was named *Bacterium pelargonii*. The stem rot phase of the disease was reported in 1932 by Dodge and Swift, but they did not conclude that the two symptoms were caused by the same bacterial pathogen. In 1952 Hellmers showed that the same bacterium caused both the leaf spot and the stem rot phases of the disease. In 1937 Burkholder had described a bacterial leaf spot on several species of *Geranium*. He called this bacterium *Phytomonas geranii*, and the name was later changed to *Xanthomonas geranii*. Starr and co-workers did comparative biochemical and cultural determinations and cross-inoculation tests with authentic cultures of *B. pelargonii* and *X. geranii* and concluded that the two species were identical. They recommended that the two species be combined as *X. pelargonii*.

At the present time the major stem rot and leaf spot disease of *Pelargonium* is caused by one organism, *X. pelargonii*.

#### Environmental Relations

**Temperature.** Symptoms of bacterial blight appear on infected plants more rapidly at higher temperatures (fig. 7). The relationship of greenhouse night tempera-

ture to disease development was studied by Kivilaan and Scheffer. They found that plants held at a night temperature of 28° C (81° F) showed first symptoms 7 days after inoculation, whereas 3 weeks were required for first symptoms to appear on inoculated plants held at night temperatures of 18° C (60° F), and symptom expression was still slower at 10° C (50° F). Disease development and symptom expression increased with increasing temperatures from 10° to 28° C (50° to 81° F). In general, at low temperatures (10°-18° C [50°-60° F]) symptoms are suppressed, at high temperatures (21°-30° C [70°-85° F]) symptom development is enhanced, and at very high temperatures (32°-38° C [90°-100° F]) symptom development is again suppressed.

**Nutrition.** Kivilaan and Scheffer studied the effect of plant nutrition on disease development in geranium plants inoculated with *X. pelargonii*. They found that the disease developed most slowly in plants receiving balanced nutrients. In plants receiving unbalanced nutrients disease development was most severe in plants receiving high nitrogen and low potassium or low nitrogen and high phosphorus. In general, plants in a high-nitrogen solution developed symptoms more rapidly than did plants in a low-nitrogen solution. Everything else being equal, one can expect fastest disease development in plants highest in organic nitrogen.

**Survival and spread of *Xanthomonas pelargonii*.** *In cuttings.* The bacterium is most commonly carried over in infected cuttings by bacteria that occur in the water-conducting tissue (vascular elements) of the cuttings. Cuttings taken from plants with stems with obvious symptoms invariably are infected with bacteria and often rot during propagation. Cuttings taken from infected plants that show no external symptoms may serve as symptomless carriers and are of much greater danger to both the propagator and the grower.

*In cutting propagation.* The propagation medium is ideal for spread of the pathogen when cuttings are rooted in a common rooting bench. Cuttings are stuck close together, and the bacterium can spread from an infected cutting into the rooting medium and infect adjacent noninfected

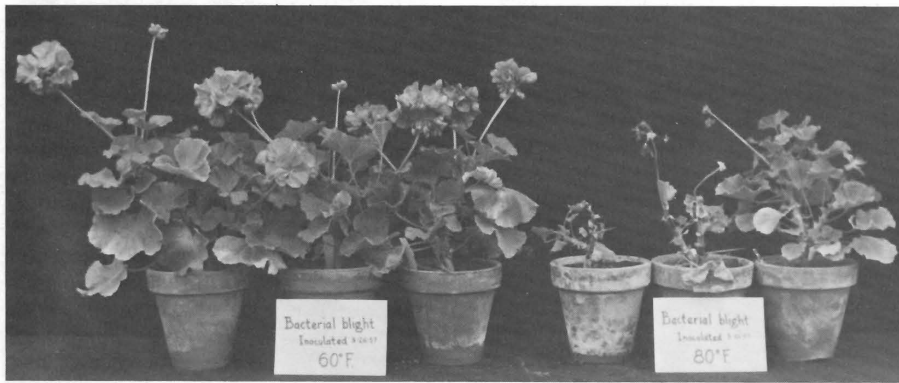


Figure 7. Bacterial blight. Plants inoculated with *Xanthomonas pelargonii* and grown at different temperatures to show the effect of temperature on symptom expression. Plants on the left grown at 18° C (60° F) and plants on the right grown at 27° C (80° F). Note the severe symptoms on the plants grown at 27° C (80° F).

cuttings. When cuttings are rooted singly in individual containers, this is not a problem because there is very little spread from container to container, and each cutting can be handled as an individual unit.

*On infested cutting knives.* The most efficient means of transmission of *X. pelargonii* from plant to plant is by the cutting knife. Because of this the preferred method of taking cuttings is to break them from the stock plants. If knives are used, they should be disinfested by dipping in 70% alcohol and flaming or by soaking for 5 minutes in sodium hypochlorite, 10% Clorox (1 oz Clorox plus 9 oz of water).

*In soil.* Munnecke (1956) studied the survival rate of *X. pelargonii* in a heavy loam soil infested by plowing under geranium plants that had been inoculated with *X. pelargonii*. Immediately after plowing and at intervals of 1, 3, 6, and 12 months, rooted cuttings of a susceptible cultivar of *P. hortorum* were planted in the field. Results of these tests showed that the bacteria have slight survival ability in moist soil, although 100 percent loss may occur if cuttings are planted immediately in infested soil. Survival depends on the rate of decay of the infected plant parts, and 6 months is probably the time limit for survival of the pathogen under these conditions.

*In overhead water and by plant contact.* Spread of *X. pelargonii* readily occurs in pots of closely spaced geraniums on a greenhouse bench. Dougherty, Powell, and Larsen showed that in blocks of 108 plants with 5 infected plants spaced throughout the block, all plants were infected and showed symptoms within 44 to 50 days when overhead watering was used. In a similar experiment using Chapin-type irrigation tubes, all noninoculated plants remained symptomless after 50 days. Munnecke reported that his field observations indicated that rapid spread of the bacterium occurred when it rained or when overhead watering was used. Spread also occurred by plant contact and on farm equipment.

*By insect transmission.* Bugbee and Anderson isolated *X. pelargonii* from live whiteflies (*Trialeurodes vaporariorum*) that had fed 24 hours on geranium with leaf spot symptoms. Whiteflies that had fed 24 hours on diseased geraniums were placed

on healthy geraniums. Leaf blisters and leaf spot symptoms appeared on some of these plants after 17 days, and after 2 weeks symptoms appeared on all the plants on which whiteflies fed. The pathogen was isolated from these lesions, and it infected healthy geraniums when the plants were inoculated.

#### Host Range and Susceptibility of Cultivars

Apparently none of the commercial cultivars of *P. hortorum* are immune from stem rot. Cultivars vary in their susceptibility to *X. pelargonii*, but none possess useful resistance to the bacterium. Knauss and Tammen tested 41 species, hybrid species, and cultivars of the genus *Pelargonium*. Resistance occurs in *P. domesticum*, *P. acerifolium*, *P. Toreno*, *P. tomentosum*, and *P. scarboroviae*. *Pelargonium graveolens* exhibits intermediate resistance or susceptibility, and *P. peltatum* is highly susceptible. The pathogen was found to persist in root-inoculated, symptomless plants of *P. domesticum* maintained for 2 months under conditions optimum for disease development. Thus, although this species is highly resistant, it is not immune and may serve as a symptomless carrier of *X. pelargonii*.

#### Anatomy of Plants Infected with *Xanthomonas pelargonii*

The mode of spread of the pathogen is the same in all *Pelargonium* species, whether they be resistant or susceptible. Initially, movement of the pathogen occurs throughout the plant in the xylem vessel elements, followed by lateral movement into adjoining parenchyma cells. The relative numbers of bacteria and the number of vascular bundles initially invaded are low in resistant species and high in susceptible species. In susceptible species, bacterial pockets form around affected xylem vessels (fig. 8), enlarging to encompass all the xylem cells in the bundle (fig. 9) and, finally, portions of the cambium, phloem, cortex, and epidermis. In resistant species the plants respond to infection by forming a ring of cells around affected portions of the vascular bundles. This appears to be a secondary defense reaction, restricting the lateral spread of the pathogen.

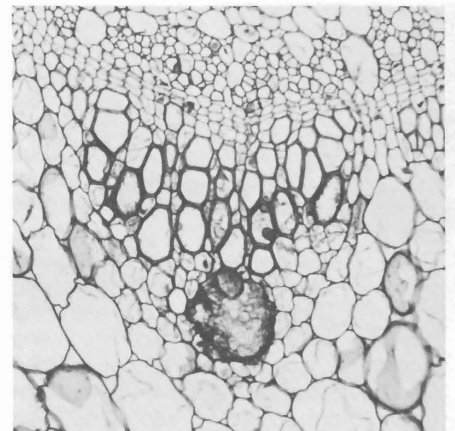


Figure 8. Bacterial blight. Cross section of a geranium stem showing the early development of a bacterial pocket in the xylem and surrounding tissue.

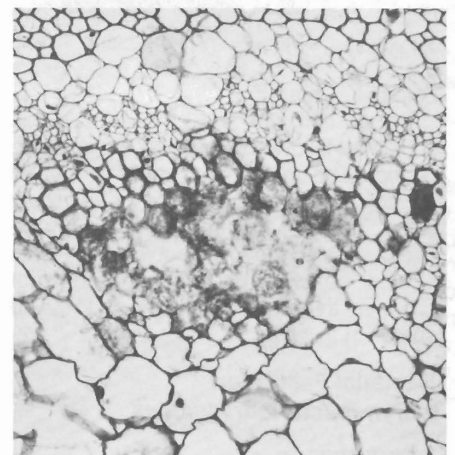


Figure 9. Bacterial blight. Cross section of a geranium stem showing disintegration of xylem tissues as the bacterial pocket continues to enlarge.

## Control

Several important steps are involved in control of bacterial blight of geraniums. The bacterium causing this disease is most commonly carried over in infected cuttings. Cuttings taken from stems showing obvious symptoms of the disease are almost always infected and serve as a means of infecting clean cuttings during propagation. Cuttings taken from infected plants showing no obvious symptoms may also be carrying bacteria. These cuttings may carry the organism for some time before showing symptoms, especially during cool weather. Because of this all cuttings used should be derived from culture-indexed plants. The culture-indexing procedure is described in the section "Detection of Fungus and Bacterial Vascular Wilt Pathogens by Culture-Indexing."

Soil or artificial growing media and containers used for geranium production should be treated with steam or chemicals before use. Because the bacterium can survive in old geranium plant tissue in soil, the soil should be free of any such debris before it is treated.

Good sanitation and cultural practices should be followed throughout the growing period. The bacterium can be spread rapidly by overhead watering or splashing water, by plant contact, and through the use of infested tools and equipment. Plants should be watered carefully and not crowded together on the bench to avoid spread in this way.

## Bacterial Fasciation *Corynebacterium fascians*

### Importance

The bacterial fasciation disease was first found in the United States on sweet pea in 1935. Before then it had been observed in England in 1927. The disease has also been reported to occur in Germany, Denmark, and Sweden. The disease occurs throughout the United States and affects many other plants in addition to geranium.

At present this disease is of minor importance, but has the potential to cause problems in the culture of geranium. The bacterial pathogen that causes this disease has a wide host range, which includes such diverse plants as lily,



Figure 10. Bacterial fasciation. Short, fleshy, thick aborted stems with misshapen leaves developed at the soil level on an infected plant.



Figure 11. Bacterial fasciation. Short, fleshy, thick aborted stems with misshapen leaves developed at the soil level on an infected plant.

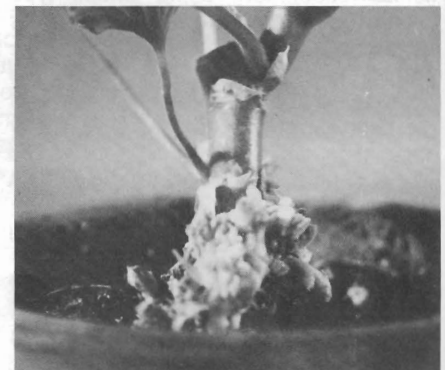


Figure 12. Bacterial fasciation. Gall-like growth that has developed at the soil level on an infected plant.



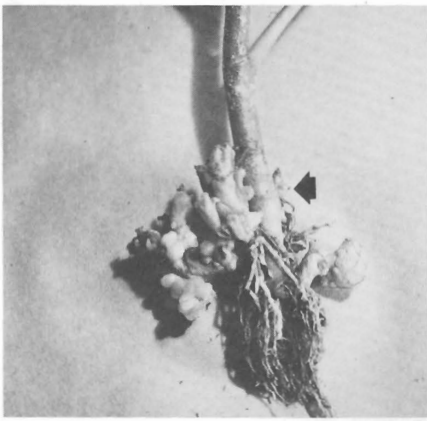


Figure 13. Bacterial fasciation. Aborted shoots and gall-like growths that have developed below the soil level on an infected plant. The soil level is indicated by the arrow.

gladiolus, *Viburnum*, carnation, chrysanthemum (*C. indicum*, *C. morifolium*, *C. maximum*), dahlia, *Pelargonium hortorum*, sweet pea, hollyhock, forsythia, phlox, primula, delphinium, and petunia. This list includes many plants commonly found in the home garden. Infected geraniums purchased by the homeowner as bedding plants may serve as a source of the bacterium to infect other plants in the home garden as well as to infest the soil.

### Symptoms

Symptoms of the disease on geranium are distinctive and usually quite obvious. Many short, fleshy, thick, aborted stems with misshapen leaves develop at or below the soil level on affected plants. The mass of fasciated growth on old plants resembles a "witches'-broom" and may reach a diameter of 1 to 3 inches (figs. 10, 11). In other cases the growth at the base of the plant resembles a gall, and no aborted shoots develop (fig. 12). The aborted shoot or gall development is usually visible above ground, but in some cases the major portion occurs below the soil level and little or no growth is visible (figs. 13, 14).

The aboveground portions of the aborted shoots and galls are a normal green color similar to the color of the rest of the plant. The underground portions are usually pale yellow. Apparently the main stem of an affected plant continues to grow normally, but there is some evidence to indicate that this growth is stunted or dwarfed and that the number of flowers is reduced. Affected plants seem to live as long as healthy plants.

### Pathogen

Bacterial fasciation is caused by the bacterium *Corynebacterium fascians*. The organism was first named *Phytomonas fascians* in 1936, then *Bacterium fascians*, and finally changed to the current name in 1942. The bacterium affects only the meristem tissue of buds and causes the buds to break dormancy. Wounds are not required for the bacterium to initiate disease development.

### Environmental Relations

Conditions that favor aborted shoot and gall development are moisture and moderately warm temperatures. The

organism is waterborne and carries over on the surfaces of affected buds and in infested soil. It can be spread in watering, in handling infected plants, and by infested soil. The bacterium may also be spread in cuttings from infected plants, but at present there is no conclusive evidence to support this belief.

### Control

Control measures consist of sterilization of all propagating media and potting soil and careful sanitation practices to prevent the reintroduction of the bacterium into the treated soil. Any stock plant exhibiting symptoms of this disease should be discarded. Culture-indexed cuttings should be used whenever possible.

### Southern Bacterial Wilt *Pseudomonas solanacearum*

#### Importance

Southern bacterial wilt is a widespread and destructive disease on many host plants in warm climates. Among the many plants attacked by *Pseudomonas solanacearum* are tomato, potato, tobacco, pepper, eggplant, peanut, banana, and ornamental plants such as dahlia, marigold, and zinnia. In addition a diverse group of weeds are also attacked by the bacterium. The first report of this disease on geranium was in 1980 from North Carolina. In a large planting of the cultivar Sprinter about one-half of the plants wilted and died. These plants were large and otherwise in good condition. Subsequent investigation by D. L. Strider, North Carolina State University, showed that *Pseudomonas solanacearum* was the causal organism, and the information given here is based on his published report.

#### Symptoms

Initial symptoms of southern bacterial wilt appear in 5 days after plants have been root inoculated. Although plants can be inoculated by dipping roots in a bacterial suspension, by puncturing stems at the junction of petiole and leaf with infested toothpicks, or by pouring a bacterial suspension over cut roots, disease development is most uniform with the method involving cut roots. The initial wilting of lower leaves is followed by chlorosis in a

Figure 14. Bacterial fasciation. Aborted shoots and gall-like growths that have developed below the soil level on an infected plant.



few days and finally necrosis of affected leaves. Two weeks after inoculation most leaves are necrotic, but the terminal shoots usually remain green until the stem turns black at the soil line and the plant collapses. Flowers fail to open normally. Vascular discoloration is present in the stem 5 days after root inoculation.

#### Pathogen

Southern bacterial blight of geranium is caused by *Pseudomonas solanacearum*. Although this bacterium was not reported on geranium until 1980, it has been known to attack other host plants, such as tomato and potato, since the 1890s. The bacterium has been given several different names, among them being *Bacillus solanacearum*, *Bacterium solanacearum*, and *Xanthomonas solanacearum*.

#### Environmental Relations

Disease development and symptom expression occur most readily at temperatures between 25° C (75° F) and 38° C (100° F). Overhead watering also favors disease development and symptom expression.

#### Control

To date no cultivars resistant to *Pseudomonas solanacearum* have been found. The use of cuttings derived from culture-indexed stock, growing geraniums from seed, and soil treatment are still probably the best control measures.

## Bacterial Leaf Spot *Pseudomonas cichorii*

### Importance

Bacterial leaf spot is a new disease of geranium described recently by Arthur W. Engelhard of the University of Florida, Bradenton, and most of the information given is taken from his report. This disease may become a major production problem with geraniums in the southeastern United States. The disease is serious because the same causal bacterium causes leaf spot of chrysanthemum and also attacks other ornamental plants such as *Philodendron panduraeforme*, *Aglaonema*, *Monstera*, *Scindapsus*, *Gerbera*, and larkspur. In addition the bacterium can also infect vegetable crops such as celery, cabbage, broccoli, cauliflower, and endive.

### Symptoms

The symptoms are leaf spots on geranium and vary depending on weather conditions. Plants grown outdoors where they are exposed to rain exhibit dark brown to black, irregularly shaped necrotic areas, 5 to 10 mm or larger. These spots may extend or enlarge along the veins, and coalescing spots may encompass large sections of a leaf. Chlorosis develops in tissues adjacent to the lesions within a few days, and when spots become numerous, general leaf chlorosis occurs. Severely affected leaves become necrotic and may fall off the plant.

Under environmental conditions less favorable for disease development and spread, such as when plants are only exposed to occasional overhead watering, sunken lesions develop on both upper and lower leaf surfaces. These lesions may have slightly raised tan centers surrounded by a dark margin with or without a chlorotic halo. Eventually, most of the leaf spots become dark brown to black. Continued development of symptoms and spread of the disease may stop in dry weather.

The flowers may also become infected, and individual flowers may fail to open when infected in the bud stage. Occasional infection of the flower peduncle occurs, but natural stem infection has not been observed.

### Pathogen

This disease is caused by the bacterium *Pseudomonas cichorii*. The organism has also been called *Phytomonas cichorii* and *Bacterium cichorii*.

### Environmental Relations

Disease development and symptom expression are favored by high humidity and the presence of free water on the foliage. Disease development is rapid on plants grown outdoors and exposed to frequent rains. The disease will also develop in plants grown under cover if they are exposed to overhead watering or dew.

### Control

Control of bacterial leaf spot on geranium is based on starting with plants free of *Pseudomonas cichorii* and excluding the pathogen from the growing area. Strict sanitation procedures must be followed in the geranium production areas. Workers must be careful coming from areas where other susceptible plants are growing because the bacterial pathogen may be carried on clothes, hands, sprayers, and other equipment. Any measures to protect plants from rain or dew and avoidance of overhead watering will aid in controlling the disease, for moisture is necessary for disease development. No effective chemical control is known at this time.

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## Fungus Diseases

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### Botrytis Blight *Botrytis cinerea*

#### Importance

The fungus *Botrytis* is one of the most common and widely distributed pathogens. It can colonize dead organic matter readily and attacks many different plants. Under proper conditions the fungus can attack geranium flowers, leaves, and stems, causing petal blight, leaf spots, and stem cankers. The blighting of flowers and the leaf spots can be a serious problem on plants being finished for sale. In addition, spores may lodge on the surface of stems of stock plants; and when cuttings are taken and stuck in the propagating bench, the spores germinate and cause a basal rot of the cuttings.

#### Symptoms

**Flowers.** Flowers attacked by *Botrytis* exhibit premature fading and drying of the petals. The central florets are often the first to be affected. These flowers turn dark, wilt, and drop prematurely. During periods of high moisture, the affected blossoms may be covered with grayish brown masses of spores, and the florets may be matted together (fig. 15).

**Leaves.** The leaf spot phase of *Botrytis* blight often appears when petals from affected flowers fall on the leaves and the fungus grows into the healthy tissue (fig. 16). Often the leaf spot assumes the outline of the infected flower part that falls on it. When the leaves are wet or the humidity is high, the spots enlarge and become irregular in shape, brown, and water-soaked. If the high humidity continues, the spots become covered with grayish brown masses of spores.

**Cuttings.** Spores on the surface of stems of the stock plant often remain dormant until cuttings are taken and stuck in the propagation bench. During the rooting process, these spores germinate and infect the tissue of the cutting, causing a cutting rot. This rot may be in the form of lesions on the cutting stems (fig. 17) or a complete basal rot of infected cuttings (fig. 18). *Botrytis* cutting rot usually is a light to dark brown rot of the cutting in contrast to the shiny coal black rot caused by *Pythium*.

*Botrytis* spores are very light and can be carried to nearby plants by air currents or



Figure 15. *Botrytis* blight. Geranium flower attacked by *Botrytis* showing the matted, fuzzy growth of the fungus on the petals.

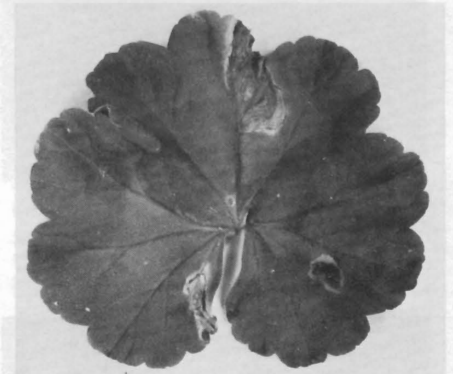


Figure 16. *Botrytis* blight. Leaf spots caused by the fungus *Botrytis*. Notice the rotted flower petals that have initiated the leaf spots.

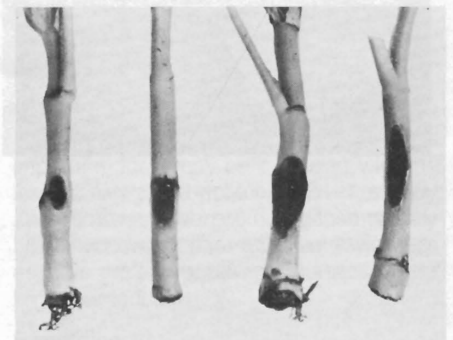


Figure 17. *Botrytis* blight. Lesions on the stems of cuttings caused by *Botrytis*.

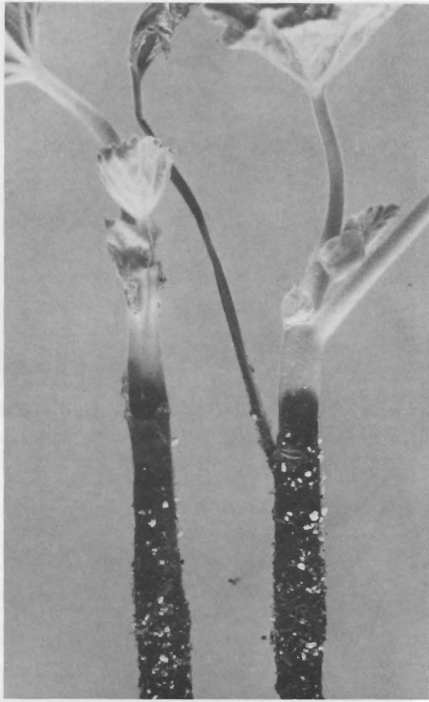


Figure 18. *Botrytis* blight. Stem rot of cuttings caused by *Botrytis*.

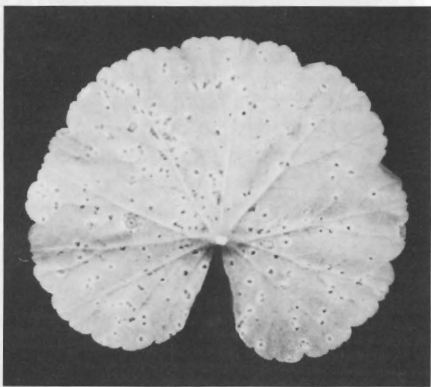


Figure 19. Rust. Yellow spots with rusty brown centers on the lower surface of a geranium leaf. The rusty brown centers are masses of urediospores.

by splashing water. The stubs of the stem left when cuttings are removed often are infected in this manner. Infected cutting stubs exhibit a brown rot that may extend several inches down the stem.

#### Pathogen

*Botrytis* blight is caused by the fungus *Botrytis cinerea*. This fungus is capable of penetrating tissues directly, but penetration is more common when the host plant is grown under unfavorable conditions or if wounds are present. Senescent tissues are penetrated and colonized readily.

#### Environmental Relations

Senescent or dead tissue on the plant and dead organic matter around the areas where geraniums are grown support the growth of *Botrytis* and, hence, add to the potential inoculum. Senescent florets and petals of geraniums are particularly susceptible to attack by this fungus.

*Botrytis* sporulates readily on flowers, leaves, and dead organic material, especially during periods of high humidity. The spores are easily detached and disseminated by air currents or splashing water. Moisture is necessary for germination and penetration, and moisture of condensation is ideal.

Temperatures from 10° C to 21° C (50° F to 70° F) favor disease development, with the optimum temperature occurring at about 18° C (65° F). When large numbers of spores are present, the occurrence of epidemics is favored by high day temperatures, low night temperatures—16° C to 18° C (60° F to 65° F)—and high relative humidities. Under these conditions dew will form on the flowers and leaves.

The size of leaf lesions caused by *Botrytis* and the amount of sporulation on these lesions increase with increasing temperature from 10° C to 25° C (50° F to 76° F). At 30° C (86° F) typical *Botrytis* lesions and sporulation do not occur. There is no significant difference in the size of leaf lesions or in the sporulation on these lesions when produced in light or darkness at 20° C (68° F).

#### Control

Control measures consist of sanitation, the use of fungicides, and the manipulation of the environment. Clean up all plant

refuse in the greenhouse or field that may serve as a good base for sporulation of *Botrytis*. Fungicides applied as sprays or thermal dusts on a regular schedule may prevent colonization of senescent tissue. Systemic fungicides may be helpful in controlling *Botrytis* blight on stock plants and in preventing cutting rot during propagation. Heat and ventilate to prevent dew formation in the greenhouse.

#### Rust

##### *Puccinia pelargonii-zonalis*

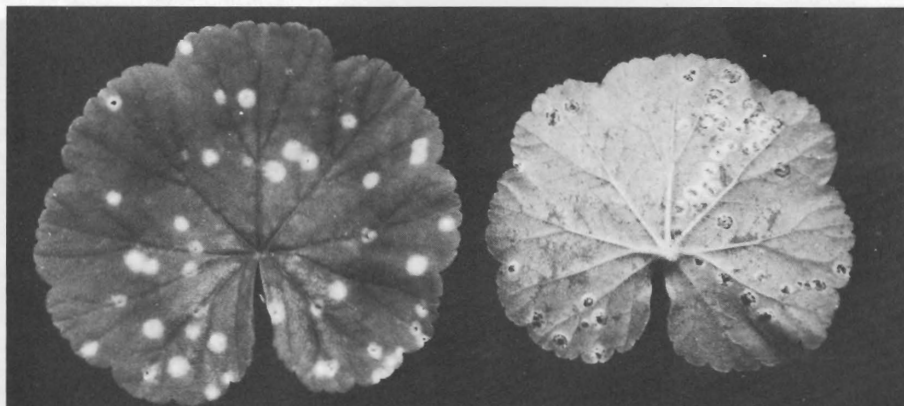
#### Importance

Geranium rust is caused by the fungus *Puccinia pelargonii-zonalis*. The disease was discovered first in South Africa and later spread to Australia, New Zealand, the Hawaiian Islands, and Europe. In Europe the disease has been reported in Britain, Belgium, France, Germany, Italy, and Switzerland. Rust was first reported in the United States in New York State in 1967. Shortly after this discovery the disease was reported from the Monterey Bay area of California. Since that time geranium rust has been found in Pennsylvania, Florida, and Minnesota. This disease is a serious problem for the grower because of the disfiguring of the foliage by the rust pustules. In addition, many states have a quarantine against this disease, which prevents growers from moving or selling their crop until the disease is eradicated.

#### Symptoms

The first symptoms on infected leaves are very small, pale yellow spots, mainly on the undersurface of the leaves. These spots increase in size, reaching a diameter of 5–8 mm, and turn rusty brown, indicating the development of masses of urediospores in uredia in these spots (figs. 19, 20). On the upper leaf surface, the spots are pale yellow, and their size corresponds to the rust spot on the undersurface (fig. 20). Although, occasionally, rust spots with uredia may be seen on the upper leaf surface, the majority are always on the undersurface. Leaves that are heavily infected and contain many rust pustules turn yellow and drop prematurely, leaving the plants partly defoliated. Not only are the brown dusty spots objectionable, but loss of leaves makes the plants unsightly,

Figure 20. Rust. Upper surface of a geranium leaf (left) showing the pale yellow spots that occur above the rust pustules on the lower surface. Lower surface of a geranium leaf (right) showing typical yellow spots with masses of rusty brown urediospores in the center.



reduces their value for customer sales, and may result in serious financial loss for the grower.

#### Pathogen

The disease is caused by the rust fungus *Puccinia pelargonii-zonalis*, which produces only the uredial stage on geranium. The telial stage is rare and apparently has been found only on plants in Switzerland and South Africa. On geraniums grown in the greenhouse, the urediospores serve as repeater spores and perpetuate the disease.

#### Environmental Relations

If a supply of urediospore inoculum is present, infection of susceptible plants may occur readily under environmental conditions that favor the development of free moisture on the plant. Spores of the fungus are effectively spread by splashed water, but they may also be disseminated by air currents. A small source of infection may endanger plants at considerable distances, not just those in the immediate vicinity.

Germination of urediospores of *P. pelargonii-zonalis* requires liquid water and occurs within 3 hours at the optimal temperature of 16° C (60° F). The pathogen usually forms appressoria and penetrates through the stomates 5 to 6 hours after the leaves are inoculated with urediospores. The hyphae are intercellular with intracellular haustoria. Symptom development is most rapid and extensive at 21° C (70° F).

#### Control

When geranium cuttings or plants are purchased, they should be examined carefully for evidence of infection by *P. pelargonii-zonalis*. If evidence of infection, such as a rust pustule, is found, the shipment should be rejected. The reason for such action is that even if only a single plant in a shipment is infected, odds are good that other plants in the shipment have incipient infections that have not yet resulted in the appearance of symptoms.

If rust becomes established on plants in the greenhouse, the disease may be controlled with regular sprays of fungicides. Because the recommendations for fungicides to use for control of this disease vary depending on the locality, consult your local plant pathology extension personnel for current recommendations.

Hot water treatment of geranium cuttings infected with *P. pelargonii-zonalis* may also be a method for eliminating the rust fungus. Experimental tests have shown that rust did not develop on cuttings of *Pelargonium hortorum* infected with the rust fungus after they were dipped for 90 seconds in water at 50° C or 52° C (120° F or 124° F) or were held for 24 or 48 hours in a water-saturated atmosphere at 38° C (100° F). The hot water treatment permitted germination of some urediospores, particularly those taken from poorly growing plants. Hot water treatment damaged the small expanding leaves, but did not retard subsequent plant growth.

Several research workers have tested cultivars of *Pelargonium hortorum* and other *Pelargonium* species for resistance

to rust. McCoy tested 17 *Pelargonium* species and cultivars for susceptibility to the rust fungus *Puccinia pelargonii-zonalis* under controlled-environment conditions. The *Pelargonium hortorum* cultivars Irene, Improved Ricard, Enchantress Fiat, Pink Enchantress Fiat, and Summer Cloud were highly susceptible, with heavy pustule formation occurring within 14 days of inoculation when the inoculated plants were held at 21° C (70° F). *Pelargonium domesticum* 'Graf Zeppelin', *P. radula*, and *P. limoneum* developed heavy flecking and occasionally small pustules within 14 days of inoculation. *Pelargonium domesticum* 'The Princess' and 'Madam Layal', *P. peltatum* 'Etincelant', *P. fulgidum*, *P. monstrum*, *P. torento*, and *P. radens* were highly resistant or immune, producing at most, a moderate fleck after 4 weeks.

Harwood and Raabe tested the *P. hortorum* cultivars Springtime Irene, Dark Red Irene, Irene, Improved Blaze, Salmon Irene, Cardinal, Genie, Snowball, Better Times, Springfield Violet, Fiat Enchantress, Appleblossom, and Penny Irene. All cultivars were susceptible, with Penny Irene and Appleblossom being the most susceptible and Springtime Irene, Dark Red Irene, and Irene, the least susceptible. Species that were tested and found to be susceptible were *P. endlicherianum*, *P. inquinans*, *P. quercifolium*, *P. salmoneum*, *P. tabularae*, and *P. zonale*. Another 29 *Pelargonium* species were tested and found to be resistant.

#### Alternaria Leaf Spot *Alternaria tenuis*

##### Importance

Alternaria leaf spot has been reported to occur in California and Florida in the United States and in some parts of Europe. Although economic losses due to Alternaria leaf spot are minor, the disease is important, for it may be confused with the leaf spot stage of bacterial blight caused by *Xanthomonas pelargonii*, and plants may be unnecessarily rogued because growers assume the leaf spotting is caused by the blight bacterium.

##### Symptoms

Initial symptoms appear as water-soaked areas, less than 1 mm in diameter,

on the lower surface of the leaf. These may enlarge to necrotic areas 2 to 3 mm in diameter with slightly sunken centers, which are less evident on the upper leaf surface. When viewed by transmitted light, these necrotic areas have small brown centers surrounded by a yellow diffuse band, and they may enlarge or remain the same size. Those that enlarge become large, irregular, necrotic areas, 6 to 10 mm in diameter. The fungus may sporulate while the leaves are still on the plant, but the most abundant sporulation occurs on fallen leaves. Often the spots coalesce and form very irregular necrotic spots, usually limited by the large leaf veins. Severe infestations may kill the leaf or cause considerable leaf fall. Dead leaves shrivel and support abundant sporulation by the fungus.

#### Pathogen

This disease is caused by the fungus *Alternaria tenuis*. It produces multicellular, brown, flask-shaped conidia in short chains on conidiophores. The conidia are usually beaked.

#### Environmental Relations

The disease usually occurs when growing conditions are not favorable for good growth of geranium plants. In California these conditions occur during the winter when low night temperatures slow the growth of plants growing outdoors. In addition, the foliage may be wet for long periods of time because of the frequent rains and fogs that prevail during the winter. In contrast, the disease is most common in Florida in warm weather when temperatures are too high for good growth of geraniums, usually in April or later.

#### Control

The disease occurs primarily on field-grown plants and usually is not severe enough to require specific control measures. If it is severe, fungicide sprays should be applied at regular intervals. Consult your local plant pathology extension personnel for current recommendations.

### Blackleg

#### *Pythium* species

##### Importance

Blackleg has been known since the late 1800s and occurs wherever geraniums are grown when environmental conditions favor disease development. Although losses due to this disease do not occur frequently, it is not unusual to find 90 to 100 percent of the cuttings in a propagating bench killed as a result of blackleg. This is primarily a disease of cuttings and young plants. The disease is becoming rare because of the use in propagation of perlite, wood pulp blocks, and expandable peat pellets, all of which are essentially free of *Pythium* species when new. Direct rooting in peat or pots filled with rooting mix and treated with steam in place on the bench also is a factor in reducing disease incidence.

##### Symptoms

The fungus may attack geranium during any stage in the growth of the plant. Cuttings, rooted cuttings, and young plants are particularly susceptible to the disease, whereas older plants are more resistant. Symptoms appear initially at the base of the stem at the soil line. Affected stem tissues turn coal black (fig. 21). The fungus may continue to colonize the stem, and the black rot continues to progress up the stem. The epidermis of the affected tissues remains intact, but is a shiny, black color. Eventually the tops of affected cuttings and plants wilt and die (fig. 22).

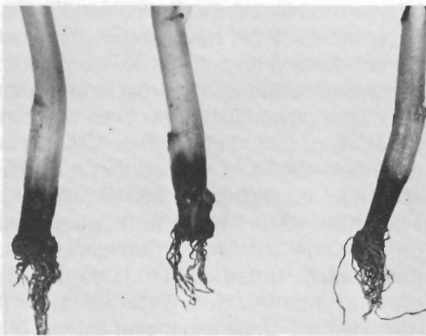


Figure 21. *Pythium* blackleg. Brown to black water-soaked rot at the base of geranium cuttings.

#### Pathogen

This disease is caused by several species of fungi in the genus *Pythium* such as *P. ultimum*, *P. debaryanum*, and *P. irregulare*. These fungi are sometimes called water molds. They are soil inhabitants, occurring in most agricultural soils, and are unspecialized parasites capable of attacking a wide range of host plants.

#### Environmental Relations

In general, *Pythium* blackleg is favored by any factor of the environment not favorable for plant growth. High soil moisture or low oxygen content of the propagation or growing medium is most important. Dissemination of the pathogen occurs by movement of plant debris colonized by the pathogen or in bits of infested soil carried by running water or on tools and growing containers.

#### Control

Control measures involve several steps. Treat the propagation and growing media with steam. In addition, pots, benches, and tools should also be treated with steam. If the pots are to be set on benches containing gravel or cinders, this material should also be treated with steam. Drenches with soil fungicides may be used to prevent the colonization of steam-treated soil by *Pythium* species. These treatments are not a substitute for the original steam treatment. Consult your local plant pathology extension personnel for current recommendations. Destroy all affected plants and crop residue.

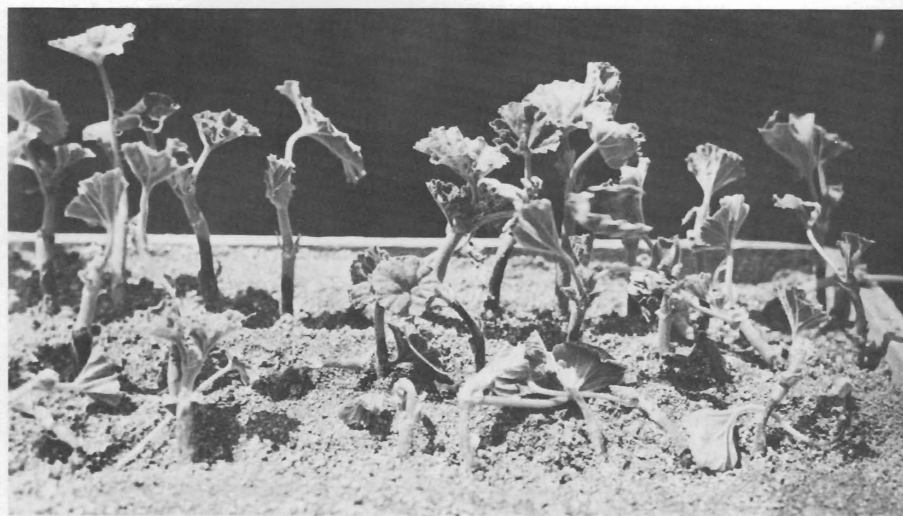
### Cutting Rots

#### *Rhizoctonia* species, *Fusarium* species

##### Importance

Diseases caused by *Rhizoctonia* and *Fusarium* species are of minor importance in the industry as a whole. Individual growers may experience extensive losses from the diseases caused by these organisms. Although cutting rots caused by these fungi have been reported for the past 50 years, these diseases are rarely seen at present.

Figure 22. *Pythium* blackleg. Coal black basal rot of cuttings in a propagation flat. Note the wilting and collapse of affected cuttings.



### Symptoms

Unrooted cuttings infected with either *Fusarium* or *Rhizoctonia* during propagation appear stunted with yellowed, wilted leaves and small new leaves that do not enlarge. Below the soil line, cuttings exhibit an extensive dark black, soft, basal stem rot that frequently involves all of that portion of the cutting below the soil line. On partially rooted cuttings, *Rhizoctonia* causes a basal stem rot that is usually restricted to about 1 cm of the basal portion of the stem. A combination of *Fusarium* and *Rhizoctonia* infecting cuttings results in an increase in the extent of the basal stem rot. Isolates of *Fusarium* species alone cause decay of some roots and browning of the surface of the basal portion of the stem. *Rhizoctonia* may also cause root rot of some of the older roots of fully rooted cuttings.

Several cultivars of seedling geraniums seem to be very susceptible to *Rhizoctonia* root and crown rot. *Rhizoctonia* is often a more severe problem when the crop is subject to a certain amount of stress caused by drought or excess salts. On seedling geraniums *Rhizoctonia* will move up the stem and cause the plant to collapse from the crown upward. The lesions and rotted tissue appear brown, and the brown weblike mycelium of the fungus can often be seen growing on the leaf and lower stem tissue that is rotting.

### Pathogens

*Rhizoctonia solani* is the species most frequently associated with this disease. The imperfect stage produces no spores, and the perfect stage is seldom seen in nature. The fungus is disseminated as vegetative mycelium or as resistant structures capable of surviving long periods when conditions are unfavorable for growth of the fungus. *Rhizoctonia* is a soil inhabitant, capable of colonizing soils in the presence of other organisms, and occurs in most agricultural soils. It is an unspecialized parasite that attacks a wide range of host plants.

*Fusarium* species, such as *F. oxysporum* and *F. solani*, have been implicated as causal organisms in cutting rots. These fungi produce two types of conidia called macroconidia and microconidia. The macroconidia are large multiseptate spores, which are slightly curved and shaped somewhat like the blade of a scythe. Microconidia are small conidia with one or two cells and oval to oblong in shape. These fungi also produce chlamydo spores, which are small, round, thick-walled cells produced in plant tissue and soil and are capable of surviving for long periods of time when the environment is unfavorable for growth and reproduction of the fungus. All types of spores can be disseminated in soil, in plant debris, or by splashing rain and wind.

### Environmental Relations

In general, *Rhizoctonia* and *Fusarium* are most severe in attacks on plants that have been injured or when conditions are unfavorable for growth of the plant. High soil temperatures and low soil moisture are particularly favorable for *Rhizoctonia*.

### Control

Control measures consist of several steps that must be integrated to achieve successful control. These steps follow:

- Steam treatment or chemical fumigation of the propagating medium, growing medium, tools, benches, and containers to eradicate the pathogens.
- Strict sanitation practices to prevent contamination of treated soil.
- Use of soil fungicides to prevent colonization of treated media, should contamination occur. Contact your local plant pathology extension personnel for current recommendations.

### Thielaviopsis Root Rot *Thielaviopsis basicola*

#### Importance

Thielaviopsis root rot, or black root rot, may occur on geranium and many other plants such as poinsettia, cyclamen, begonia, tobacco, cotton, and bean. This disease is not common on geranium, but it does occur in several eastern states where geraniums are grown. The incidence of Thielaviopsis root rot on geranium is often high when geraniums are grown in greenhouses after poinsettias, for the fungus occurs on both hosts and is carried over in the soil as chlamydo spores. In general, this disease is of minor importance in the production of geranium.

#### Symptoms

Infected plants are slow growing and stunted, and the lower leaves may turn yellow and drop. Roots of plants showing these foliar symptoms have dark brown to black lesions. Unrooted cuttings planted in soil infested with the Thielaviopsis root rot fungus exhibit delayed or reduced rooting, or rooting is prevented completely. The base of the new cutting is susceptible for only 1 to 2 weeks and becomes highly resistant or immune following this period.



Figure 23. *Verticillium* wilt. Leaf from infected geranium plant, cultivar Springfield White, showing wilting and yellowing, one of the early symptoms of this disease.



Figure 24. *Verticillium* wilt. Cultivar Springfield White with healthy plant (right) and infected plant (left) showing extensive defoliation of the infected plant.

### Pathogen

This disease is caused by the fungus *Thielaviopsis basicola*. This fungus produces single-celled hyaline endoconidia. Black, thick-walled chlamydospores are also formed in root lesions on infected plants. The pathogen has a limited distribution in agricultural soils; but once it is introduced, it may persist for long periods of time in the absence of a susceptible plant by means of chlamydospores.

### Environmental Relations

*Thielaviopsis basicola* is probably a facultative parasite and requires some predisposing factor to allow it to invade geranium roots and cause typical root lesions and foliar symptoms. If cuttings become infected in the propagating bench, a rot of the cut end may occur. More important, though rooting is reduced, many infected cuttings will root without showing any symptoms. Later, during production, root growth on these plants is poor and the plants are stunted.

### Control

Control measures consist of steam treatment of the propagation medium, the potting medium, pots, production bench, and tools. Strict sanitation measures must be followed to prevent infestation of steam-treated media.

### Verticillium Wilt *Verticillium albo-atrum*

#### Importance

The *Verticillium* wilt disease occurs on many crops and may be a problem on greenhouse-grown crops such as geranium, chrysanthemum, rose, and snapdragon. This disease may also occur on geraniums and other crops grown outdoors. The pathogen attacks both *Pelargonium hortorum* and *P. domesticum*, and the disease has been reported to occur in New York, California, and Oregon. Recently the disease has been observed primarily on *P. domesticum*.

#### Symptoms

The first symptoms of the disease on *P. hortorum* consist of the collapse of a few leaves in the middle or upper portion of the main stem or side branches of the plant. At

first the petioles of the affected leaves remain turgid, but after a day or two wedge-shaped areas on affected leaves turn yellow, or the entire leaf may turn yellow, and the petioles wilt (fig. 23). This is followed by a gradual drying of the affected leaves and petioles, resulting in leaf drop. As the disease progresses, more leaves collapse, yellow, dry up, and drop, resulting in the defoliation of the affected area of the plant (fig. 24). The growth of affected plants may also be stunted. The progress of the disease varies from plant to plant. In cases where progress is rapid, the plant soon loses most of its leaves, and the remaining, unwilted leaves are pale green and may show interveinal yellowing, which looks very much like a nutrient deficiency or a virus disease symptom. In the final stages, an affected plant may show dieback or drying of the tips of branches and brown to black discoloration of the main stem and branches (fig. 25). These stem areas are completely discolored in cross section, but above the externally discolored area the browning is limited to the vascular tissue.

In some cases an infected plant may not show symptoms for weeks or even months. But after this period of time, the entire plant may suddenly collapse (fig. 26). Shortly thereafter, the plant will die.

Symptoms of *Verticillium* wilt on *P. domesticum* are much the same as those on *P. hortorum*, except that the wilting and collapse of leaves do not occur as readily (fig. 27). Affected leaves turn yellow, but often do not wilt for several days. With some cultivars the defoliation is not severe, but the stunting of infected plants is often pronounced.

The *P. hortorum* cultivars Better Times, Olympic Red, Ricard, Wendy Ann, Diddon's Improved Picardy, Springfield White, Radio Red, Penny, Genie, Irene, and Dark Irene have been inoculated with *V. albo-atrum*, and all cultivars were found to be susceptible. The *P. domesticum* cultivars The Princess, Marie Vogel, Graf Zeppelin, and Mrs. Loyal were also tested, and all found to be susceptible to attack by the fungus.

The symptoms of *Verticillium* wilt and the stem rot phase of bacterial stem rot and leaf spot are similar in many respects. The early symptoms of both diseases are wilting of leaves, followed by defoliation,



## Virus Diseases



Figure 25. *Verticillium* wilt. Infected plant of cultivar Springfield White showing severe symptoms. Notice the brown to black discolored areas on the branches.



Figure 26. *Verticillium* wilt. Plant of cultivar Irene showing a healthy plant (right) and an infected plant (left). Note the collapse of all the foliage on the infected plant.

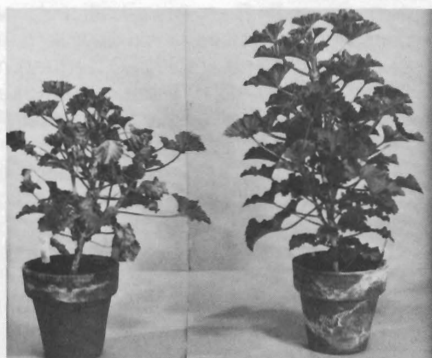


Figure 27. *Verticillium* wilt. Healthy plant (right) and infected plant (left) of *Pelargonium domesticum* showing stunting of the infected plant.

dieback of branch tips, and brown to black discoloration of the main stem and branches. It is possible that plants infected with *V. albo-atrum* have been mistakenly diagnosed as cases of bacterial stem rot and vice versa. It is also possible that one plant could be infected by both organisms at the same time. The only way to make a positive diagnosis is by making a culture from the plant in question.

### Pathogen

This disease is caused by the fungus *Verticillium albo-atrum*, which produces large numbers of single-celled hyaline conidia on verticillately branched conidiophores. The conidia are short lived and are seldom seen in nature on infected plants. The fungus also produces microsclerotia, which are long-lived resistant structures capable of carrying the fungus over long periods of time when environmental conditions are unfavorable for growth and reproduction. Under some conditions microsclerotia have survived 14 years in the absence of a suitable host. In addition to survival by means of microsclerotia, the fungus may also survive on infected, symptomless weed hosts. One such weed host is *Solanum sarachoides*, a nightshade weed. Infected nightshade plants, despite extensive infection of the xylem by the fungus, are symptomless, except for occasional reddish brown vascular discoloration in older plants.

### Environmental Relations

The fungus *Verticillium albo-atrum* can be spread in infested soil and in symptomless but infected cuttings. The pathogen can survive in soil for long periods of time in the absence of a suitable host. Therefore, treatment of propagating media and potting media is necessary for disease control.

### Control

The control of this disease involves several steps. First, all propagation and growing media should be treated with steam. In addition, the containers, production benches, tools, and the like used in geranium production should also be treated with steam. Second, careful sanitation should be practiced to prevent contamination of steam-treated media.

Third, only cuttings derived from carefully maintained culture-indexed stock should be used in geranium production.

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## Virus Diseases

The economic significance of virus diseases affecting commercial geraniums has been difficult to assess. None of the 12 known viruses affecting geraniums will alone kill a plant. Viruses may cause slower rooting, fewer flowers, poor production, nonuniformity, and unsightly appearance. The assessment of the economic importance of geranium virus diseases is complicated by the fact that many commercial cultivars are virus infected and also that symptoms may be relatively mild or not apparent under certain environmental conditions. Most commercial production of geraniums has been primarily accomplished by vegetative propagation, which perpetuates the spread of virus. There has been increased interest in the commercial use of seedling geraniums. Because viruses are not generally transmitted through seed, it has been assumed that virus problems could be avoided by this means of propagation; but it is now known that some viruses that affect geraniums are seed transmitted.

Heat therapy and meristem tip culture have been used to remove viruses from vegetatively propagated crops including many ornamentals. These procedures have been applied by a limited number of major suppliers of commercial geraniums. The establishment of geranium propagating material free of specific viruses is based on the ability to index for viruses and the development of a suitable medium to regenerate shoots and roots from meristematic tips, as well as adequate survival of heat-treated geraniums before meristematic tip culture. Such procedures are now available for geranium certification programs. Certification programs are described under "General Control Measures." Although most of the described viruses occur in low concentrations in pelargonium and may be difficult to isolate and identify in this host, all can be cultured in *Nicotiana clevelandii*, and most can then be assayed in *Chenopodium quinoa*. Table 1 summarizes symptoms on geranium and indicator plants for viruses affecting geranium.

### Tobacco Ringspot Virus

#### Importance

Tobacco ringspot virus (TRSV) was first reported by Kemp on geranium in 1967 in Ontario, Canada. The virus is transmitted by the nematode *Xiphinema americanum*. Seed transmission is characteristic of most nematode-borne viruses, and TRSV is known to be transmitted in seeds of soybean, petunia, and *Gomphrena globosa* and to the seed of geranium through the maternal tissue, but not by the pollen.

#### Symptoms

Symptoms on the foliage may consist of various combinations of vein yellowing and yellow to necrotic spots, rings, and line patterns (fig. 28). Symptoms are usually masked at temperatures of 16°-18° C

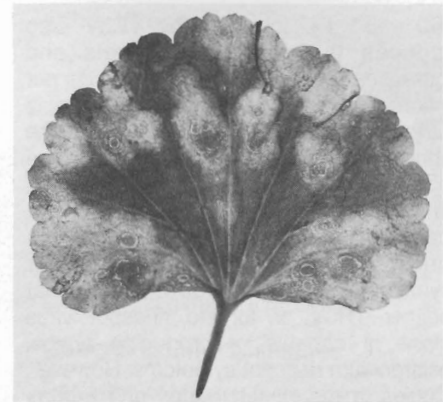


Figure 28. Tobacco and tomato ringspot. Yellow rings and spots on leaves of geranium caused by tobacco ringspot and tomato ringspot viruses.

Table 1. Symptoms on geranium and indicators for viruses affecting geraniums

Virus	Major symptoms	Indicator species*
Tobacco ringspot, Tomato ringspot, Pelargonium ringspot	Yellow to necrotic spots, rings, and line patterns on leaves	2-5
Pelargonium ring pattern	Yellow ringspots on mature leaves of <i>P. zonale</i>	2,4
Pelargonium line pattern	Yellow to green spots and line patterns along veins on leaves	2,4
Pelargonium leaf curl	Yellow and brown asteroid spots on leaves; leaf distortion	4
Cucumber mosaic	Purple spotting along the veins of leaves; yellow mottling, vein clearing, vein banding on leaves	2,5
Pelargonium flower break	Color streaking on flowers	2,4
Tobacco mosaic	Not established	1,5,7
Tobacco rattle	Not established	1,3-5,7,8
Tomato black ring	Not established	1-3,5-7
Arabis mosaic	Not established	1-3,5-7
Not established	Yellow vein clearing on leaves (yellow net vein)	9

\*1. *Chenopodium amaranticolor* (goosefoot)  
2. *C. quinoa*  
3. *Cucumis sativus* (cucumber)  
4. *Nicotiana clevelandii*  
5. *N. tabacum* (tobacco)

6. *Petunia* hybrids (petunia)  
7. *Phaseolus vulgaris* (bean)  
8. *Vigna sinensis* (cowpea)  
9. Susceptible geranium cultivars

(60°–65° F). Infection by TRSV also reduces the number of florets and increases the number of aborted buds per inflorescence. In England the disease is called pelargonium ringspot. During the spring clear ringspot symptoms can be observed in *P. peltatum* and a line pattern in *P. zonale*. Pelargonium ringspot is a catchall name for diseases caused by the ringspot viruses resulting in similar symptoms. Stone in 1980 indicated that neither TRSV or tomato ringspot virus alone is capable of producing typical pelargonium ringspot symptoms. However, studies in the United States and Europe reveal that those viruses independently can produce symptoms.

### Tomato Ringspot Virus

#### Importance

Tomato ringspot virus (TomRSV) was first reported by Kemp on geranium in 1969 in Ontario, Canada. The virus is transmitted by the nematode *Xiphinema americanum*. TomRSV is transmitted in seeds of soybean, red clover, strawberry, and raspberry and to the seed of geranium through the maternal tissue and pollen.

#### Symptoms

Symptoms on the foliage associated with TomRSV infections are similar to those described for infections with TRSV (fig. 28). Florets of geraniums infected with TomRSV contain more aborted anthers and a greater percentage of nonviable pollen grains than do florets of TRSV-infected plants. Furthermore, plants infected with TomRSV, when self-pollinated, produce fewer fruit per pollination, seed per pollination, and viable seed than healthy self-pollinated plants.

### Pelargonium Leaf Curl

#### Importance

Pelargonium leaf curl (PLCV) has also been called crinkle. PLCV was first described in the United States by Jones in 1940 and later in England by Hollings in 1962. When this disease was first reported and characterized, it was frequently found in pelargonium; but in recent years it has not been frequently observed. This may be associated with the availability of virus-

indexed geraniums and the efforts of growers to maintain geranium stock in glasshouses where disease and pest control is more readily attained. The relationship of PLCV to petunia asteroid virus would indicate that this virus is probably soilborne. Although the vector has not been identified, it is thought to be transmitted by a fungus.

#### Symptoms

The symptoms of PLCV are distinctly different from other geranium virus diseases. Yellow stellate spots develop only during the winter months. These spots become necrotic with age, distortion and a crinkled appearance occurring as the leaves expand. PLCV is readily isolated and sap transmissible from leaves showing symptoms, but is difficult to detect in symptomless leaves, especially during summer months. PLCV induces distinct symptoms in *N. clevelandii* inoculated with juice from infected geraniums.

### Pelargonium Ring Pattern

Pelargonium ring pattern virus (PRPV) has been confused with pelargonium ringspot caused by TRSV and TomRSV, but is now known to be a distinctly different virus. PRPV does not infect *P. peltatum*, and thus, it differs from TRSV and TomRSV. True ring patterns are produced in *P. zonale*, and it is fairly common in older cultivars. It has sometimes been isolated from recently introduced seedlings. Symptoms appear as yellow ringspots in the older leaves of plants 10 to 12 months after infection. No vector is presently known for this virus.

### Pelargonium Line Pattern

Pelargonium line pattern virus (PLPV) was first described in England by Hollings and Stone in 1976 and 1977 and in Yugoslavia by Plese and Stefanac in 1980. PLPV has been characterized as distinctly different from PRPV, TRSV, TomRSV, and flower break virus. Symptoms do not develop in pelargonium until 18 months after infection and usually develop during winter months. Leaves of infected plants exhibit yellow to green spots and line patterns, particularly along veins.

### Pelargonium Flower Break

Pelargonium flower break virus (PFBV) has been reported to cause disease in rare instances and is, therefore, thought to be of little importance to commercial geranium production. PFBV is serologically different from all other viruses known to infect geraniums. The virus is difficult to detect in infected cultivars, and most cultivars are symptomless after infection. Attempts to infect *P. peltatum* have been unsuccessful. Susceptible cultivars show flower color breaking, which appears as light-colored streaks in petals. Growth is retarded, flowers are smaller, and rugose petals have been observed.

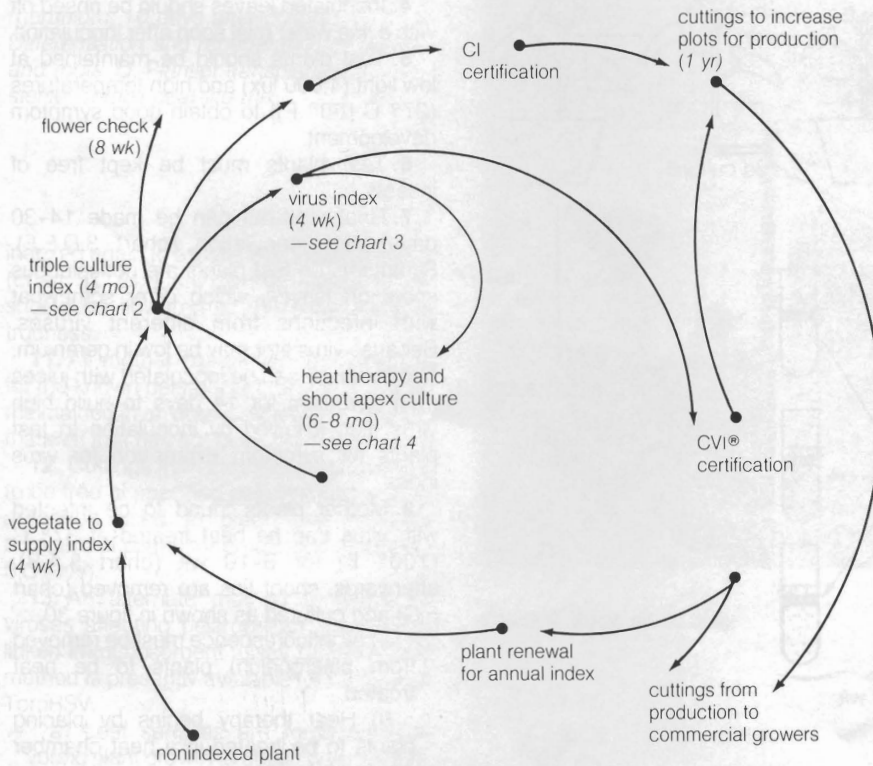
### Pelargonium Mosaic

Pelargonium mosaic is sometimes called leaf break. Mosaic has been reported in the United States and Denmark. Cucumber mosaic virus (CMV) is thought to be the cause of mosaic and leaf break. Mosaic-like symptoms include chlorotic mottling, vein clearing, and vein banding in younger and partly in older leaves of geranium infected with CMV; CMV failed to induce such symptoms in *P. peltatum* and *P. zonale* in England, but appeared to enhance symptoms of infections with other viruses. In leaf break symptoms CMV interferes with anthocyanin formation resulting in replacement of the normal leaf zone with purple spotting along veins. There is no reduction in leaf size or distortion. Symptom development is seasonal with a masking of symptoms during the summer.

### Yellow Net Vein

Yellow net vein is suspected to be caused by a virus, but none has yet been identified. The symptoms are distinctive and considered beautifully ornamental by some. Veins on both young and old leaves are yellow throughout the year (fig. 29). The remainder of the affected plants appear to be normal. Sometimes affected plants exhibit a faded yellowing of leaf veins. Manganese deficiency may cause similar symptoms.

**Chart 1. Diagram for control of viruses and wilt pathogens in pelargoniums**



**Other Viruses**

Several other viruses have been reported to occur in geranium and include tobacco mosaic, arabis mosaic, tobacco rattle, tomato black ring, an unidentified bacilliform, and an unidentified isometric virus. It is unclear whether these viruses incite specific diseases with which specific symptoms can be associated and whether they are economically important to commercial geranium production.

**General Control Measures**

**Detection of Viruses by Indexing**

Plants of any pelargonium cultivar can be freed of viruses known to infect them by heat treatment and meristem tip culture procedures diagrammed in chart 5. The manner in which virus-indexing (charts 3 and 4) fits into a complete program, which includes culture-indexing (chart 2) to remove vascular pathogens, as well as heat therapy and shoot-tip culture to free pelargoniums from known viruses, is illustrated in chart 1. The time required for following this program to completion to obtain either culture-indexed (CI) certification or culture-indexed-virus-indexed (CVI)<sup>R</sup> certification is indicated in the diagram as well as the complexity of such a program.

A detailed description of virus-indexing follows:

**1.** Leaf samples are removed from young plant growth to obtain pelargonium sap for testing for viruses known to infect pelargonium (charts 3,C; 4,C). The sap is rubbed on *Chenopodium quinoa*, *Gomphrena globosa*, *Vigna sinensis* cv. Big Boy and *Cucumis sativus* cv. Chicago Pickling, which are used as test plants.

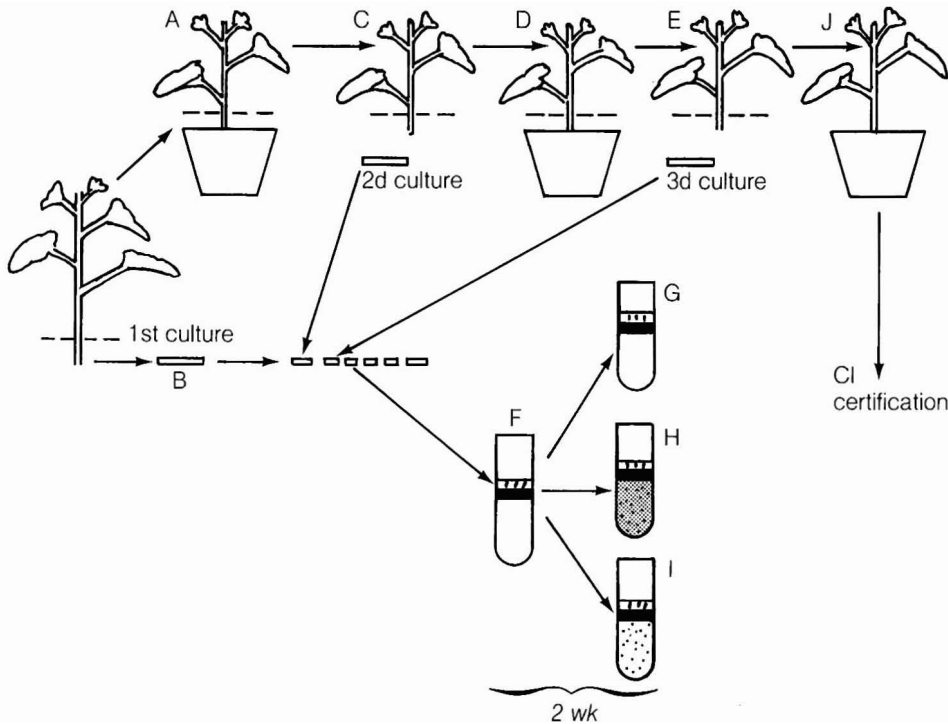
**2.** One gram of leaf samples is ground in phosphate buffer (0.05-0.33 M) at pH 7-7.2 containing 3-4% polyethylene glycol MW 6,000 (PEG).

**3.** A fine carborundum powder is dusted on young test plant leaves, and the pelargonium sap is rubbed on the leaves. Hands must be washed before inoculating each plant, or care must be exercised by using tissue paper to handle leaves during inoculation (which can be discarded after

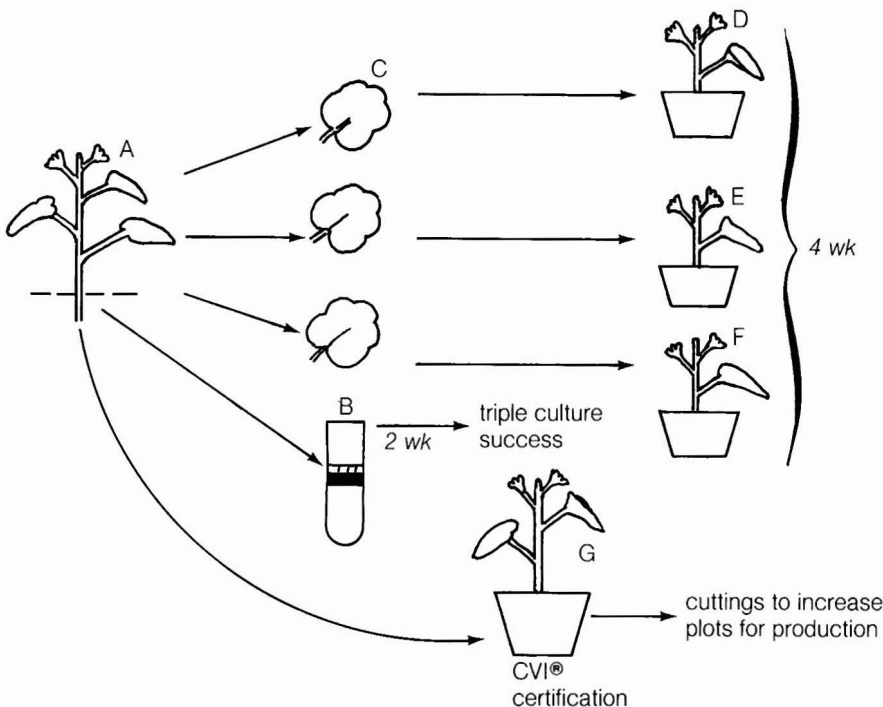


*Figure 29. Yellow net vein. Prominent yellowing of veins of geranium leaf, which is thought to be caused by a virus not yet identified.*

**Chart 2. Culture index**



**Chart 3. Virus bioassay**



each inoculation) to prevent viral contamination from plant to plant.

4. Inoculated leaves should be rinsed off with a fine water mist soon after inoculation.

5. Test plants should be maintained at low light (4,000 lux) and high temperatures (27° C [80° F]) to obtain good symptom development.

6. Test plants must be kept free of insects.

7. Final read-out can be made 14-30 days after inoculation (chart 3,D,E,F). Symptoms on test plants are conspicuous spots on leaves, which differ somewhat with infections from different viruses. Because virus titer may be low in geranium, *N. clevelandii* can be inoculated with juices from geranium for 14 days to build high virus titer, followed by inoculation to test plants for symptom expression for virus index.

8. Mother plants found to be infected with virus can be heat treated at 37° C (100° F) for 8-10 wk (chart 5,A,B); afterwards, shoot tips are removed (chart 5,C) and cultured as shown in figure 30.

a) All influorescence must be removed from pelargonium plants to be heat treated.

b) Heat therapy begins by placing plants to be treated in a heat chamber with a 16-hr photoperiod.

c) The initial temperature should be 24° C (75° F) day and 21° C (70° F) night.

d) A 3° C (5° F) day/night differential being maintained, the temperature within the chamber should be raised 3° C (5° F) daily until a final setting of 38° C (100° F) day and 35° C (95° F) night is obtained.

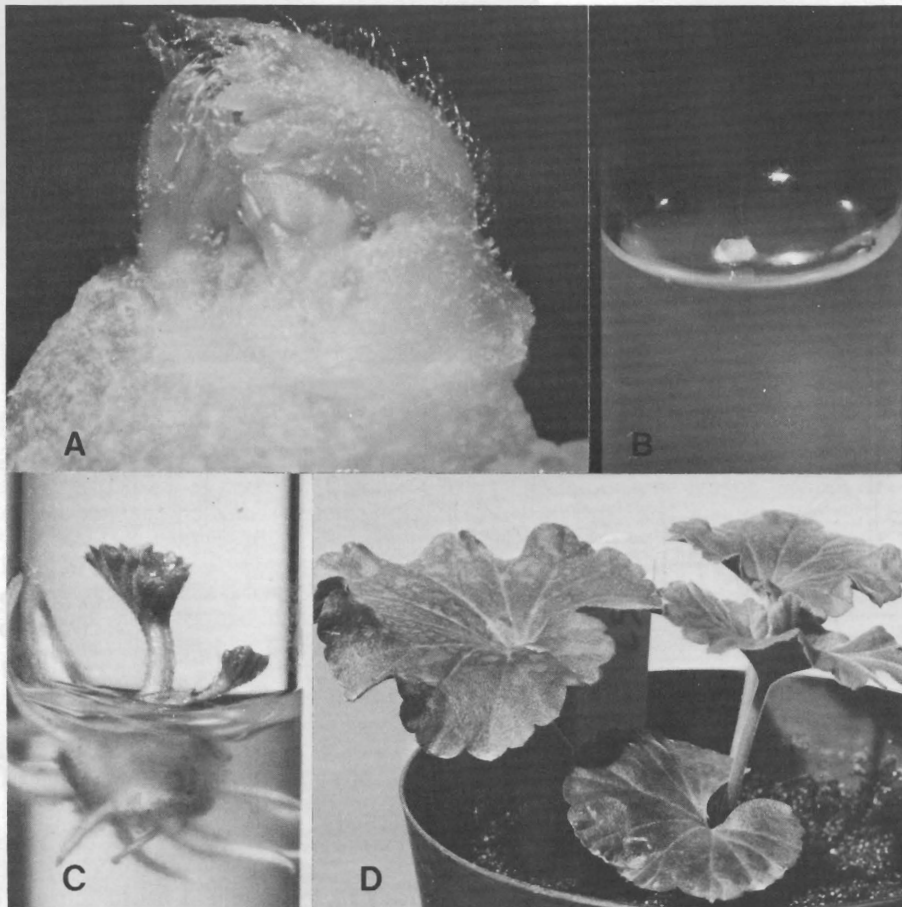
e) Plants are maintained under these conditions until either 4 weeks of heat therapy has been achieved or serious plant deterioration occurs.

f) Shoot tips (0.5-1.0 mm) are removed from the plants at this time.

9. Shoot tips are removed with the aid of a stereomicroscope (15x-40x) and sterile tools and placed on a defined nutrient culture medium.

10. By removing a shoot tip and growing a plant from this as shown in figure 30, one can obtain plants free of viruses that affect pelargoniums and are tested in the indexing system. Plants must be virus-

Figure 30. *Geranium* meristem tip culture. A, Meristem tip with leaf initials (*geranium* X30). B, Proliferation before differentiation (*geranium*, 10 days after culture). C, Differentiation and regeneration of shoots and roots. D, Plantlet transplanted to sterile Cornell peat-lite mix.



indexed again to assure that they are clean (chart 5,D,E). Cuttings from these plants should be flowered to determine cultivar trueness.

11. All mother plants that test negative for the known pelargonium viruses must be maintained in an area isolated from all plant material that has not been virus-indexed.

12. Cuttings from mother plants certified to be free of specified pelargonium viruses are then used to plant and increase numbers of plants for production (charts 1; 3,G; 4,H).

13. An alternate method to index for viruses affecting pelargonium is enzyme-linked immunosorbent assay (ELISA). This method is presently available for TRSV and TomRSV.

a) Leaf samples are removed from young plant growth to obtain pelargonium sap for ELISA (chart 4,C).

b) Virus specific antibody is adsorbed to ELISA plates (chart 4,D).

c) Pelargonium sap containing possible virus is added (chart 4,E).

d) Enzyme-labeled specific antibody is added (chart 4,F).

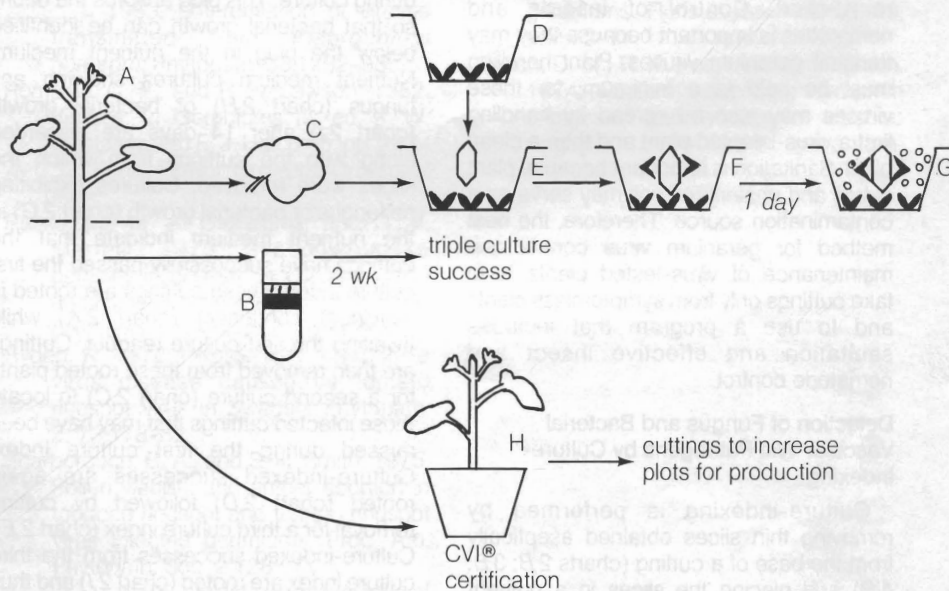
e) Finally, enzyme substrate is added (chart 4,G).

f) Virus presence is determined by color formation resulting from hydrolyzation of enzyme substrate.

All procedures that involve handling of cuttings from CI- and VI-certified plants must be done in a manner to avoid juice contamination. Tissue paper shields, sterile forceps, and (or) sterile razor blades can be used to take these cuttings. Forceps, razor blades, or knives can be sterilized by dipping in alcohol and flaming before each cut.

Obvious improvement in geranium flower production is shown in figure 31 of plants that have been VI certified.

Chart 4. Virus seroassay



D = antibody adsorbed to plate

E = test sample (pelargonium sap) added containing possible virus

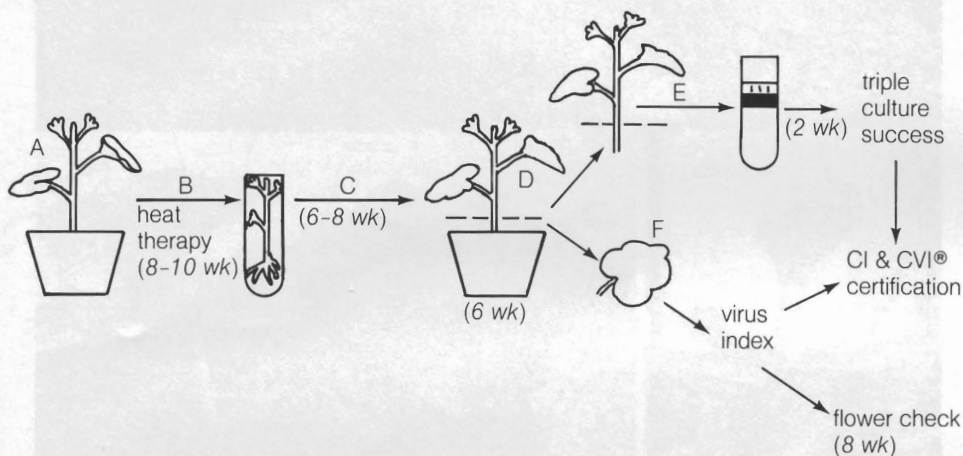
F = enzyme-labeled specific antibody added

G = enzyme substrate added; color intensity indicates virus titer



Figure 31. Comparative meristem tip cultured and nonmeristem tip cultured geraniums. Cultivar Wendy Ann on the left was grown from meristem tip cultured tissue and exhibits increased vigor and earlier flowering compared with the Wendy Ann on the right, which was derived from nonmeristem tip cultured tissue. The plants are the same age from the time of rooting.

Chart 5. Heat therapy and shoot tip culture



#### Maintenance of Virus-Tested Plants

Plant material that has been freed of specific viruses is not immune. Good management is required to prevent reinfection. Control of insects and nematodes is important because they may transmit geranium viruses. Plant handling must be held to a minimum, for these viruses may also be spread by handling first a virus-infected plant and then a clean plant. Sanitation is important because plant debris and unsterilized soil may serve as a contamination source. Therefore, the best method for geranium virus control and maintenance of virus-tested plants is to take cuttings only from symptomless plants and to use a program that includes sanitation and effective insect and nematode control.

#### Detection of Fungus and Bacterial Vascular Wilt Pathogens by Culture-Indexing

Culture-indexing is performed by removing thin slices obtained aseptically from the base of a cutting (charts 2,B; 3,B; 4,B) and placing the slices in a nutrient medium such as a nutrient broth supplemented with dextrose (chart 2,F). Slices from pelargonium often have debris associated with them that can be confused with bacterial growth in the culture

medium; therefore, it is helpful to place a portion of a sponge-rubber test-tube plug in the medium to which the slices are placed during culture. This plug absorbs the debris so that bacterial growth can be identified below the plug in the nutrient medium. Nutrient medium cultures showing any fungus (chart 2,H) or bacterial growth (chart 2,I) after 14 days are discarded along with the cuttings from which the slices were removed. Cultures exhibiting no fungus or bacterial growth (chart 2,G) in the nutrient medium indicate that the cuttings have successfully passed the first culture index. These cuttings are rooted in individual containers (chart 2,A) while awaiting the first culture readout. Cuttings are then removed from these rooted plants for a second culture (chart 2,C) to locate those infected cuttings that may have been missed during the first culture index. Culture-indexed successes are again rooted (chart 2,D) followed by cutting removal for a third culture index (chart 2,E). Culture-indexed successes from the third culture index are rooted (chart 2,I) and thus become the CI-certified mother plants.

The culture-index procedure is done before heat therapy, for plants infected with *X. pelargonii* (bacterial vascular wilt pathogen) will not survive heat treatment.

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## Nonparasitic Diseases

### Edema

Symptoms of edema appear on the lower leaf surface, on petioles and stems as tiny pimblelike blisters (fig. 32). Later these blisters enlarge and become brown and corky (fig. 33). Affected leaves may yellow and drop off.

Edema is a nonparasitic condition that often develops during periods of cloudy, cool weather. The occurrence of this condition is thought to result from an imbalance of water uptake and water loss by plants. A high level of water absorption by the roots and a low level of water loss by the leaves result in excessive water retention in the cells of the leaves, petioles, and stems. Because of this, some cells burst and form watery blisters, which later become dry and corky (fig. 33).

Edema is most likely to develop when the soil is moist and warm and the air is moist and cool. Such environmental conditions around the plants result in rapid water absorption from the soil and slow water loss from the leaves, producing the symptoms described.

The Irene cultivars of *Pelargonium hortorum* and *P. peltatum*, the ivy geranium, are especially susceptible to edema.

Control of this condition is difficult, but the following steps will help to minimize the occurrence of edema:

- Space the plants to allow good air circulation.
- Do not overwater plants. This is especially critical during periods of cloudy cool weather. Water in the morning so that the growing medium is not too wet overnight.
- Avoid wetting the leaves because this will retard transpiration and favor excessive water retention.

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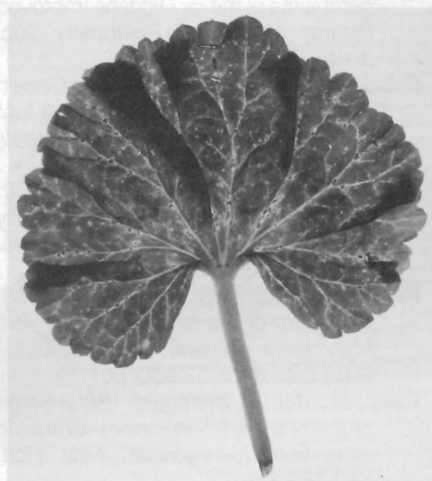


Figure 32. Edema. Early stage showing small watersoaked and pimblelike blisters on the lower leaf surface of geranium.



Figure 33. Edema. Brown corky blisters on the lower leaf surface of geranium.

## Fungicides

The control of plant pathogenic microorganisms by fungicides involves protection and therapy. Treatment with fungicides before the pathogen infects the plant is protection, and treatment with fungicides after the plant is infected is therapy.

Protection involves killing the pathogen or limiting its growth before it attacks the plant; this can be accomplished in two different ways. In the first case, the fungicide can be applied to the pathogen after it is in contact with the host plant as a contact fungicide. In the second case, the fungicide can be applied to the host plant before the pathogen is on the plant as a residual fungicide. The production of geraniums may involve the use of contact fungicides, but primarily involves the use of residual fungicides because attempting to destroy the pathogen after it has been deposited on the plant is too risky under the intense growing conditions of the greenhouse or field. For this reason most fungicides used in the production of geraniums are the residual type of protective fungicide. A good residual protective fungicide has the following characteristics:

- Remains active for a relatively long period of time. To apply a fungicide every day to maintain the necessary toxicity level around the clock would be nearly impossible and too expensive if it were possible.
- Has good adhesive properties. Because the dissemination of most pathogens is favored by rainy weather, the fungicide must resist the erosive action of water.
- Has good spreading properties. Because it is necessary to completely protect leaf and stem surfaces, the fungicide should spread evenly over the surface of the leaf. This is usually accomplished by adding a wetting agent to reduce surface tension. If too much wetting agent is added to a formulation, runoff may occur, resulting in lower concentrations of fungicide than required. Wetting agents also facilitate penetration of fungicides into leaves or stems; if too much is used, phytotoxicity may occur.
- Is stable against oxidation in sunlight.
- Is toxic to plant pathogenic microorganisms, but nontoxic to the plant.

● Is active against a wide range of pathogenic microorganisms. Actually, most of the presently available fungicides are rather specific. Thus, a particular fungicide must be selected for control of a particular disease. Frequently, spray programs are devised involving the use of more than one fungicide, either as combination sprays or in alternate applications. Formulations of two or more fungicides in a single package are marketed for use in the home garden.

Many different types of protective fungicides are in use today. The following discussion is limited to those chemicals of demonstrated effectiveness and to those presently in general use for control of geranium diseases.

### Organic Chemicals

Organic chemicals were not commonly used until after World War II. Although they are, in general, more specific than the earlier inorganic fungicides, the level of control they afford is much higher. The carbamates were the first organic chemicals to be commonly used. The first carbamate, tetramethylthiuram disulfide (thiram), was developed by the rubber industry as a more-efficient sulfur compound for vulcanizing. Although its fungicidal properties were demonstrated in 1934, not until 1940 did it come into general use, and it was used as a base for developing other fungicidal compounds. Because the carbamates controlled many foliar diseases that could not be controlled with the existing fungicides, they are said to have revolutionized fungicidal control of plant diseases. Some carbamates in general use today are listed in table 2.

Other organic fungicides of importance to the ornamentals industry are benomyl (Benlate), captan, Daconil, and folpet (Phaltan) (table 3). These are all fungicides with broad-spectrum activity, used for the control of foliar and flower diseases. Karathane and Pipron (table 3) are specific fungicides for control of powdery mildews.

### Antibiotics

Antibiotics are chemicals derived from the metabolic products of microorganisms. Penicillin was one of the first to be discovered. Although it has not been effective against plant pathogens, other

Table 2. The dithiocarbamates, listed by chemical, accepted common and trade names, and their most effective uses

<i>Accepted common name</i>	<i>Trade names</i>	<i>Chemical name</i>	<i>General use</i>
ferbam	Fermate, Carbamate	ferric dimethyl dithiocarbamate	Foliar diseases
zineb	Dithane Z-78, Parzate	zinc ethylene bisdithiocarbamate	Foliar and flower diseases, rusts
maneb	Dithane M-22, Manzate	manganese ethylene bisdithiocarbamate	Foliar disease
maneb + zinc	Manzate D, Dithane M-22-Special	manganese ethylene bisdithiocarbamate plus zinc sulfate	Foliar diseases
mancozeb	Manzate 200, Dithane M-45, Fore	zinc ion-maneb coordination product	Foliar diseases
ziram	Zerlate	zinc dimethyldithiocarbamate	Foliar diseases
metiram	Polyram	zinc ethylene bisdithiocarbamate complex	Foliar diseases

Table 3. Some fungicides other than carbamates

<i>Accepted common name</i>	<i>Trade names</i>	<i>Chemical name</i>	<i>General use</i>
cyclohexamide	Actidione PM	3-{2-(3,5-dimethyl-2-oxocyclohexy)-2-hydroxyethyl} glutarimide	Powdery mildew
benomyl	Benlate	{Methyl 1-(butylcarbamoyl)-2-benzimidazole-carbamate}	Leaf spots, powdery mildew, root and crown rots, and soil drenches
captan	Captan, Orthocide	N-((trichloromethyl) thio)-4-cyclohexene-1,2-dicarboximide	General foliar diseases
chlorothalonil	Daconil 2787, Bravo 75, Exotherm Termil, Termil	Tetrachloroisophthalonitrile	Foliar and flower blights
folpet	Phaltan	N-(trichloromethyl-thio) phthalimide	Foliar diseases
dinocap	Karathane WD, Mildex	Mixture of 2-(1-Methylheptyl)-4,6-dinitrophenol and 2-(1-Methylheptyl)-4,6-dinitrophenyl crotonate	Powdery mildew
piperalin	Pipron	3-(2-methylpiperidino) propyl 3,4-dichlorobenzoate	Powdery mildew

antibiotics are active against both plant pathogenic fungi and bacteria. Actidione, used for control of powdery mildew, is an example of an antibiotic chemical.

### Thermal Dusts

Thermal dusts are prepared from chemicals with the characteristic of subliming when heated to about 427° C (800° F). The vaporized chemicals condense into particles that appear as a dense smoke penetrating the entire greenhouse atmosphere. The particles then settle out as an extremely fine dust that deposits on plant surfaces. At present Daconil is available under the name Termil as solid tablets for use as a thermal dust and under the name Exotherm Termil for use in smoke generators. Both formulations are very effective for control of *Botrytis* on the foliage and flowers of many ornamental plants.

### Systemic Fungicides

Systemic fungicides are absorbed by the plant through the leaf, stem, or root surface and translocated varying distances within the plant. This distance may be as small as from one surface to the other or as far as from the roots to the shoot apex. Benomyl is a systemic fungicide. Systemic fungicides have the following advantages: (1) The plant can be continuously protected throughout the growing season without repeated application of fungicides. (2) The systemic can be taken up by the roots and transported to newly formed tissues. (3) The systemic is not subjected to weathering as are fungicides applied to the foliage. (4) Unsightly residues on flowers and foliage can be avoided. (5) The systemic can provide a means of controlling and eradicating vascular wilt diseases as well as other internal disorders of plants. (6) Because the toxicant is in the plant, there is minimal toxic effect to people working in the greenhouse during the growing season.

### Use of Fungicides

A frequent question regarding the use of fungicides is whether the grower should use a spray or a dust. Sprays still take precedence over dusts simply because the coverage is better, particularly on the undersides of the leaves. Although insects may move to chemical deposits on the upper leaf surface, plant pathogens do not, and effective control is achieved only if both leaf surfaces are covered thoroughly.

Proper use of a fungicide includes selecting the right chemical for a given disease. A pathogen can be spread by a fungicide spray if the wrong fungicide is used. Good disease control requires the correct chemical, applied to give adequate coverage, without runoff, at the proper time, and at regular intervals, determined by residual activities and weathering.

## Use of Soil Fungicides

### Recontamination Problem

The heat treatment of soils at temperatures of 100° C (212° F) and above results in the eradication of not only the plant pathogens, but also most of the naturally occurring soil microflora. Although certain spore-forming bacteria and thermophilic fungi survive these temperatures, for all intents and purposes, heat treatment results in a biological vacuum. This vacuum persists for a few days after treatment. Then the surviving microorganisms and the microorganisms introduced from the air begin to colonize the soil. Within a few weeks, the population exceeds that of the original population.

If plant pathogens are introduced during the period of the biological vacuum, when the competitive, antagonistic, and antibiotic activities of the soil saprophytic microorganisms are essentially absent, the pathogens colonize the soil mass rapidly and in high population. The result, upon planting, is a greater loss than might have been experienced if the soil had not been treated.

*The recontamination problem*, the greatest one connected with the heat treatment of soils, is a major reason for crop failure after treatment. The critical nature of this problem dictates a strict, continuous sanitation program.

*Sanitation* is and must be an integral part of greenhouse or nursery production. Soil treatment is the initial step in any production practice. Sanitation begins as soon as soil treatment has been completed; it ends only when a crop has been finished and the soil is again ready for treatment. Sanitation means, in effect, "keeping a clean shop" and is stressed because a "dirty shop" affords the soilborne pathogens the means of spread essential to their survival and increase.

*The most-important plant pathogens inciting root diseases are not airborne, but are dependent upon the mechanical transfer of infested soil or water or infested plant material for their spread.*

Soil fungicides offer another method for controlling the recontamination problem. A soil fungicide can be defined as any chemical that prevents colonization of steam-treated soil by plant pathogens when the chemical is applied to the soil in the presence of living plants. Soil fungicides can be distinguished from soil fumigants by three criteria: (1) They are nonvolatile. (2) They retain activity over a relatively long period of time. (3) They are not phytotoxic and can be applied to soil in which plants are growing. To classify a given chemical into one or the other group may be difficult because the chemical may show properties of both.

An ideal soil fungicide would exhibit the following characteristics: (1) broad-spectrum activity, that is, activity against many different soilborne plant pathogens; (2) little or no activity against the saprophytic microorganisms; (3) activity against plant pathogens at concentrations not toxic to plants or man; (4) activity for the period of time required to produce a crop. There is no such soil fungicide today, but all fungicides meet some of the requirements (table 4).

The activity of most *fungicides* in soils is fungistatic rather than fungicidal; that is, they limit or suppress the growth and development of plant pathogens rather than kill them. For this reason, their use is restricted to application *after* the plant pathogens have been eradicated by steam treatment to prevent or limit colonization should the pathogens be introduced.

### Application of Soil Fungicides

Soil fungicides are formulated as wettable powders or liquids. The wettable powders can be used as a soil mix after steaming or in a water suspension as a soil drench. The liquids are applied as a soil drench and can be metered through fertilizer proportioners. The method of application that best fits a given operation can be used. *What is important is to apply the correct amount to each plant.* Too little will result in poor control; too much will result in plant injury.

Table 4. Soil fungicides commonly used to limit colonization of steam-treated soils and pathogens against which they are effective

<i>Fungicide</i>	<i>Name</i>	<i>Pathogen (fungi)</i>
N-(2,6-dimethylphenyl)-N-(methoxyacetyl)-alanine methyl ester	metalaxyl Subdue 2E	<i>Pythium</i> spp., <i>Phytophthora</i> spp.
N-[(trichloromethyl)thiol]-4-cyclohexene-1,2-dicarboximide	captan (WP)*	Broad spectrum
Sodium-p-(dimethylamino) benzenediazo-sulfonate	Lesan (WP)	<i>Pythium</i> spp., <i>Phytophthora</i> spp., <i>Aphanomyces</i> spp.
Ferric dimethyldithiocarbamate	ferbam (WP)	Broad spectrum
Pentachloronitrobenzene	Terraclor (WP)	<i>Rhizoctonia</i> spp., <i>Sclerotinia</i> spp., <i>Sclerotium</i> spp.
Bis(dimethylthiocarbamoyl) disulfide	thiram (WP), Arasan	Broad spectrum

\*WP = wettable powder.

If a soil mix is used, the correct amount must be *weighed* out, not measured in tablespoons or cups. Not only do "tablespoons" and "cups" vary in size, but the amounts of fungicide will vary depending upon whether the material "settled" in the package or is "fluffed" out. Mixing must be thorough to assure an even distribution in the soil mass. Unless the chance of recontamination is slight, mixing fungicides with steam-treated soil should be avoided.

In applying soil drenches, three steps are essential:

1. Weigh or measure out the proper amount of fungicide.
2. If a wettable powder is used, continuously agitate the suspension.
3. Deliver the proper amount of the suspension per square foot of bench space or per container.

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# Soil Treatment

## Heat Treatment

The use of heat to eradicate plant pathogens from infested soil or soil containers is based upon the fact that most soilborne plant pathogens have low thermal death points. Under ideal conditions most plant pathogens are killed by heating to 60° C (140° F) for a 30-minute period.

In general, the higher the moisture content of living organisms, the greater their susceptibility to killing by heat. In dry soils, fungi form resistant resting structures, which are less susceptible to heat than their actively growing vegetative or reproductive structures.

Although most plant pathogens are killed at 60° C (140° F) when held for 30 minutes, higher temperatures are required for killing some pathogens, soil insects, and weed seeds. Under ideal treating conditions, a temperature of 71° C (160° F) for 30 minutes should thus be used. Because ideal conditions are seldom encountered in commercial production, temperatures higher than those required must be employed to provide a margin of safety. The recommended temperature for treating soils is 82° C (180° F), to be held for 30 minutes.

Steam treatment is the most efficient means of eradicating plant pathogens from soils. Compared with dry heat, steam imparts a large quantity of heat (over 1,100 Btu per lb) at low intensity 100° C (212° F) and flows through soil to the cold area. One of the principal advantages of steam over dry heat is that the Btu are released at the point to be heated. Finally, when soil is heated with free-flowing steam, the natural heat ceiling of 100° C (212° F) precludes charring organic matter. In addition, steam is nonselective, killing all plant pathogenic microorganisms at 100° C (212° F).

Steam treatment of soil is not without disadvantages. The greatest of these, from the disease control standpoint, is that steam is nonselective in the microorganisms it destroys. Not only the plant pathogens are killed, but the soil saprophytes as well. If a pathogen is introduced into newly steam-treated soil, it colonizes the soil mass rapidly and, in the absence of competitive and (or) antagonistic microorganisms, luxuriates.

As a result, losses due to disease may be greater than if the soil had not been treated at all. This phenomenon has been termed the recontamination problem. The purpose of sanitation is to prevent this problem.

When organic materials high in organic nitrogen are incorporated into a soil mix and the mix is steam treated, ammonia toxicity may occur. Many of the organisms that convert organic nitrogen to ammonia are spore formers, and some survive the steam treatment; the bacteria that convert ammonia to nitrite and nitrite to nitrate are not spore formers and are killed. As a result, ammonia may accumulate in toxic amounts within 2 weeks after treatment and remain in toxic concentrations for up to 8 weeks. Ammonia toxicity can be avoided by using organic matter with no organic nitrogen. An increase in soluble salt and manganese levels may also occur with steam treatment. If the increase is great enough, injury may occur.

*Free-flowing steam* is steam at atmospheric pressure. It is at a temperature of 100° C (212° F) and contains a potential 1,152 Btu for heat transfer. When properly used, it affords the most-efficient method of heat treating soils to eradicate plant pathogenic microorganisms.

Assuming optimum conditions, it is not possible to treat soil with free-flowing steam at less than 100° C (212° F). In actual practice, the thermometer is placed at the coolest point in the soil mass, and timing is begun when this point reaches 82° C (180° F). If the volume of steam is then reduced to a "trickle," this temperature may be maintained at this point. It should be evident, however, that most of the soil is treated at 100° C (212° F).

*Aerated steam* is produced when air is injected into a free-flowing steam line. The result is to disperse the steam vapor. When this occurs, the temperature of the steam-air mixture is reduced. Thus, steam-air at 82° C (180° F) will heat soil to 82° C (180° F) and no higher; condensation and heat transfer will only occur until the soil reaches 82° C (180° F). The same would be true of steam-air mixtures of 76.5° C (170° F), 71° C (160° F), 65.5° C (150° F), or 60° C (140° F).

The application costs are reduced because either a smaller boiler is required

for a given job or a larger area is treated in a given time. Poststeaming soil toxicity is reduced because of the lower temperature. Finally, a portion of the established saprophytic soil microflora remains and luxuriates, providing competition and (or) antagonism for any pathogens introduced.

## Chemical Fumigation

A *soil fumigant* can be generally defined as a chemical that, when applied to soil, will volatilize and diffuse through the pore spaces in amounts toxic to pathogenic microorganisms. Although it is considered to be a substitute for steam, steam does not provide a practical means of treating large field areas. In addition, many nursery and greenhouse establishments do not have a steam facility. Thus, chemical soil fumigants have a decided advantage over steam in the production of field-grown cut flowers, in most nursery establishments, and in small greenhouse operations.

Briefly, the advantages of chemical fumigants are the following:

- They are adaptable to most greenhouse or nursery operations and can be used to eradicate plant pathogens from large acreages or small cans of soil.

- Treatment does not alter the structure of the soil.

- Treatment does not result in the release of toxic amounts of soluble salts or manganese (though ammonia toxicity may still be a problem).

There are, of course, certain disadvantages:

- The fumes, in general, are phytotoxic, and chemical fumigants cannot be used in the vicinity of growing plants (see †methyl bromide in table 5).

- Fumigants may be highly selective in regard to organisms killed.

- They may be absorbed by the soil or by organic matter and leave residues toxic to plant growth.

- In general, they are highly toxic to humans.

*Principles of fumigant activity.* The activity of a soil fumigant is determined by its ability to diffuse through soils and its toxicity to microorganisms.

Table 5. Soil fumigants useful in control of soilborne pathogens of geranium and application procedures

Pesticide	Major uses	Min. soil temp.	Application procedure and precautions
Larvacide Picfume Acquimite Chlor-O-Pic Niklor Tri-Clor (†chloropicrin)	Weeds, most fungi, nematodes, and soil insects. Controls <i>Verticillium</i> .	15.5° C (60° F)	†Chloropicrin usually applied to soil with a hand applicator or a small, self-propelled tractor fumigator. Use at the rate of 2-2½ cc on 10-in. centers, or 12 lb/1000 sq ft. Heavier soils require increased dosage. It is important that gas be confined by sprinkling soil surface thoroughly with water immediately after treatment or, preferably, by covering with a gasproof cover, which should be left on the soil for at least 24 hr. Soil must be well aerated for 10-21 days before planting. Bulk soil for potting can be sterilized in prepared bins, sealed garbage cans, or drums; use †chloropicrin at 5 cc/cu ft of soil. †Chloropicrin works best when soil temperature is between 15.5° C and 32° C (60° F and 90° F). Fumes toxic to plants; greenhouse must be empty.
Vapan VPM Sistan Trimaton (liquid carbamate)	Nematodes, most weeds, and fungi.	10° C (50° F)	Apply 1 qt/100 sq ft with a sprinkling can or a hose proportioner. If sprinkling can is used, add required amount of chemical to can, fill with water, stir, and distribute evenly over measured area. Treat only 100-200 sq ft at a time; then water-in thoroughly to carry the chemical through the layer to be fumigated. Do not plant for 2-3 weeks after treatment; then make test plantings of seedlings or cuttings, and wait a few days before planting entire crop. If the soil is cold or excessively wet, wait 3-4 weeks. Fumes toxic to plants; greenhouses must be empty.
Vorlex Di-Trapex (mixture of 80% dichloropropene-dichloro-propane, 20% methyl isothiocyanate)	Nematodes, weeds, and fungi.	10° C (50° F)	Apply with hand injector or tractor-mounted equipment. See label for rates. Wait 14-28 days before planting. Fumes toxic to plants; greenhouse must be empty.
Dowfume MC-2 (98% †methyl bromide, 2% †chloropicrin. Under pressure in 1- and 1½-lb cans and 30-lb cylinders)	Weeds, insects, and nematodes at 1 lb/100 sq ft for 24 hr. At 4 lb/100 sq ft for 24 hr, bacteria and most fungi are killed.  <i>Verticillium</i> is not adequately controlled even at higher rates; where control is desired, use †chloropicrin.	10° C (50° F)	†Methyl bromide is very poisonous to humans, but can be applied with complete safety when all precautions are followed. It can be used in greenhouses where plants are growing although slight leaf injury has been observed on carnations, chrysanthemums, geraniums, and lilies. It is sold in convenient 1-lb and 1½-lb tin cans for application with a Jiffy applicator or in 30-lb cylinders for large-scale treatment. A thoroughly tight seal with a plastic cover is necessary to prevent escape of the gas. For sterilizing bulk soil for potted plants, use 4 lb/100 cu ft or approximately 1 lb/cu yd. Soil must be thoroughly aired for 3-7 days before use. Length of airing will depend on soil type, moisture, and temperature. Normally, in clear, warm weather, sandy and other light soils, air in 3-4 days, heavier soils in 3-7 days. WARNING: Do not use bromine-containing fumigants (†methyl bromide, †methyl bromide mixtures, and ethylene dibromide) for treating soils to be planted to carnations or salvia. Fumes slightly toxic to plants; can be used in greenhouses with vents open.
Brozone (Mixture of 68.6% †methyl bromide with 1.4% †chloropicrin in petroleum solution)	Insects and nematodes; fungi, weeds, and bacteria only at higher rates.	10° C (50° F)	A preparation of †methyl bromide in a solvent with a very small amount of †chloropicrin, which serves as a warning agent, comes in 5- and 30-gal drums, and can be applied with a hand injector. Use 6-8 cc per injection on staggered 10-in. centers. After injection, step on the holes to prevent rapid escape of the gas. Use a water seal. Use of a gastight cover laid over soil gives even better control. Soil should be well aired for several days before planting. Fumes slightly toxic to plants; can be used in greenhouse with vents open.
Microfume, Prezervit, Crag Fungicide 974, Crag Nematocide (Mylone 25% G)	Nematodes, many weeds, and fungi.	10° C (50° F)	Apply 2 lb 25% granular Mylone/100 sq ft. Rototill and water with 1-2 in. of water. Do not plant until 3 weeks after treatment; then make test plantings of seedlings or cuttings, and watch for a few days before planting entire crop. Fumes toxic to plants; greenhouses must be empty.

Note: Soil fumigants should be used with all precautions given on the label. †Restricted-use pesticide.

The ideal soil fumigant would exhibit

- low chemical reactivity with soil components,

- low diffusibility,
- high water solubility,
- low vapor pressure, and
- low adsorption by soil components.

The ideal soil for fumigation would have

- low organic matter content,
- low adsorptive capacity for fumigants,
- low continuous air space, and
- low water content.

The biologic component of the soil (microorganisms, weeds, insects) should be metabolically active rather than in some resting phase of the life cycle.

**Soil fumigants and their uses.** Although none of the presently known chemicals fulfill all the requirements of the ideal fumigant, many fulfill enough of them for practical use. Several soil fumigants useful in control of soilborne pathogens of geraniums are listed in table 5. In addition to the specific recommendations for each fumigant, there are a few general rules concerning use of fumigants. Restrictions on usage of these materials vary from state to state. Consult your Extension Service for further information.

**Special chemicals and dosages required to kill fungi.** Fungi are, in general, more difficult to kill than insects, nematodes, and most weed seeds. This fact must be kept clearly in mind when selecting a chemical and when deciding the rate at which it should be used. Growers often make the mistake of assuming that if weeds and nematodes are killed, the fungi are also. Although this is not true, it is a general rule that if the fungi are killed, the weeds and nematodes will be killed as well. Nematocides or herbicides cannot be used to control soil fungi.

**Soil preparation, temperature, and aeration.** Because a water seal or plastic cover is used in applying most fumigants to prevent too rapid diffusion from the soil, soil conditions optimum for treating will be those optimum for planting.

- The soil should be in good planting condition, free of lumps or clods.

- Soil temperature should be in the range of 18°-24° C (65°-75° F) for best results.

- After fumigation, the soil must be thoroughly aerated so that all trace of the fumigant is gone before transplanting.

- In general, the higher the temperature and the lighter the soil, the shorter the aeration period.

- Always use a chemical fumigant on a small scale before treating the soil for an entire crop.



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