Field Crop Fungicides for the
Field Crop Fungicides for the North Central United States

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Fungicide Terminology

The use of foliar-applied fungicides is common in some field crops grown in the north central United States, such as sugarbeet and potato, but it has not been as common in crops such as corn and soybean. With the availability of many new fungicides on the market that provide very good control of many foliar diseases, and the threat of new diseases (i.e., soybean rust), the use of foliar fungicides on crops where foliar fungicides have not been used historically may increase. This publication will help producers understand fungicides and how they affect plant pathogens. Some common terms are defined below.

**Fungicide**: a chemical agent that kills or inhibits the growth of fungi or fungal-like organisms. Fungicides have at least three names, all of which can be found on the label:

- **Chemical name**: the name of the active ingredient (a.i.) in a fungicide (e.g., methyl (E)-2-{2-[6-(2-cyanophenoxy)pyrimidin-4-yloxy]phenyl}-3-methoxyacrylate).
- **Common name**: a less technical name of the active ingredient (e.g., azoxystrobin).
- **Trade name**: the patented name under which a product is commercially available (e.g., Quadris). The active ingredient (the active component of a fungicide) may be marketed under several different trade names.

**Classification of Fungicides**

Fungicides can be classified a number of different ways, including (1) mobility in the plant, (2) role in protection of plants, (3) breadth of activity, (4) mode of action, (5) chemical group, and (6) Fungicide Resistance Action Committee (FRAC) group.

**1) Mobility in the plant**

*Contact fungicide*: a fungicide that remains on the surface of the plant where it is applied but does not go deeper; these fungicides have no after-infection activity. Repeated applications are needed to protect new growth.
Field Crop Fungicides for the 

of the plant and to replace fungicide that has been washed off by rain or irrigation, or degraded by environmental factors such as sunlight.

Systemic fungicide: a fungicide that is absorbed into plant tissue and may offer some after-infection activity. Very few fungicides are truly systemic (i.e., move freely throughout the plant); however, some are upwardly systemic (i.e., move only upward in the plant through xylem tissue), and some are locally systemic (i.e., move into treated leaves and redistribute to some degree within the treated portion of the plant.

(2) Role in protection (some fungicides can fall into more than one of these categories)

Preventative activity: occurs when a fungicide is present on the plant as a protective barrier before the pathogen arrives or begins to develop, that is, the fungicide prevents infection from occurring (also referred to as a protective activity).

Early-infection activity: occurs when the active ingredient of a fungicide can penetrate the plant and stop the pathogen in the plant tissues, usually most effective 24 to 72 hours after infection occurs, depending on the fungicide. This type of activity is sometimes referred to as “curative” or “kickback” activity. Most fungicides that have early-infection activity also have preventative activity and are most effective when applied before infection occurs.

Anti-sporulant activity: an ability to prevent spores from being produced. In this case, disease continues to develop (e.g., lesions continue to expand), but spores are not produced or released, so the amount of inoculum available to infect surrounding plants is reduced.

(3) Breadth of metabolic activity

Single-site fungicide: fungicide active against only one point or function in one of the metabolic pathways of a fungus or against a single critical enzyme or protein needed by the fungus. These fungicides tend to have systemic properties.

Multi-site fungicide: fungicide that affects a number of different metabolic sites within the fungus.

(4) Mode of action

Mode of action: how a fungicide kills or suppresses a target fungus, which is the specific biochemical process of the target fungus that is affected by a fungicide. Examples are damaging cell membranes, inactivating critical enzymes or proteins, or interfering with key processes such as energy production or respiration.

(5) Chemical group or class

Chemical group or class: the name given to a group of chemicals that share a common biochemical mode of action and may or may not have similar chemical structure. Fungicides approved for use on field crops fall into different chemical groups.
Examples of field crop fungicides that vary in classification.

<table>
<thead>
<tr>
<th>Trade name</th>
<th>Headline</th>
<th>ProLine</th>
<th>Manzate, Dithane, and Penncozeb</th>
</tr>
</thead>
<tbody>
<tr>
<td>Active ingredient</td>
<td>pyraclostrobin</td>
<td>prothioconazole</td>
<td>mancozeb</td>
</tr>
<tr>
<td>Mode of action</td>
<td>Quinone outside inhibitor (QoI)</td>
<td>Demethylation inhibitor (DMI)</td>
<td>Multi-site contact activity</td>
</tr>
<tr>
<td>Chemical group or class</td>
<td>Strobilurin</td>
<td>Triazole</td>
<td>Dithiocarbamates</td>
</tr>
<tr>
<td>Mobility in plant</td>
<td>Locally systemic</td>
<td>Upwardly systemic</td>
<td>Contact</td>
</tr>
<tr>
<td>Role in protection</td>
<td>Protectant</td>
<td>Protectant and early-infection</td>
<td>Protectant</td>
</tr>
<tr>
<td>Breadth of activity</td>
<td>Single-site</td>
<td>Single-site</td>
<td>Multi-site</td>
</tr>
<tr>
<td>FRAC Code</td>
<td>11</td>
<td>3</td>
<td>M</td>
</tr>
</tbody>
</table>

(6) FRAC code

An organization known as FRAC was developed to address the issue of fungicide resistance. This organization developed a code of numbers and letters that can be used to distinguish the different groups based on the mode of action. This code is known as the FRAC code. A detailed description of this code is provided later in this publication.
Fungicide Use

**Foliar-Applied Fungicides**

Foliar fungicides are used to manage fungal disease organisms that infect the aboveground portions of plants. Fungicides are used to protect the potential yield and quality of a crop. The majority of these fungicides protect foliage from infection; therefore, these fungicides should be on the foliage before fungal spores germinate.

Spray control programs to prevent disease have been developed from data through years of research. However, the decision to apply foliar fungicides to a specific field only should be made after considering current and future weather conditions, disease development, potential yield of the crop, and the dollars returned to management with use of the fungicides. Because each disease infestation is unique, the decision to use fungicides may vary depending on conditions in each individual situation.

Droplet size, nozzle type, operating pressure, volume of water, and formulation of fungicide all influence how fungicides should be applied. Fungicide coverage on the targeted crop may be improved with careful consideration and optimization of these variables. Applications can be made either through ground or air application equipment.

Some plant surfaces have a waxy or hairy coating causing some fungicides to collect in large droplets that run off the plant surface, thus reducing fungicide coverage. Using a wetting agent such as spreader-stickers (surfactants) will improve coverage. Information on wetting agents usually can be found on the label or in supplemental brochures. Spreader-stickers usually are incorporated in flowable formulations, so adding a spreader-sticker to fungicides in this form is not necessary and may be detrimental to fungicide performance.
**Seed Treatments**

Fungicidal seed treatment helps protect seed from soil-borne or seed-borne fungi that cause rotting, damping off, seedling blight, or a combination. When seeds germinate under favorable soil conditions, there is less danger of seed and seedling attack from soil-borne pathogens unless seed is of poor quality. Treatment of seed with a protectant fungicide may help with stand establishment when seeds are germinating under unfavorable conditions, such as cold wet weather, or when seed is of poor quality.

Seed may be treated commercially or on the farm. Commercial seed treatment is done using either a slurry treater or various automatic seed treaters. On-farm seed treatment is done using various home-type or slurry mixers. One method is to use a drill-box seed treatment, which is popular because it is quick and easy; no extra steps are required because seed is treated in the drill-box at planting. Another common on-farm method is to add powder or liquid fungicide seed treatment into the base of the auger used to fill the drill-box. This method ensures good mixing and seed coverage; however, if a powder is used, it may cause worker irritation, so adequate protective clothing and a chemical respirator are recommended.

**Other Application Types**

Other fungicide application types may be available for certain fungicides. Check the label carefully to see whether these options are available.

**Fungigation**: This term is used when fungicide is applied through a sprinkler irrigation system. Fungigation is sometimes referred to as chemigation on fungicide labels.

**In-Furrow**: A term used when fungicides are applied in rows of the targeted crop, often at planting time.
Why Fungicides Fail

Many factors may affect success of fungicide application. On certain occasions, fungicide applications fail to manage the targeted disease. The following are possible factors that affect fungicide application success or failure.

**Diagnosis and Fungicide Selection**

One reason for fungicide failure is inaccurate disease diagnosis. Common problems that may be misidentified as fungal diseases include insect damage, chemical injury, bacterial diseases, nematodes, and environmental damage. Fungicide applications do not affect problems due to these causes.

However, even if the problem is accurately diagnosed as a fungal disease, there are some fungicides that will not manage all fungal diseases. Without proper diagnosis, a fungicide may be selected that does not manage the targeted disease. Fungicide labels specify the disease organisms that are controlled by the specific fungicide.

Outdated or improperly stored fungicide materials may lose their activity and fail to work. Fungicides stored longer than 2 years or in inadequate conditions (such as freezing) may lose their activity. Some flowable formulations of fungicides tend to settle out in their containers over time. To help assure the proper dosage of active ingredient, containers must be thoroughly mixed before dispensing the fungicide into the sprayer.

**Fungicide Rates and Proper Mixing**

Fungicides should be used at recommended rates for effective disease management. Fungicide label rates are based on multiple year and location testing to establish the most effective rates under a wide variety of environmental conditions.

Treatment area and the amount of product to add to the mixing tank should be carefully calculated. Errors in calculation can result in ineffective disease control or excessive fungicide bills.
Mixing fungicides with too acidic or alkaline of water can reduce fungicidal activity, especially for water with a pH greater than 8.0. Ideally, water with a pH near 7.0 should be used for mixing pesticides. If water pH is not favorable, it can be corrected with pH buffers that are added to the water before mixing in fungicides.

Mixing multiple pesticides in a spray tank can save time but compatibility of products should be tested. Incompatibility can result in the formation of insoluble precipitates in the spray tank. Fungicide labels often contain information on mixing compatibility. If the label does not address compatibility, a small volume of the spray mix may be tested in a glass jar for 30 minutes; separation or settling of pesticides in the jar indicates incompatibility.

The order that pesticides of different formulations are added to the tank also may affect compatibility. Different formulations of pesticides should be added to the tank in the following order: wettable powders, flowables, solubles, powders, surfactants, and then emulsifiable concentrates.

Fungicides begin to lose their activity if they sit too long in the spray tank. Fungicide activity often declines within 12 hours after mixing, and this process is accelerated by poor water quality (sediment, high or low pH).

**Sprayer Calibration and Application**

The most common cause of fungicide-application failure is incorrect sprayer calibration. If a sprayer is not properly calibrated, too much or too little fungicide can be applied, which can result in fungicide toxicity or unmanaged disease. To avoid these problems, sprayers should be recalibrated after any modification to nozzles, pressure, or speed. Also, the fungicide should be applied in the recommended volume of water, at a constant speed, and at the recommended pressure. Spray pressure should be adjusted for the nozzles used. Excessively high sprayer pressures result in small droplets that may drift. Calibrating and adjusting a sprayer takes time and effort, but it can save money and make fungicide applications more effective. The boom width should be carefully measured and drive rows adjusted to avoid sprayer misses or overlap between field passes.

**Environmental Considerations**

Weather forecasts help predict success of a fungicide application. A general rule for length of time of application before rainfall: systemic fungicides need a minimum of 3 hours on the plant surface before a rain event; contact fungicides are always sensitive to rain removal, but more so before their drying on the plant surfaces.

**Resistance**

Fungicide resistance also is one cause of fungicide failure, but often may not be the most likely reason. The only way to be certain if there are fungicide-resistant pathogens in the field is to have the pathogens tested in a qualified lab. A more complete discussion of fungicide resistance is on page 12.
Safety and Fungicide Use Restrictions

A pesticide label will provide most of the needed safety information for both the applicator and others while spraying field crops. A synopsis of some of the dangers and restrictions for some common fungicides is provided below.

Personal protective equipment

Fungicides labeled for use on field crops have minimal requirements for personal protective equipment, with a few exceptions:

- long-sleeved shirt and pants,
- shoes plus socks, and
- chemical-resistant gloves.

Some fungicides require coveralls over regular work clothing, and some fungicides only require waterproof gloves. Also, many of the available fungicides require protective eyewear.

Other personal protective equipment requirements may include chemical-resistant footwear, chemical-resistant headgear for overhead exposure, and a chemical-resistant apron when cleaning, mixing, or loading (e.g., Headline®). A few fungicides may require the use of a respirator. The details about the specific type of respirator will be listed on the label.

Worker Protection Standard (WPS)

The WPS is a federal regulation designed to protect agricultural workers and handlers. It covers pesticides that are used in the production of agricultural plants on farms, forests, nurseries, and in greenhouses. If the pesticide being used has an “Agricultural Use Requirement” statement in the “Directions for Use” section of the label, the applicator must comply with the
WPS. The most recent information about the Standard may be obtained by checking the September 2005 updated WPS *How to Comply* manual. A helpful website that has information about the WPS is [http://www.epa.gov/agriculture/twor.html](http://www.epa.gov/agriculture/twor.html).

**Restricted-Entry Interval (REI)**

All agricultural pesticides labeled after April 1994 are required to have a REI stated on the label. REIs for fungicides, like other pesticides, are established to reduce pesticide exposure and are based on the product toxicity. REIs typically range from 12 to 24 hours for most fungicides available for field crops. In general, workers may not enter a treated area during an REI. Early entry that will result in contact with surfaces treated with pesticides is permitted in only three work situations:

- **Short-term tasks that last less than 1 hour and do not involve hand labor.**
- **Emergency tasks that take place because of an agricultural emergency.**
- **Specific tasks approved by EPA through a formal exception process, which includes additional pesticide training for the worker.**

**Preharvest Interval (PHI)**

A PHI is the minimum amount of time that must pass between the last pesticide application and the harvesting of the crop, or the grazing or cutting of the crop for livestock feed. Typically, PHIs for fungicides applied to field crops range between 21 and 30 days depending on the crop and applied fungicide. Chlorothalonil products have 42-day PHIs. Some fungicides have restrictions based on growth stages instead of a specific number of days (e.g., fungicides cannot be applied later than soybean growth stage R5). If a crop is harvested before the PHI has passed, there may be excessive pesticide residues on that crop. Fungicide labels should be carefully reviewed for specific use limitations.

**Other restrictions and precautions**

Additional restrictions or precautions are specific to individual fungicide labels. Labels should be read carefully before application to get specific information for the product being used. Some examples of specific restrictions or precautions include

- **Restrictions against using treated crop for livestock bedding or feeding.**
- **Restrictions on use of fungicide near waterways.**
- **Plant back restrictions for certain crops.**
- **Precautions about use on certain varieties of a crop.**
Safety and Seed Treatments

Seed treatment products also need care in handling—if not highly poisonous, many are at least irritating to the eyes and nose. Treated seed usually is identified by the dye used with the chemical. Treated seed should not be fed to livestock or used for human food. Pesticide containers should be disposed of properly in a landfill or buried in an area where there is no surface drainage to nearby waterways. If seed treatment cannot be done outdoors, it should be done in a well-ventilated room. Commercial seed treaters should have an adequate air exhaust system for treatment rooms. Workers exposed to seed treatment chemicals for long periods should have an approved chemical mask and the filter should be changed frequently.

For more detailed information on pesticide safety and restrictions, fungicide labels and material safety data sheets (MSDSs) should be carefully read. Many fungicide labels and MSDSs can be found online at manufacturer websites as well as the Crop Data Management Systems (http://www.cdms.net) and Greenbook (http://www.greenbook.net) websites.

Also, information can be found at local extension offices or at the following websites:

- American Association of Pesticide Safety Educators (AAPSE): http://aapse.ext.vt.edu/
- What is a pesticide? (U.S. EPA): http://www.epa.gov/pesticides/about/
- EXTOXNET—Extension Toxicology Network: http://extoxnet.orst.edu/
- National Pesticide Information Center (NPIC): http://npic.orst.edu/

Soybean seeds treated with a fungicide and blue dye.
Fungicide Resistance and the FRAC Code

Because fungal pathogens are often highly variable and may be able to adapt to repeated fungicide sprays, resistance management may become an issue. Because resistance may lead to unexpected and costly crop losses to growers, and loss of a valuable product, it is important to protect effective groups of fungicides.

The first fungicides were sulfur and copper based. Mercury fungicides were developed in the early 1900s, and they were widely used until it was discovered that they were highly toxic to animals. In the 1940s and 1950s, fungicides such as Captan® and Maneb® were introduced. All of these fungicides are contact fungicides and only work if applied before infection. These older fungicides have another important characteristic: they affect a number of different biochemical sites within the fungus, so fungicide resistance has not readily appeared.

More recently, highly effective fungicides, such as the demethylation inhibitors (DMIs) (e.g., triazoles) and quinone outside inhibitor (QoI) fungicides (e.g., strobilurins) with specific modes of action, have been developed. These fungicides affect one specific site or function in one metabolic pathway of the fungus. The fungus only has one barrier or one change in site or function to overcome the action of the fungicide. Thus, the problem of fungicide resistance has emerged, and it is on the increase because growers have relied more and more on these newer fungicides.

Avoid Fungicide Resistance

To reduce the pressures that select for fungicide resistance in a pathogen population, it is important to know which fungicides belong to the same chemical class. A descriptive numerical code has been developed to help define fungicides that have the same mode of action and belong in the same chemical class. (A thorough description of this code follows; see FRAC code section). Fungicides should be periodically alternated or
used in mixtures with fungicides belonging to different chemical classes, to reduce the risk of selecting for fungicide resistance. Thus, alternating between azoxystrobin and trifloxystrobin does not result in alternating between chemical classes, because both fungicides belong to the QoI fungicide class. In this case, resistance to one of these products will result in resistance to the entire QoI chemical family (referred to as cross-resistance).

The number of applications allowed for each fungicide is indicated on the label. Fungicides should not be applied below the recommended rates. A solo or single application of the same high-risk fungicide, or fungicide class, should not be applied in back-to-back applications, regardless of how many applications the label allows. If available, premix products that contain both preventative and early-infection fungicides may be used. Treated fields should be monitored for signs of resistance development. Fields should be scouted prior to fungicide application and after application to detect fungicide-resistant pathogens. Note, however, that some diseases will continue to develop in fields where the first application was made if some infections had already occurred but weren’t visible. These situations could easily be confused with resistance development.

### Fungicides available for use on different field crops in the North Central Region*

<table>
<thead>
<tr>
<th>FRAC Code</th>
<th>Chemical group</th>
<th>Active ingredient common name</th>
<th>Risk of resistance</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Methyl Benzimidazole Carbamates (MBC)</td>
<td>Thiabendazole, Thiophanate-methyl</td>
<td>High</td>
</tr>
<tr>
<td>2</td>
<td>Dicarboximides</td>
<td>Iprodione, Vinclozolin</td>
<td>Medium to high</td>
</tr>
<tr>
<td>3</td>
<td>Demethylation inhibitors (DMI)**</td>
<td>Cyproconazole, Difenconazole, Fenbuconazole, Flusilazole, Flutriafol, Imazalil, Metconazole, Myclobutanil, Propiconazole, Prothioconazole, Tebuconazole, Tetraconazole, Triticconazole</td>
<td>Medium</td>
</tr>
<tr>
<td>4</td>
<td>Phenylamides</td>
<td>Mefenoxam, Metalaxyl</td>
<td>High</td>
</tr>
<tr>
<td>7</td>
<td>Carboxamides</td>
<td>Boscalid, Carboxin, Flutolanil</td>
<td>Medium</td>
</tr>
<tr>
<td>9</td>
<td>Anilinopyrimidines</td>
<td>Cyprodinil, Pyrimethanil</td>
<td>Medium</td>
</tr>
</tbody>
</table>
# Fungicides, continued

<table>
<thead>
<tr>
<th>FRAC Code</th>
<th>Chemical group</th>
<th>Active ingredient common name</th>
<th>Risk of resistance</th>
</tr>
</thead>
<tbody>
<tr>
<td>11</td>
<td>Quinone outside Inhibitors (QoI)***</td>
<td>Azoxystrobin</td>
<td>High</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Famoxadone</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Fenamidone</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Fluoxastrobin</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Pyraclostrobin</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Trifloxystrobin</td>
<td></td>
</tr>
<tr>
<td>12</td>
<td>Phenylpyrroles</td>
<td>Fludioxonil</td>
<td>Low to medium</td>
</tr>
<tr>
<td>14</td>
<td>Aromatic hydrocarbons</td>
<td>Chloroneb</td>
<td>Low to medium</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Quintozene (PCNB)</td>
<td></td>
</tr>
<tr>
<td>21</td>
<td>Quinone inside inhibitors (QiI)</td>
<td>Cyazofamid</td>
<td>Medium to high</td>
</tr>
<tr>
<td>22</td>
<td>Benzamides</td>
<td>Zoxamide</td>
<td>Low to medium</td>
</tr>
<tr>
<td>27</td>
<td>Cyanoacetamide-oximes</td>
<td>Cymoxanil</td>
<td>Low to medium</td>
</tr>
<tr>
<td>28</td>
<td>Carbamates</td>
<td>Propamocarb</td>
<td>Low to medium</td>
</tr>
<tr>
<td>29</td>
<td>Oxidative phosphorylation uncouplers</td>
<td>Fluazinam</td>
<td>Low</td>
</tr>
<tr>
<td>30</td>
<td>Organo tin compounds</td>
<td>Fentin hydroxide (triphenyltin hydroxide)</td>
<td>Low to medium</td>
</tr>
<tr>
<td>32</td>
<td>Heteroaromatics</td>
<td>Hymexazole</td>
<td>Not known</td>
</tr>
<tr>
<td>33</td>
<td>Phosphonates</td>
<td>Phosphorous acid and salts</td>
<td>Low</td>
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<tr>
<td>40</td>
<td>Carboxylic acid amides</td>
<td>Dimethomorph</td>
<td>Low to medium</td>
</tr>
<tr>
<td>M</td>
<td>Multi-site activity</td>
<td>Captan</td>
<td>Low</td>
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<tr>
<td></td>
<td></td>
<td>Chlorothalonil</td>
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</tr>
<tr>
<td></td>
<td></td>
<td>Copper</td>
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<tr>
<td></td>
<td></td>
<td>Mancozeb</td>
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<tr>
<td></td>
<td></td>
<td>Maneb</td>
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<td></td>
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<td>Metiram</td>
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<td>Sulfur</td>
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<tr>
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<td></td>
<td>Thiram</td>
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</tr>
</tbody>
</table>

*At the time this table was developed, some active ingredients may have emergency use exemptions only or are experimental. Also, some may be part of a pre-mixture or co-pack and some may not be available for all states.

**Some in the DMI group may be referred to as “triazoles.”

***Some in the QoI group may be referred to as “strobilurins.”
General recommendations for avoiding fungicide resistance:

- Tank mix "at risk" fungicides with fungicides that have a different mode of action. The other fungicide also has to provide effective disease control.
- Follow label instructions concerning the maximum number of sprays per season.
- When multiple applications are required, alternate or tank mix fungicides with fungicides with a different mode of action.
- Apply fungicides according to manufacturers’ recommendations for the target disease at the specific crop growth stage indicated.
- Apply fungicides preventively or as early as possible in the disease cycle. Do not rely on fungicides for management once disease intensity has passed economic threshold levels. Avoid curative fungicide applications, especially with single site fungicides.
- Reduced rate programs must not be used because they tend to accelerate the development of resistant populations.
- Refer to label recommendations for rates.

The FRAC code

FRAC is a group of professionals whose goal is to provide fungicide resistance management guidelines to prolong the effectiveness of fungicides and to limit crop losses should resistance occur. The committee is comprised of a Central Steering Committee, four Working Groups, and three Expert Forums. Each of the Working Groups and Expert Forums represent a fungicide class. Each publishes background information, resistance status and specific recommendations for resistance management (http://www.frac.info/frac).

The FRAC group developed codes that represent the mode of action of individual fungicides. To avoid the selection of fungicide resistance, fungicides with the same FRAC code should not be tank mixed or alternated with fungicides with the same FRAC number in a spray program. Some fungicides are labeled "M," which means that the fungicide acts upon multiple sites and resistance risk is low.
Chemical Classes

**FRAC Code 1 • Methyl Benzimidazole Carbamate (MBC) Fungicides**

MBC fungicides are registered on many different field crops as both seed-applied and foliar-applied products. These fungicides are effective against a broad range of fungi that cause leaf spots, root and crown rots, stem rots, and powdery mildew, but not rusts. MBC fungicides registered for use on field crops include thiophanate-methyl and thia benzazole (TBZ).

**How do they work?**

MBC fungicides inhibit tubulin biosynthesis, which interferes with normal cell division (mitosis) in sensitive fungi. MBC fungicides have both preventative and early-infection activity on target fungi.

**Where do MBC fungicides move in the plant?**

These fungicides have systemic properties, but they cannot move down the plant, so they are more effective when complete coverage of the plant is achieved. Canopy penetration is essential for good control.

**What is the risk of fungicide resistance?**

The target site for MBC fungicides is β-tubulin. Modification of a single amino acid in a fungus can result in resistance; therefore, the risk of resistance developing to these fungicides is high. Resistance to MBC fungicides was first reported in 1970, and MBC fungicides have lost effectiveness for many important diseases.

**FRAC Code 2 • Dicarboximide Fungicides**

Dicarboximide fungicides are used on many different types of plants, including field crops, stone fruits, grapes, ginseng, cole crops, some berry, greenhouse, vegetable, field, turf and ornamental crops. Iprodione and vinclozolin are dicarboximide fungicides registered for use on a few field crops.
These fungicides are highly effective against several different fungal pathogens, including \textit{Alternaria}, \textit{Botrytis}, and \textit{Sclerotinia} spp.

**How do they work?**

These fungicides interfere with the osmotic signal transduction pathway, which affects germination of spores and growth of mycelium.

**Where do dicarboximide fungicides move in the plant?**

Some dicarboximide fungicides exhibit locally systemic properties. Depending on product and crop, dicarboximide fungicides may provide protection for 14 to 21 days.

**What is the risk of fungicide resistance?**

The risk of fungicide resistance is medium to high, so appropriate resistance management strategies should be followed. To minimize the risk, the number of applications should be limited to two or three per crop per season. Where possible, dicarboximide fungicides should be rotated or tank mixed with fungicides from different chemical groups.

**FRAC Code 3 • DMI Fungicides**

The fungicide group DMIs that contain the triazole fungicides was introduced in the mid-1970s. Several DMI fungicides have been labeled or are in the process of being labeled for use on field crops—including cyproconazole, difenoconazole, fenbuconazole, flusilazole, flutriafol, imazalil, metconazole, myclobutanil, propiconazole, prothioconazole, tebuconazole, tetraconazole, and triticonazole.

DMI fungicides are used on field crops, fruit trees, small fruit, vegetables, and turf. These fungicides are highly effective against many different fungal diseases, especially powdery mildews, rusts, and many leafspotting fungi.

**How do they work?**

The DMI fungicides inhibit one specific enzyme, C14-demethylase, which plays a role in sterol production. Sterols, such as ergosterol, are needed for membrane structure and function; thus they are essential for the development of functional cell walls. Therefore, these fungicides result in abnormal fungal growth and eventually death.

Each DMI compound may act in a slightly different part of the biochemical sterol-producing pathway. Although the results are similar in various fungi—abnormal fungal growth and death—there are great differences in the activity spectra of these fungicides. For example, triazoles have no effect against spore germination because spores contain enough sterol for the formation of germ tubes. Some spores even have enough sterol to produce infection structures so, in some cases, triazoles may not be effective against infection of the host tissue.
DMI fungicides may be applied preventively or as early-infection treatments. When applied as an early-infection treatment, applications must be made early in the fungal infection process. Some triazole fungicides have antisporeulant properties, which means they inhibit spore production and therefore help to slow disease development. However, if a fungus begins to produce spores on an infected plant, triazole fungicides are then not effective.

Where do DMI fungicides move in the plant?

Although the DMI fungicides don’t have the degree of systemic movement of many herbicides, they are locally systemic and more mobile in plant tissues than some fungicides. After application, the active ingredient is readily taken up by leaves and moves within the leaf. Studies have shown that three droplets of a labeled rate of a DMI fungicide applied to a soybean trifoliolate leaf covered the entire leaf within one day. Note, however, that DMI fungicides are not necessarily transported from one leaf to another leaf or from one part of the plant to another part. They also do not move down plants through the phloem. Most DMI fungicides have a residual period of approximately 14 days.

What is the risk of fungicide resistance?

There are resistance concerns because the fungicide site of action is very specific. Resistance has occurred on other plant pathogens, including some rusts. Some of the DMI fungicides have disappeared from the marketplace because resistance to them developed and they no longer provided any benefit or advantage in a disease control program. Resistance management practices for DMI fungicides should include avoiding repeated applications of DMI fungicides alone in the same season against a high-risk pathogen.

FRAC Code 4 • Phenylamide Fungicides

Phenylamide fungicides are used to control fungi-like organisms known as oomycetes (a.k.a. water molds), such as *Phytophthora* and *Pythium*. These fungicides are often used as seed treatments or in-furrow treatments, and include mefenoxam and metalaxyl.

How do they work?

Phenylamide fungicides inhibit the synthesis of ribonucleic acid (RNA). This affects mycelial growth and the formation of spores and infection structures.

Where do phenylamide fungicides move in the plant?

Phenylamide fungicides exhibit systemic properties. The primary movement of phenylamide fungicides in the plant is upward.
What is the risk of fungicide resistance?

The risk of resistance to phenylamide fungicides is high. Resistance of the potato late blight pathogen (*Phytophthora infestans*) and the sunflower downy mildew pathogen (*Plasmopora halstedii*) to phenylamide fungicides is common.

**FRAC Code 7 • Carboxamide fungicides**

Carboximide fungicides registered on field crops include boscalid, carboxin, and flutolanil. Although in the same group, these fungicides differ in their method of application and spectrum of diseases controlled. Boscalid is used primarily as a foliar fungicide with activity against *Botrytis*, *Sclerotinia*, and *Alternaria* species. Carboxin is used primarily as a seed treatment with activity against *Rhizoctonia*, *Tilletia*, and *Ustilago* species. Flutolanil is generally used as a seed treatment or in-furrow treatment to control *Rhizoctonia*.

How do they work?

Carboxamide fungicides inhibit respiration in target fungi. Specifically, the carboxamide fungicides inhibit complex II of fungal respiration.

Where do carboxamide fungicides move in the plant?

Carboxamide fungicides have locally systemic to systemic properties. Movement of carboximide fungicides is translaminar and upwards.

What is the risk of fungicide resistance?

The risk for resistance developing to the carboxamide fungicides is medium. Resistance has been documented for some fungi.

**FRAC Code 9 • Anilinopyrimidine (AP) Fungicides**

The AP fungicides registered on field crops include cyprodinil and pyrimethanil. These primarily foliar fungicides have activity against *Botrytis* species and a few other fungi.

How do they work?

AP fungicides inhibit the synthesis of amino acids. This inhibits fungal penetration and fungal growth both inside and outside the leaf.

Where do AP fungicides move in the plant?

AP fungicides are systemic with upward movement in the plant. Depending on conditions, crop, and disease, AP fungicides can provide protection for 7 to 14 days.
What is the risk of fungicide resistance?

The risk for resistance developing to AP fungicides is medium. Resistance to AP fungicides has already occurred in some Botrytis species. To broaden the spectrum of activity and delay the formation of resistance, AP fungicides often are mixed with other fungicides with activity against the targeted pathogen. In addition, there are restrictions as to the number of applications per season.

FRAC Code 11 • Quinone Outside Inhibitors (QoI) Fungicides

QoI fungicides include three fungicide families, strobilurins and two newer families, represented by fenamidone and famoxadone. Strobilurins labeled for use on field crops include azoxystrobin, fluoxastrobin, pyraclostrobin, and trifloxystrobin. These fungicides are used on most field crops, as well as many fruit trees, small fruit, vegetables, and turf. Strobilurins were derived from a naturally occurring compound found in wood-rotting fungi. Fenamidone and famoxadone, however, are synthetic fungicides. These compounds are very effective on a broad spectrum of fungi. The antifungal activity of QoI fungicides is different than other available fungicides.

How do they work?

QoI fungicides act at the quinol outer binding site of the cytochrome bc1 complex (complex III of fungal respiration). Thus, these fungicides act by inhibiting fungal mitochondrial respiration that stops energy production in the fungus and results in its death.

This group of fungicides should be applied preventively or as early as possible in the disease cycle. They are effective against spore germination and early fungal growth. Once the fungus is growing inside the leaf tissue, QoI fungicides have little or no effect.

Where do QoI fungicides move in the plant?

Most QoI fungicides are locally systemic. They are absorbed into leaf tissue. If a droplet of fungicide is applied to the top surface of a leaf, it will spread out on the surface of the leaf and even move to the cuticle on the other side of the leaf. Some of these fungicides move up the plant in the xylem. Additionally, some may move as a gas above the leaf and readily rebind to the waxy leaf surface. Most have a residual period of approximately 7 to 21 days.

What is the risk of fungicide resistance?

Because QoI fungicides are active only at one specific site, the risk of fungicide resistance is high. To date, there are more than 20 different plant pathogens that have some level of resistance to QoI fungicides.
**FRAC Code 12 • Phenylpyrrole (PP) Fungicides**

PP fungicides include fludioxonil, which is used mostly as a seed treatment in field crops with a broad disease control spectrum. Fludioxonil also has limited use as a foliar fungicide on a few crops.

**How do they inhibit fungi?**

Similar to the dicarboximide fungicides, the PP fungicides interfere with the osmotic signal transduction pathway, affecting germination of spores and growth of mycelium. There is no cross-resistance between the dicarboximide and PP fungicides.

**Where do PP fungicides move in the plant?**

PP fungicides do not have systemic properties so do not move in the plant.

**What is the risk of fungicide resistance?**

The risk of resistance developing to PP fungicides is low to medium.

**FRAC Code 14 • Aromatic Hydrocarbon (AH) Fungicides**

AH fungicides are used primarily as seed treatments on some field crops and include quintozene (a.k.a. pentachloronitrobenzene [PCNB]) and chloroneb. Some AH fungicides can be applied as foliar or in-furrow treatments for control of *Rhizoctonia* and *Sclerotinia*.

**How do they inhibit fungi?**

The mode of action of AH fungicides is not certain, but it is proposed that AH fungicides interfere with lipid and membrane synthesis in target fungi, which will affect mycelial growth.

**Where do AH fungicides move in the plant?**

Some AH fungicides have upward systemic activity, and others are redistributed in the plant through a vapor phase.

**What is the risk of fungicide resistance?**

The risk of resistance developing to AH fungicides is low to medium.

**FRAC Code 21 • Quinone Inside Inhibitors (QII) Fungicides**

Currently, the only QII fungicide commercially available is cyazofamid, which has activity against oomycetes. It is labeled for control of late blight on potatoes.

**How do they inhibit fungi?**

QII fungicides inhibit respiration and energy production by affecting the same enzyme as the QO1 fungicides; however, they act at the quinone “inside” (QI) binding site. Studies have shown that although QO1 and QI
fungicides act on the same enzyme, they remain in different FRAC classes because the binding sites are sufficiently distinct.

Where do Qil fungicides move in the plant?
Cyazofamid has limited systemic activity and should be applied before the pathogen infects the crop.

What is the risk of fungicide resistance?
The risk of fungicide resistance is medium to high, although no resistance has been detected to date. This is because the fungicide is a single-site inhibitor. General fungicide resistance management guidelines should be followed to delay fungicide resistance development.

FRAC Code 22 • Benzamide Fungicides
The only benzamide fungicides currently labeled for use on field crops is zoxamide, which was first used commercially in 2001. Zoxamide specifically targets diseases caused by oomycetes, like late blight on potatoes and downy mildew on vines and vegetables.

How do they work?
Benzamide fungicides destroy microtubules, which affect mitosis and cell division. This inhibits germ tube and mycelial growth. Zoxamide is the first fungicide that targets microtubule assembly in oomycetes.

Where do benzamide fungicides move in the plant?
Zoxamide is not a systemic fungicide, but does have good residual efficacy.

What is the risk of fungicide resistance?
The risk of fungicide resistance is relatively low. There have been no reports of fungicide resistance to zoxamide, both in the field and in laboratory studies. Zoxamide is sold primarily in mixtures with mancozeb.

FRAC Code 27 • Cyanoacetamide-Oxime Fungicides
Currently, the only cyanoacetamide-oxime fungicide available for use on field crops is cymoxanil. This product is applied as a seed treatment to cut potato seed pieces or as a foliar application to potato plants to control late blight.

How do they work?
The mode of action for cymoxanil is unknown. Cymoxanil is a preventative fungicide with some early-infection activity.
Where do cyanoacetamide-oxime fungicides move in the plant?

Cymoxanil has local systemic activity. It penetrates rapidly and when inside the plant, it cannot be washed off by rain. Cymoxanil has relatively short persistence so its period of action improves when combined with other fungicides.

What is the risk of fungicide resistance?

The risk of fungicide resistance is low to medium; however, repeated use of cymoxanil may lead to fungicide resistance. Therefore, it is required that cymoxanil as a foliar spray be tank mixed with another protectant fungicide with a different mode of action. As a seed treatment, cymoxanil must be combined with other fungicides that have registered seed treatment uses in potatoes.

FRAC Code 28 • Carbamate Fungicides

The only carbamate fungicide available is propamocarb hydrochloride, which is labeled for use against potato early and late blight. The mode of action is different compared to other oomycete fungicides, so it provides an option against strains that have developed resistance to other fungicides. Propamocarb also is available for use on certain vegetables, turf, ornamentals and some greenhouse grown plants.

How do they work?

Carbamate fungicides disrupt the formation of fungal cell walls by interfering with synthesis of phospholipids and fatty acids. They also affect mycelial growth, spore production and germination.

Carbamate fungicides are protectant fungicides with systemic activity. They should be applied before infection when conditions are favorable for disease development.

Where do carbamate fungicides move in the plant?

Carbamate fungicides are absorbed by roots and leaves and are transported upwards in the plant.

What is the risk of fungicide resistance?

Fungicide resistance risk for carbamate fungicides is low to medium. It is recommended that these fungicides are rotated with different groups of fungicides that control the same pathogens, or to use tank mixtures with fungicide from a different group, including the multi-site activity fungicides. Another precaution to minimize fungicide resistance is to use propamocarb no more than three times per season.
FRAC Code 29 • Oxidative Phosphorylation Uncoupler Fungicides

Currently, the only oxidative phosphorylation uncoupler fungicide available for field crops is fluazinam, which only is labeled for use against late blight on potatoes. Fluazinam has been shown to control some mites as well.

How do they work?

These fungicides act by inhibiting energy production. Unlike the QoI fungicides, respiration continues but the energy is not converted to a usable form, eventually leading to cell death. Fluazinam inhibits spore germination and the formation of infection structures.

Fungicide applications should begin when weather conditions favor disease development, because it works best as a preventative fungicide with little early-infection activity.

Where do oxidative phosphorylation uncoupler fungicides move in the plant?

Fluazinam is a protectant fungicide and has no systemic activity so thorough coverage is needed.

What is the risk of fungicide resistance?

Resistance is a major concern for most fungicides that affect energy production; however, the risk of fungicide resistance developing for uncouplers is low. Despite being used for several seasons with up to 10 applications per season and no mixture partners, there is no indication of a change in sensitivity of the late blight pathogen. Still, it is recommended not to rely exclusively on one product for pest control so fluazinam should be rotated with different groups that control late blight.

FRAC Code 30 • Organo Tin Fungicides

Fentin hydroxide (triphenyltin hydroxide) is the only fungicide in this class that is registered for use on field crops. It is used to control Cercospora leaf blight on sugar beet and early blight and late blight on potato.

Care must be taken when applying because combinations with some pesticides (especially emulsifiable concentrate insecticides), micronutrients, spreaders, stickers, surfactants, or buffering agents, can increase phytotoxicity. Triphenyltin hydroxide carries the signal word “DANGER” and is a restricted use fungicide.

How do they work?

The organo tin fungicides disrupt oxidative phosphorylation, which inhibits respiration in target fungi.
Where do organo tin fungicides move in the plant?
This group of fungicides is not systemic.

What is the risk of fungicide resistance?
The risk of fungicide resistance developing is low to medium, although resistance in the Cercospora leaf spot fungus of sugar beet has been documented.

FRAC Code 32 • Heteroaromatic Fungicides
Heteroaromatic fungicides are used to control oomycete pathogens such as *Aphanomyces* and *Pythium*. Hymexazol, the only current fungicide registered for use on field crops in this class, is used as a seed treatment to control soilborne pathogens on sugarbeet.

How do they work?
Hymexazol affects targeted pathogens by inhibiting nucleic acid synthesis.

Where do heteroaromatic fungicides move in the plant?
Hymexazol has upward systemic properties.

What is the risk of fungicide resistance?
The risk of fungicide resistance is not known. However, hymexazol has a broad spectrum of activity.

FRAC Code 33 • Phosphonate Fungicides
Organic phosphate compounds, including fosetyl-aluminum, are systemic fungicides that have preventative and early-infection activity against oomycete diseases, including Phytophthora and Pythium root and crown rot and downy mildews.

How do they inhibit fungi?
Phosphonate fungicides act by inhibiting spore germination and blocking development of mycelium. These fungicides also enhance the plant’s own natural defense systems against diseases.

These fungicides are most effective when applied prior to disease development, but they do have some early-infection activity. These fungicides can be applied when plants display early disease symptoms. These fungicides should be applied to actively growing plants.

Where do phosphonate fungicides move in the plant?
These compounds are rapidly absorbed through the plant leaves or roots, with translocation both up and down inside the plant. These fungicides are
the only fungicides that are fully systemic. The systemic activity creates a complete barrier of protection while preventing wash-off.

**What is the risk of fungicide resistance?**

These fungicides have a low risk of fungicide resistance developing. However, fungicide resistance may occur if these fungicides are used repeatedly.

**FRAC Code 40 • Carboxylic Acid Amide (CAA) Fungicides**

CAA fungicides are systemic fungicides that are effective against oomycetes. Currently, the only CAA fungicide labeled for use on field crops is dimethomorph, which controls late blight on potatoes and downy mildew on grapes and vines.

**How do they work?**

CAA compounds affect the formation of cell walls. CAA fungicides should be applied just before the onset of infection or when first visible signs of disease occur within the field or nearby.

**Where do CAA fungicides move in the plant?**

CAA fungicides move up the treated plant stem and into growing leaves. They also have anti-sporulant activity, which helps prevent the spread of diseases.

**What is the risk of fungicide resistance?**

The risk of fungicide resistance in potato late blight pathogen is low to medium. Resistance has not been found on this pathogen; however, resistance has been found in the grape powdery mildew pathogen. It is recommended that this fungicide be alternated with other modes of action for management of potato late blight. Also, mixtures with multi-site fungicides may be used to reduce risk of resistance development.

**FRAC Code M • Multi-Site Activity Fungicides**

Multi-site activity fungicides are applied to the leaf and stem surfaces and are considered protective or preventive fungicides. Multi-site activity fungicides have a broad spectrum of disease control activity. Multi-site activity fungicides approved for use on field crops include inorganic compounds (copper and sulfur), dithiocarbamates (mancozeb), and chloronitriles (chlorothalonil).

**How do they inhibit fungi?**

They inhibit fungi on the plant surface so the fungus will not be able to infect the plant. Contact fungicides affect multiple biochemical sites in fungi; they kill fungi by overwhelming them with poisonous materials.
They should be applied preventively. Multi-site activity fungicides do not affect fungi once they have infected the plant.

**Where do multi-site activity fungicides move in the plant?**

These fungicides remain on the plant surface and do not penetrate into the plant. They remain active only as long as the fungicide remains on the plant surface in sufficient concentration to inhibit fungal growth, usually 7 to 14 days.

On plant surfaces, contact fungicides are sensitive to environmental conditions like rainfall and solar radiation, unlike systemic fungicides, which are absorbed into the leaf after application (once the residue has dried) and are not affected by rain wash-off and solar radiation. A general rule of thumb for the effect of rain on washing off protectant fungicides follows:

- Less than one inch of rain since the last spray will not significantly affect residues.
- One to two inches of rain will reduce the residue by half.
- Over two inches of rain since the last spray will remove most of the spray residue.

**What is the risk of fungicide resistance?**

Resistance to multi-site activity fungicides is low. Multi-site activity fungicides are a part of fungicide resistance programs. If multiple applications of fungicides are needed, the benefit of including a multi-site activity fungicide is not to eliminate the use of other fungicides with higher risk of resistance, but to reduce the number of applications of higher risk fungicides made in any one year. This may extend the number of years a higher risk fungicide can be used, but it does not prevent the eventual selection of fungicide resistant pathogens.
References


