The Plant Doctor:

Greenhouse Basil Downy Mildew

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Most common seasons

Late fall, winter, and early spring.

Weather

Rain and high humidity, especially originating from the Gulf of Mexico. Temperatures between 53 and 77°F.

Basil types affected

Especially bad on sweet basil. Colored types and other species are not so susceptible.

Greenhouse-grown basil plants.

Quick symptoms

Chlorotic (yellow) area in center (mid-rib) of leaf. May develop fuzzy, gray growth on undersides of leaves. In very conducive situations, fuzzy growth may be on upper leaf surfaces, as well.

A Very Short History of the Pathogen

(*Peronospora belbahrii*)

Downy mildews are members of the water mold group. Other well-known water mold plant pathogens are Pythium and Phytophthora. Pathogens in this group thrive in wet or moist environments, and the plant-pathogenic members develop resistance to chemicals used for their control.

Basil downy mildew was first noticed on a significant commercial basis in Switzerland in 2001. In 2003, it was found in Italy. By 2004, it was found in most Italian growing regions and in France. The disease was in several African countries in 2005. By 2008, it was found in at least nine U.S. states. It is considered established in Florida.

The rapid spread of basil downy mildew is due to two key characteristics:

- Its spores can move many miles on winds.
- It is seed-borne.

Another key point that is crucial to the spread of basil downy mildew is it is very difficult to manage and control.

Life Cycle of Basil Downy Mildew

Seeds

Movement of the pathogen between continents is probably a result of the unintentional distribution of contaminated seeds. Basil plants grown from known infected seeds were systemically and latently infected (plants did not express symptoms), so contaminated seeds were harvested from these plants. Recently, seed companies have started to decontaminate their seeds by steaming.

Symptoms

The first symptom is a slight chlorosis (yellowing), usually in the central area of the leaf around the mid-rib. Further disease development produces dark-colored (gray) "thread-like" structures similar to fungal hyphae, on the lower side of the leaf (Figure 1). They may take on a "fuzzy" appearance (Figures 2 and 3). In very conducive conditions, the dark, hyphal-like threads may emerge on the upper side of the leaf. These dark, fuzzy threads produce the asexual spores.

Environmental Conditions

Spore production requires very high humidity for some hours after symptoms develop. Symptom severity depends on the length of the leaf wetness period that produces infection. Six hours of leaf wetness is needed for minimal

Figure 1. Young basil plant with a downy mildew infection. Note the yellow (chlorotic) blotches on the leaves and the black mycelia on the underside of the leaf seen on the opposite side of the plant.

Figure 2. The upper and lower sides of sweet basil 'Nufar' infected with downy mildew. Note the chlorotic areas on the upper side of the leaf (left), which relate to mycelial growth on the lower side of the leaf (right).

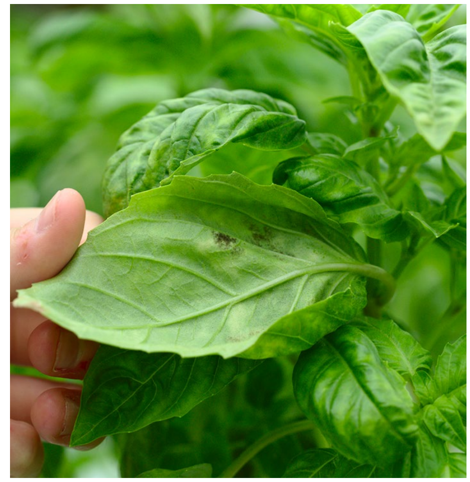

Figure 3. Sweet basil 'Nufar' infected with downy mildew. Note the yellow (chlorotic) splotches on the upper sides of the leaves. The dark-colored mycelia will grow from the chlorotic areas on the undersides of the leaves—and on the top of the leaves if the environment is very conducive.

infection, whereas 12 hours of leaf wetness will produce severe infections, prolific sporulation, and rapid spread of the disease.

Optimum pathogen growth occurs at 68°F—not much warmer than the energy-saving winter temperature settings used in many greenhouses. Pathogen growth is suppressed at or below 53°F or above 77°F. Growth in warmer temperatures suppresses expression of the dark mycelial threads on the lower side of the leaf, but chlorotic patterns will still be present (Figure 4).

Spores are easily moved on wind currents. They apparently can travel many miles.

Observed Patterns in the Greenhouse

Early symptoms of the disease (leaves with a chlorotic central area) will appear in a patchy pattern in areas of the greenhouse where temperatures and relative humidity are highest and air movement is lowest. This is usually in the central part of the greenhouse and in the middle of benches.

Management

Management Overview

Basil downy mildew is a fairly difficult pathogen to manage. To do so successfully requires use of all or most of the strategies discussed in this section.

- Probably the most significant advancement in the management of this disease is the development of resistant varieties. Use them. Their use will reduce disease pressure and allow you more leeway in the use of management tools other than expensive fungicides to which the pathogen may develop sensitivity (resistance).
- Nighttime illumination prevents asexual spores from forming, greatly reducing both spread and severity.
- Fans reduce local humidity and prevent free water (guttation and dew) from forming. Both are essential for pathogen sporulation and infection.
- Temperature manipulation.
  - Heat mats to raise the soil temperature around the plant roots permit air temperatures to be maintained around 68°F (20°C) while still reducing pathogen growth.
  - Daytime solar heating, using plastic tenting, can kill or suppress pathogen asexual spores and mycelium.
- Supplemental nutrition.
- Proper application, timing, and choice of fungicides.
- Sanitation after sale and during the crop, especially the removal and destruction of old plants and plant parts, which can harbor sexual spores that can reinfect following crops.

Host Resistance

- **Other than sweet basil:** In general, the less it looks and tastes like conventional sweet basil, the less basil downy mildew infection. Sweet basil (*Ocimum basilicum*) is most susceptible, and spice species (*O. americanum, O. basilicum* var. *americanum*) are the most resistant to the disease. In between, Thai basil (*O. basilicum* var. *tenuiflorum, O. basilicum* var. *thyrsiflorum*), cinnamon basil (*O. basilicum* 'Cinnamon'), and 'Red Rubin' basil (*O. basilicum*) are susceptible, but noticeably less so than sweet basil.

Figure 4. Sweet basil infected with downy mildew growing in 80–95°F temperatures. The chlorotic splotches are visible, but the mycelia is not expressed (inset photo).

Fewer disease symptoms will be seen in citrus basil (*O. citriodorum*).

- **Sweet basil:** Over the last few years, basil breeders have done a remarkable job developing varieties resistant to basil downy mildew, and it appears future advancements are likely. While none of the new sweet basil varieties are immune, some are very good and should be your first line of defense, if your market allows. Notable resistant varieties are Prospera; Amazel and Pesto Besto, which provided nearly 100 percent control in two field tests; and Rutgers Obsession DMR, Rutgers Passion DMR, Rutgers Thunderstruck DMR, and Rutgers Devotion DMR, which provided good control with some variation. Some of these employ the same resistance genes, so resistance-breaking basil downy mildew strains might become a problem. However, a gene combination is coming that should avoid resistance-breaking strains for years to come.

Ventilation and Air Movement

Greenhouse ventilation is a key management tool. Reducing relative humidity (RH) and free moisture (especially water in the form of guttation/dew) will prevent spores from infecting the plants or from being produced in the first place. The target is less than 85 percent RH to prevent spore formation, and constant air circulation to reduce local humidity and guttation/dew formation.

- Asexual spore formation by *P. belbahrii* is almost nothing at 85 percent RH and is maximized at 97.6–100 percent RH. But even a decrease to 94.6 percent RH results in many fewer spores being produced than at 97.6 percent RH.
- Even with humid winds from the Gulf of Mexico, fans can reduce local humidity sufficiently (<95 percent RH) to make a notable difference. This is especially critical at night because it reduces spore germination and standing moisture, preventing plant infection by the spores.
    - To reduce humidity inside the greenhouse, ventilate the greenhouse in the late afternoon, starting about 3–3:30 p.m. in the winter. Heat the air. Exhaust the air by opening all the vents and running all fans. Close the vents. Repeat at least three to five times. Make sure that you have internal circulation fans going one direction on one side of the greenhouse and the other direction on the opposite side.
    - Automatic controllers should be set to ventilate the greenhouse during the night. The more air changes you can afford, the better.

Temperature

Basil downy mildew develops in the temperature range of 41–86°F (5–30°C), with the least disease occurrence at 41 and 86°F. Most spores germinate (in the dark) in a temperature range of 68–73°F (20–23°C). For economic reasons, most Mississippi greenhouses set their night temperatures at about the optimum temperature for disease development.

- Raising root temperatures to 79–88°F (26–31°C) while maintaining the upper plant parts at an air temperature of 68°F (20°C) suppresses canopy downy mildew, apparently killing all but the sexual spores (oospores) in the leaves. But even they appear not to be viable as favorable conditions fail to germinate them. High heat may make sweet basil an unfavorable host. Heat mats that maintain soil temperatures at 79–88°F may allow you to reduce disease while not expensively heating the entire greenhouse. You can maintain the air temperature at 68°F.
- Air temperatures greater than 77°F (25°C) reduce disease severity. Higher temperatures can kill the pathogen altogether. Covering shade cloth houses with polyethylene to increase the air temperature to 136°F (58°C) for a few hours on 1–3 consecutive days kills the pathogen, suppresses disease progress, and enhances basil growth. Inside your greenhouse, you might try a similar technique by tenting the basil benches with plastic to raise the local temperature to 136°F (58°C) for a few hours on 1–3 consecutive days.

Lights

Spores are the primary means of pathogen movement in a planting. Spore production requires high humidity and 6 or more hours of leaf wetness. These conditions are most often met at night or, in the Gulf Coast states, during overcast winter days with winds from over the gulf.

The importance and use of ventilation and fans in reducing the humidity inside the house and on the plants themselves has been discussed, but in some circumstances, these are barely sufficient or even insufficient. Proper lighting can offer a major assist in stopping spore production when house temperatures are greater than 60°F (15°C).

Factors affecting artificial lighting efficacy:

- The inhibitory effect of light is limited to the area of the leaf that receives illumination, and to inhibiting spore production but not the hyphal, fuzzy growths that produce the spores.
- Direct light to the leaf underside is more effective than illuminating the upper leaf surface. As the plants grow, the leaves will start to shade one another. Shaded leaves will start to produce spores.
    - You may choose to use light-colored materials on the bench top to scatter the light and improve the light's contact with the lower leaf surfaces.
    - You may choose to mount the lights to the sides of the basil canopy and angle the light toward the canopy's sides, instead of placing the fixtures directly above the canopy.
- Continuous light with long nighttime photoperiods (about 12 hours) work best.
    - Intermittent light is less effective.
    - Do not allow more than 7 hours of dark.

LED Lighting

Newer greenhouse lighting is based on energy-efficient light emitting diodes (LED), which can emit light in narrow wavelengths. LED systems used in many greenhouses have both red and blue LEDs, which give a purple color. Some lighting systems can be configured to use their multiple-colored LEDS to emit light at specific wavelengths.

For the same light intensity (photosynthetic photon flux density [PPFD], measured as micromoles per square meter per second [µmol/m2/s or $\mu mol{\cdot}m^{-2}{\cdot}s^{-1}$]), red light (maximum wavelength [λmax] 625 nm) suppresses spore production more than blue light (λmax 440 nm), and green light (λmax 500 nm) was in between red and blue. See Table 1.

If growing basil by artificial light alone, then light intensities of 150 to 500 mmol/m2/s are required (note the intensity is in millimoles, 1000 times more than the micromoles quoted earlier). Light intensities as low as 5 µmol/m2/s can effectively suppress sporulation, but 10 µmol/m2/s suppresses well over 90 percent of spore production.

Fluorescent or Incandescent Lighting

Fluorescent or incandescent lighting of the cool white (CW) color at light intensities of 6, 21, and 35 µmol/m2/s (micromoles per square meter per second) stops spore production regardless of which leaf surface it contacts. Fewer spores will be produced at 2 µmol/m2/s.

Table 1. Red light wavelengths (λ) and photosynthetic photon flux density (PPFD; light intensity and duration) known to suppress downy mildew spore production.

Red wavelength range	Peak wavelength in the range (nm)	Photosynthetic photon flux density (PPFD; light intensity and duration)
590–670 nm (estimated)	625 nm	4–10 µmol/m2/s (10 µmol/m2/s best); 12 hr
575–662 nm	625 nm	12 µmol/m2/s; 12 hr
646–649	670 nm	60 µmol/m2/s; 12 hr best

More information on greenhouse lights, lighting terms, and use is available online:

GLASE (Greenhouse Lighting and Systems Engineering)

Cornell University, Controlled Environment Agriculture

Cornell University, Greenhouse Lighting fact sheet (PDF)

Macro- and Micronutrients

Macro- and micronutrients can often encourage or discourage disease. Several groups have conducted extensive testing of nutrients either added to the fertigation solution or sprayed on plant foliage. Some treatments encouraged disease, some decreased disease severity, and two not only decreased disease severity but increased sweet basil fresh and dry weight and essential oil production.

- An Egyptian study sprayed various potassium (K) salts (mono- and di-potassium phosphate, potassium carbonate) and anti-transpirants [potassium silicate, aluminum silicate (kaolin), and silicon dioxide] at weekly intervals prior to downy mildew infection. The result was decreased disease severity, increased sweet basil essential oil production, and increased fresh and dry weight.
- Two products increased essential oil production and fresh and dry weights of sweet basil: dibasic potassium phosphate (K_2HPO_4) (20 mM) and potassium silicate[2] (K_2O_3Si) (20 mM).
    - To make 4000 mL (milliliters) (7.25 fluid ounce more than a gallon) of 20 mM dibasic potassium phosphate, add 14 grams (about 0.5 oz) of the powder to 4000 mL of water and mix.
    - Making 4000 mL of 20 mM potassium silicate might be more difficult since there is variability in the amount of water incorporated into the molecular formula. If other than anhydrous potassium silicate is used, then make sure the label states the molecular weight, and use the link in the next bullet to figure the amount to use.
    - If you want to make a differing amount, use the calculator provided by Physiology Web. The molecular weight of dibasic potassium phosphate is 174.2. The molecular weight of anhydrous potassium silicate is

248.5. Enter the molecular weight in the top row. In the third row, enter the total number of mL (milliliters) you want to make and click the radio button next to "mL" in the right box. In the bottom line, enter 20 and click the radio button next to the "mM" in the right box. In the second line, click the radio button next to the "g" for grams. Click the "Calculate" button in the bottom right box. The "Mass of solute" box in the second line should return the amount of chemical you need to add for the number of mL you entered.

- These treatments decreased disease severity:
  - Sprays made twice a week for 3 weeks of 1 percent foliar applications of KCl (134 mM K) and K_2SO_4 (114 mM).
  - Sprays of low concentrations of Zn (applied as Zn-EDTA, 0.006% solution) and Mn (applied as Mn-EDTA, 0.014% solution) or applied as part of the irrigation solution (1–2 mg/L in the irrigation solution). In some cases, the combination of microelements and fungicide (applied separately) reduced disease significantly as compared to fungicides alone.
  - Increasing concentrations of Ca in the fertigation solution from 0.5 to 1.56 mM.
  - Increasing concentrations of Mg in the fertigation solution to 3.0–4.94 mM, unless the Mg in the water is already high enough. See Elad (2021) in the references for more information on calcium, magnesium, and potassium supplementation.
- This treatment increased downy mildew severity:
  - Increased K concentration (0.5, 0.8, 1.3, 2.6, and 5.1 mM) in the fertigation solution—the highest rate much more so than the second-highest rate.
- A single study found that sweet basil grown hydroponically was less susceptible to basil downy mildew than soil-grown plants. It also had greater antioxidant capacity but was more susceptible to leaf browning and heat stress.

Conventional Fungicides

Downy mildew is a type of water mold organism. Water molds—downy mildew in particular—develop tolerance (or resistance) to fungicides fairly quickly. To guard against this, you need to rotate among fungicides that target the downy mildew in different parts of its physiology. Fungicide experts term these different modes of action FRAC groups.

The very real threat of resistance necessitates the use of three or more products belonging to different FRAC groups. Most FRAC groups consist of a number only. There are a few FRAC groups that have both a number and a letter, such as "M," which in this case means it has multiple modes of action.

Because of cloudy days and humid winds from the Gulf Coast, Mississippi growers will need to rely on fungicides more than basil growers elsewhere, especially if they do not employ other management options discussed in this publication. Using alternative management tools can reduce the number of fungicide sprays needed to produce a healthy and attractive crop.

A current listing of fungicides labeled for use on basil for downy mildew may be found in the annual issue of the Southeastern U.S. Vegetable Crop Handbook or on the Basil Ag Pest Monitor site. The listing does not tell you if the product is labeled for greenhouse use. You need to check the labels themselves. The products do not include biological fungicides, presumably because they are mostly ineffective against basil downy mildew.

Also keep in mind that many months may have passed between the time the product listing was made and your reading, so check frequently to see if anything has been added or removed. A pesticide label database can help you do this, and you can learn more about the labels by reviewing Extension Publication 3155 *Pesticide Label Databases*, available at extension.msstate.edu. In these databases, you can search for the occurrence of multiple factors, such as basil as the host and downy mildew as the pest.

Doing this in December of 2021 showed that a new active ingredient had been labeled—oxathiapiplorin, a product in a brand new FRAC group, 49. This is vitally important because it provides a unique FRAC group, and trials have shown that oxathiapiplorin is quite effective against basil downy mildew. Sold as Segovis, it may be used on greenhouse-grown basil to be sold to consumers. Table 2 provides a fungicide product summary.

An extensive set of fungicide trials was conducted in New York and Illinois for control of basil downy mildew. These are recommendations from those trials:

- The spray program should be done weekly.
- All products work best if applications are started before infection. Some labels state the application *must* be started before infection.
- The spray application should cover the entire plant, including the lower side of the leaves. Use sufficient water and correct water pH and adjuvant.
- Consider using drop nozzles to ensure good vertical coverage of the plants.
- The application of a particular active ingredient needs to follow label instructions for the total number of applications and sequential applications made. See the comments in Table 2 for examples.
- Tank mixing a P07 FRAC group fungicide, such as ProPhite, with non-P07 fungicides increased product efficacy in multiple tests.
- Illinois work suggests a program alternating among azoxystrobin, cyazofamid, and mandipropamid, each

mixed with ProPhyt (a P07), yields consistent results. This work was done before the approval of oxathiapiprolin, which tests well individually. So incorporating it into the program would probably improve results and further reduce chances of downy mildew resistance.

- Organic fungicides have generally not shown efficacy. Products tested include *Streptomyces lydicus* (Actinovate), *Bacillus subtilis* (Companion), copper octanoate (Cueva), *Bacillus amyloliquefaciens* (Double Nickel), thyme oil (Forticept6 EP #1), *Bacillus subtilis* (Milagrum Plus), polyoxin D zinc salt (Oso), hydrogen dioxide (OxiDate), citric acid (Procidic), *Reynoutria sachalinensis* extract (Regalia), *Bacillus amyloliquefaciens* (Stargus), and neem oil (Trilogy). Sesame oil (Organocide) was an exception.
- Red light enhanced the activity of the normally effective phosphite fungicide ProPhyt (referenced in Table 2), and less so a systemic acquired resistance (SAR) product (Actigard) and a sesame oil (Organocide). The latter two offered about 50 percent reduction in disease severity in the presence of red light.

The proper use of fungicides will likely help you only if you are implementing the other management tools discussed here.

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Table 2. A search of pesticide databases lists these products as labeled for basil downy mildew. The list does not include biological fungicides, because none have proven effective against this pest. Eight FRAC groups are represented, but only seven might be construed as labeled for greenhouse production. Any spray program should use at least three of these in rotation with one another. Each label should be read individually before designing your program and before purchase. A program for greenhouse-grown transplants and field basil is discussed in the text. Some active ingredients are no longer protected by patent, and many generic formulations containing that active ingredient are available. These generics are not listed to conserve space.

Active ingredient	FRAC group	Trade names	Label rates	Harvest (days)	Reentry (hours)	Comments
Azoxystrobin	11	Heritage (and roughly 18 other azoxystrobin generics)	0.18 oz/1000 ft sq (0.25 lb a.i./A)	0	4	For transplants to be sold to consumers. One application during plug production and one application after transplant to tray using 3.4 gal water/5000 ft sq. No more than 1.5 lb a.i./A/year of azoxystrobin. If using fenamidone (also FRAC 11), see other rotation directions.
Fluopicolide	43	Adorn, Presidio (not for greenhouse use)	4 fl oz/A	1	12	Presidio fungicide must be tank-mixed with a labeled rate of another fungicide active against the target pathogen, but with a different mode of action. 7- to 14-day intervals. Apply no more than 12 fl oz/A/year.
Cyazofamid	21	Ranman 400 SC, Zilka SC, RenaZ SC, Segway O (greenhouse)	2.75–3 fl oz/A	0	12	Tank-mix with an organosilicone surfactant when the disease infection is severe, or a nonionic surfactant or a blend of organosilicone and a nonionic surfactant when disease infection is moderate or light. Apply up to nine times with no more than three consecutive applications before switching FRAC for at least three applications. Do not apply more than 27 fl oz/A/year. For water volumes less than 60 gal/A, Segway O should be tank-mixed with an organosilicone surfactant when the disease infection is severe. 7- to 10-day schedule. Do not apply more than 27 fl oz/A/year.
Fenamidone	11	Reason 500 SC (field and greenhouse)	6 fl oz/A	2 days	12	Minimum of 7 days between applications. Do not make more than a single application before switching to a different FRAC code. Do not make more than four FRAC 11 applications total. Maximum of 24 fl oz/A/year. The number of FRAC group 11 applications should be no more than one-third the total number of fungicide applications for basil downy mildew; can go to half of the total if pre-mixes or tank mixes of the FRAC 11 are made with another FRAC.
Mandipropamid	40	Revus (no greenhouse)	8 fl oz/A	1	4	Can be applied up to four times with no more than two consecutive applications before switching to another FRAC. No more than 32 fl oz/A/season. The addition of a spreading/penetrating adjuvant such as a nonionic surfactant or crop oil concentrate or blend is recommended.
		Micora (greenhouse application on basil grown for consumer transplants)	8 fl oz/A	1	4	For use in basil grown for sale to consumers and grown in an enclosed greenhouse with permanent flooring.
Mefenoxam	4	Subdue Maxx (greenhouse; some resistance)	21.7 mL/1000 ft sq	21	48	Must be mixed with another FRAC group. Apply at seeding or as a transplant tank mix. One application each.

Active ingredient	FRAC group	Trade names	Label rates	Harvest (days)	Reentry (hours)	Comments
Oxathiapiprolin	9 (formerly U 15)	Segovis (greenhouse application on basil grown for consumer transplants)	4–8 mL/5,000 ft sq (1.1–2.4 fl oz/A)	N/A, trans-plants only	4	For re-sale as consumer transplants only. Apply in at least 15 gal/A.
Potassium phosphite	P 07	ProPhyt (label is silent on greenhouse use)	3–4 pt/A	0 days	4	7-day interval. Apply in 30 gal/A. Water pH >5.5.
Mono- and di-potassium salts of phosphorous acid and mono- and di-potassium phosphite and variations of these active ingredients (many possible brands; those listed here have been used in-house)	P 07	Confine Extra (greenhouse)	3–4 quarts/A	Up to day of harvest	4	Read label for specific warnings. General warnings: Apply in at least 20 gal/A. Do not apply at less than 3-day intervals. Do not apply to foliage of plants treated with copper-based compounds at less than 20-day intervals. Do not apply when conditions favor wet tissue for prolonged periods (>4 hours). Do not use acidifying type compatibility agents.
		K-Phite	1–4 quarts in a minimum of 50 gallons of water/A	Up to day of harvest (0-day PHI)	4	Lower rate 7–28 days, higher rate at 7- to 14-day intervals until control is reached. Under severe circumstances, application can be made at intervals of up to every 3 days. Do not apply when conditions favor wet tissue for prolonged periods.
		Resist 57 (greenhouse)	1–3 quarts/A	Up to day of harvest	4	Apply in at least 20 gal/A. Apply in 2- to 3-week intervals. Do not apply at less than 3-day intervals. Do not apply when conditions favor wet tissue for prolonged periods (>4 hours). Do not apply to foliage of plants treated with copper-based compounds at less than 20-day intervals.
		Rampart Fungicide (greenhouse)	3–4 quarts/A	Up to day of harvest	4	Apply in at least 20 gal/A. Do not apply in less than 3-day intervals. Do not apply when conditions favor wet tissue for prolonged periods (>4 hours). Rampart Fungicide is a slightly acidic buffer solution. Avoid mixing Rampart with strongly acidic or alkaline materials or compatibility agents. Do not apply to foliage of plants treated with copper-based compounds at less than 20-day intervals.

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