The Basics of Turfgrass Fungicides
Part Four: Handling and Applying Fungicides

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Acquiring knowledge of fungicide properties and their behavior in soils and plants is only half the job of implementing an effective and environmentally responsible fungicide program. Undoubtedly the most important part of this process is making sure that you are delivering the proper amounts of the correct fungicide to the appropriate place at the right time. To assure this, routine monitoring of your application procedures and equipment is necessary.

Studies have shown that the vast majority of turfgrass managers do not actually apply what they think they are applying. Nearly all make mistakes in mixing, loading, configuring equipment, and calibrating delivery devices. National losses due to these mistakes have been estimated to be in the billions of dollars. Additional losses have occurred because of reduced fungicide efficacy resulting from improper measuring and calibration. It is important, therefore, that care be taken in measuring, mixing, and loading fungicides and in routinely calibrating and maintaining equipment. Further precautions should be taken to assure proper timing and placement of fungicide applications.

Measuring, weighing and mixing fungicides

It is important that the proper protective clothing, including chemical-resistant gloves, goggles, and a respirator be worn when handling any fungicide since the concentrated forms of the fungicides can be particularly dangerous if splashed onto your skin or in your eyes. Also, some fungicide formulations such as wettable powders may be quite dusty during handling and may easily be inhaled. It is important to avoid smoking, eating, or drinking during fungicide handling operations since you could easily carry the fungicide to your mouth with contaminated hands or food. In general, utmost cleanliness and hygiene should be practiced during any and all fungicide handling operations.

Nearly all fungicides commonly used for turfgrass disease control are purchased as concentrated formulations and require some sort of measuring and mixing to dilute the fungicide prior to application. The amount of mixing and handling depends to a large extent on the type of formulation. Many granular formulations come packaged in bags in sufficient quantity to cover a designated area. Similarly, water soluble packets contain prepackaged fungicide formulations that are mixed with water and used to treat a designated area. In both of these cases, minimal measuring and weighing are required. However, for formulations such as wettable powders (WP), water dispersable granules (WDG), emulsifiable concentrates (EC), and flowables (F or FLO), a certain degree of measuring, weighing, and mixing are necessary for proper application.

It should be obvious that measuring out the correct amount of fungicide is critical for optimum fungicide efficacy. Too little may result in inadequate control and too much may result in phytotoxicity or other undesirable side effects. Both liquids and wettable powders/WDG's are mixed with water in basically the same manner. A given volume or weight of formulations is added to a measured volume of water. The amount of fungicide and water are determined from the desired rates of application and the output of the sprayer.

Fungicide compatibilities

When mixing fungicides together with other pesticides, growth regulators, or fertilizers, the compat-

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ibility of the mixture can be a serious consideration in determining fungicide efficacy. In some cases, combinations resulting in enhanced levels of fungicidal activity have been identified. These include combinations of sterol inhibiting systemic fungicides and chlorothalonil for the control of a number of turfgrass pathogens, combinations of metalaxyl/mancozeb, fosetyl Al/mancozeb, chloroneb/thiram, and etridiazole/PCNB for the control of *Pythium* diseases, and anilazine/Zn (or Cu) for the control of anthracnose. However, in many cases, combinations of other chemicals with fungicides can reduce the efficacy of the fungicide. The physical and chemical compatibilities of the spray partners are of the most concern.

The physical compatibility of the materials should first be tested to be sure that no unwanted oily films and layers, foams, flakes, gels, or precipitates are formed. Additionally, wettable powders should be checked for lumps when mixed with some materials whereas some liquid formulations may settle into layers when mixed with other chemicals. Physical compatibilities can be tested easily by preparing the appropriate concentrations of tank-mixed components each in a small container. Add each component one by one to the fungicide suspension, shaking between each addition. When all of the components have been mixed together, gently shake the container and examine the contents immediately after shaking to see if there is any excessive foaming, and after 30 minutes to 1 hr to check for any precipitates. If the mixture does not look uniform, it should not be used as a tank mix.

The chemical compatibility of the tank mix partners should also be considered. Don't mix anything that will lead to a highly alkaline or highly acid condition, since this will lead to the degradation of some fungicides. Don't use adjuvants unless you know they are safe. If you are unsure of the phytotoxicity of a mixture, perform a test on a small area of turf before mixing on a large scale. Phytotoxicity can be affected by the air temperature, plant stress, plant genotype, etc. Finally, do not mix materials targeted for both foliar and root problems unless each material in the mixture behave similarly in the plant (e.g., they are each contact materials, each localized penetrants or each upwardly-moving systemic fungicides). Otherwise, less than optimal control will result for one of the diseases in the complex. Similarly, do not mix fungicides with essentially the same mode of action. This can lead to phytotoxicity.

Fungicide formulations are more effectively mixed with other chemicals of similar formulation. For example, liquids can be mixed more effectively with other liquids and wettable powders or water dispersable granules can be mixed with other wettable powders or water dispersable granules. However, it is also common to mix fungicides with other materials having different formulations.

When mixing liquids and solids in the same spray tank, it is important that they be added in the correct order to insure proper dispersion and uniformity. A convenient way to remember the proper order is to use the sequence W-A-L-E where W stands for wettable powders and water-dispersable granules, A stands for agitation, L stands for liquids, and E stands for emulsifiable concentrates. The proper procedure is as follows:

1. Add wettable powders and water dispersable granules first to a tank half full of water.

2. Agitate until these formulation are uniformly dispersed while adding water until the tank is 90% full.

3. Add all flowable liquids and other water soluble formulations.

4. Finally, add emulsifiable concentrates.

5. Top off the tank and continue agitation.

The materials are now properly mixed.

As always, the tank contents should be properly and continuously agitated during spray operations since many formulations form suspensions and not true solutions. And finally, always consult the label for compatibility information. Most fungicide labels will list compatible or incompatible combinations when they are known and have been tested.

Tank storage time and pH affect fungicide efficacy

Fungicides should, whenever possible, be mixed and sprayed as soon after mixing as possible. However, in cases where fungicide mixtures are placed in the spray tank in advance of the application, special precautions must be taken to avoid chemical decomposition of the fungicide as it sits in the tank. One of the primary factors contributing to the instability of a fungicide is the pH of the water.

Most of the water used to prepare fungicide sprays in the United States is quite alkaline (high pH). Studies have shown that under these alkaline conditions, a number of commonly-used fungicides can break down and lose their effectiveness (Table 1). For example, anilazene, chlorothalonil, thiophanates, and thiram are all hydrolyzed at pH values greater than 9.0. A few fungicides such as fosetyl Al and benomyl are unstable at pH levels below 5.0. Fungicides such as iprodione, vinclozolin, propiconazole, and triadimefon are insensitive to pH and remain stable even after storage in the spray tank for 24 hr.

Even though many fungicides are relatively stable at extremes in pH, storage in the tank for prolonged periods of time will accelerate their decomposition and the loss of their effectiveness. For example, even though fenarimol is relatively stable when initially mixed, it is unstable at acid pH values when stored for 24 hours or more.

Because of the critical role of pH in fungicide efficacy, the water used for spray applications should be checked on a weekly basis and the pH adjusted if necessary. More importantly, the pH of the fungicide mixture should be determined and adjusted if necessary. A number of commercially available buffering agents are useful for such pH adjustments. A pH range of 5-6 is most desirable.

Table 1. pH stability and photostability of turfgrass fungicides

Fungicide	Comment
Chloroneb	Stable
Cyproconazole	Stable
Etridiazole	Stable
Flutolanil	Stable
Metalaxyl	Stable
Propamocarb	Stable
Propiconazole	Stable
Triadimefon	Stable
Benomyl	Unstable at pH<4
Fosetyl Al	Unstable in acidic (pH<2) and alkaline (pH>9) conditions
Anilazene	Unstable at pH>9
Chlorothalonil	Unstable at pH>9
Mancozeb	Unstable at pH>7
Quintozene	Unstable at pH>9
Thiophanate methyl	Unstable at pH>9
Thiram	Unstable at pH>9
Vinclozolin	Unstable at pH>9
Fenarimol	Photodecomposes rapidly
Iprodione	Unstable at pH>7, Photodecomposes in aqueous suspensions

Compiled from: Tomlin, C., 1994. The Pesticide Manual, 10th Edition, Crop Protection Publications, British Crop Protection Council, UK, 1341 pp.

Proper equipment calibration

Considerable effort goes into the determination of proper fungicide application rates described on the label. It is important, therefore, that the proper amount of fungicide is delivered to the area to be treated. The effectiveness of any fungicide will depend on the proper application and placement of the material. Proper calibration insures that your application equipment is delivering the correct amount of fungicide to the area being treated. Even if you have meticulously weighed and mixed the fungicide, improper delivery of the spray will result in less than desirable disease control.

It has been estimated that 60% of all sprayers have calibration errors greater than 10%. Nearly 45% of all sprayers have more than a 10% variation in discharge from individual nozzles. In addition to these problems, many sprayers are used at inaccurate travel speeds and improper boom height for the type of nozzle and spacing, have pressure gauges that read too low, and have an inadequate match between hose size and nozzle type.

Determining the output of a sprayer

The output of a sprayer is one simple estimate of overall sprayer performance. It is the amount of spray material delivered per unit area. The output can be measured by first marking off an area 100 ft by 100 ft or any area equivalent to 10,000 sq. ft. Fill the spray tank with water and spray the entire area as if you were applying the fungicide. When you have finished, measure the amount of water needed to refill the tank. Divide this amount by 10; this represents the delivery rate per 1000 sq. ft. Also the amount of spray delivered per 1000 ft^2 multiplied by 43,5 equals the amount applied per acre. Alternatively, you can determine the time it takes to cover the desired treated area. With the sprayer motionless, you can then collect the spray delivered in the predetermined time period and measure its volume. While it is useful to perform this test from time to time through the season to monitor sprayer performance, it will not reveal problems with unequal delivery among nozzles. These should be examined separately.

Calibration of nozzle output on boom sprayers

The following steps are recommended for the calibration of boom sprayers:

1. Make sure all nozzles are of the desired type and that the pressure at the nozzle is appropriate for the nozzle being used. Flat fan and swirl chamber nozzles often perform best at pressures of 30-60 psi.

2. Clean nozzles and screens to remove any material that could potentially clog the nozzle or impede delivery.

3. Check to see that the spray pattern from each nozzle is uniform and that the spray patterns overlap by 30-50%.

4. Measure the delivery volume of each nozzle. This can be done by placing the same-sized containers under each nozzle. If all containers fill at the same rate, your nozzles are OK. Replace nozzles that deliver more or less volume than the average nozzle output.

5. Select your operating speed (usually 3-5 mph). Be sure to use the same speed during calibration as that used during spray applications.

6. Determine the delivery rate as described above.

Calibration of granular applicators

Granular application equipment comes in a variety of sizes and consists of drop types and rotary types. In either case, calibration involves determining the weight of material applied per unit area. In all cases, the granular material to be applied should also be used in the calibration since different granule sizes and shapes flow at different rates. Speed is usually not a critical factor but should be chosen such that it allows the material to flow freely.

It is important to realize that once your equipment is properly calibrated, it needs to be recalibrated and the delivery checked on a regular basis. Fungicide delivery may change with equipment wear, gauge error, nozzle wear, wheel slippage, speedometer error, and friction loss. It is important, therefore to monitor your equipment continuously and recalibrate regularly. This includes cleaning or replacing nozzles and checking nozzle pressure, checking nozzle spacing, boom height, and sprayer output. Proper calibration will insure that you are not wasting material or sacrificing fungicide efficacy.

Timing of fungicide applications

The timing of fungicide applications is another critical aspect of maximizing fungicide performance. Application timing is more complicated than it appears at first glance. Of obvious importance is the timing of an application relative to the active stages of the pathogen. However, other timing considerations include the time of day, temperature/humidity relationships, wind patterns, and practical considerations of traffic and public perceptions.

For optimum disease control, fungicide applications must be timed to coincide with periods when the target pathogen is in an active growth stage. This is the stage most susceptible to fungicide treatment. Most often these periods of pathogen activity correspond with symptom development in the turfgrass plant. Therefore, most fungicide applications are best made as a curative application after a correct diagnosis has been made. However, with some diseases, the period of maximum pathogen activity precedes the development of symptoms, sometimes by several months. This is the main reason why fungicides used for summer patch control must be applied in the late spring even though summer patch symptoms typically appear in mid to late summer.

Pathogens in a dormant stage are generally not susceptible to fungicides.

Another important timing consideration is the time of day, particularly as it relates to temperature and humidity relationships. Both temperature and humidity can affect fungicide drift. The higher the temperature and lower the relative humidity, the greater the opportunity for fungicide evaporation or volatilization. Under these conditions, small spray droplets may evaporate completely, leaving volatilized fungicide residues in the air where they may travel up to several miles from the spray site. This can be avoided by applying early in the morning when temperatures are lower and relative humidifies are higher than is normally the case during the middle parts of the day.

In addition to the reduced drift hazard from fungicide volatilization early in the morning, drift may also be minimized in the morning hours because of calmer winds and lower convective air turbulence. As the turf surface heats up and solar radiation becomes stronger during the day, a greater temperature differential occurs between the turfgrass surface and the air. This creates upward air currents that can carry spray droplets away from the target site.

Another important timing consideration is the impact of spray applications on public exposure. With the exception of some golfers, most people are less likely to frequent turfgrass sites early in the morning or late in the evening than at other times of the day. Therefore, these times are ideal for avoiding potential public exposure to fungicides and for minimizing the opportunities for the public to become concerned over a pesticide application and to question the environmental responsibility of the pesticide application and of the applicator.

Fungicide placement

Fungicide placement is one of the more important factors affecting fungicide performance. Generally, if the fungicide does not come in contact with the pathogen, the disease will not be controlled. The nature of the disease to be controlled, the amount of thatch, and some of the inherent properties of the fungicide being used all determine where the fungicide should be placed. For example, if the disease to be controlled is caused by a pathogen that infects and survives in the foliage, placement of the fungicide is generally not a problem. The fungicide can simply be applied as a spray. However, if the disease to be controlled is caused by a root-infecting pathogen, placement of the fungicide becomes more problematic.

The main difficulty in placing the fungicide in contact with root pathogens is getting the fungicide through the thatch layer. Generally, the thicker the thatch layer, the more impenetrable it is to fungicide movement. Since many of the fungicides used for turfgrass disease control are adsorbed quite readily to thatch, other techniques must be used to get the fungicide into the root zone. This can be accomplished either by aerification prior to the fungicide application, or by applying excessive amounts of water to leach the fungicide into the root zone.

Another consideration in fungicide placement is making sure that you avoid skips and overlaps when making applications. Skips leave untreated areas where disease symptoms may develop whereas overlaps may lead to phytotoxicity. There are various ways of monitoring your spray patterns. The most common method involves the use of dyes that color the turf slightly so that the actual spray pattern can be visualized. As with other tank mixed materials, however, care should be taken to assure that dye materials are compatible with the fungicides being applied.

Post-application irrigation and fungicide efficacy

Often, for the control of root diseases on turfgrasses, it is recommended that the fungicide be watered-in. This is because most fungicides are not taken up and translocated inside turfgrass plants to turfgrass rootsand therefore must be moved into the soil profile to contact pathogens. On the other hand, if they are absorbed and only translocated upward in the plant, some action must be taken to place the fungicide in the root zone and allow the fungicide to reach its intended target. Moving the fungicide through the turf/soil profile with water is usually the method of choice.

No firm recommendations are usually made regarding the amount of water required for optimum fungicide activity. This is because the water status of the soil, the soil type, and the chemical nature of the fungicide all affect how much watering-in should be done. Apply too much water, and you leach the fungicide from the root zone or dilute it to the point where it loses efficacy. Use too little water and the fungicide never reaches its intended target.

Little research has been conducted to establish optimum post-irrigation schedules for turfgrass fungicides. However, some general guidelines might be helpful. First, never water in fungicides used for foliar disease control. Studies have shown that if a fungicide applied for foliar disease control is not allowed to dry on the leaf surfaces, there is a significant reduction in its efficacy. For products such as sterol inhibiting fungicides applied for root disease control, the amount of water used to move the fungicide into the root zone should be sufficient also to wet the upper root zone. If the soil is dry to begin with, movement of the water front can be monitored to determine the depth of water penetration. If the soil is already moist, post-spray irrigation should not exceed 1 inch of water. On sandier root zones, this should be reduced to $\frac{1}{2}$ inch.

Often times, fungicides applied for root disease control may be applied in excess of 5 gallons of water per 1000 ft^2. In these cases, a minimal amount of post-irrigation watering is necessary. In all cases, the irrigation should be applied before the fungicide has dried on the foliage.

Monitoring the results of fungicide applications

Many times following a fungicide application, little effort is made to monitor the results of the fungicide application other than by observing that, after a few days, the disease problem does not seem to be getting worse or, alternatively, the fungicide application appears not to have worked. Often, detailed monitoring of the results of a fungicide application can shed light on the nature of the problem, point to potential equipment or application failures, effectively assess fungicide efficacy, and provide a means of adjusting fungicide timing or placement for more effective future disease control.

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