FUNGICIDE RESISTANCE (FR) MANAGEMENT

Soybean Disease Management

Diseases can and do cause economic losses in midsouthern soybean systems. Until the early 2000's, many diseases could only be managed with resistant varieties or with cultural practices that were marginally effective.

A White Paper titled "Guidelines and Resources for Managing Soybean Diseases" on this website should be used as a supplement to the following information.

Fortunately, there are now preventive and/or curative controls for most major foliar diseases of soybean. **Tables 1 and 2** below provide a list of fungicides that are available to manage various soybean diseases.

Several important diseases [sudden death syndrome (SDS), stem canker, Phytophthora root rot, charcoal rot, seed and seedling diseases] of soybean have no curative control; i.e., these diseases may be prevented but not cured once present. SDS and stem canker can be managed or avoided by using less-susceptible or resistant varieties. Phytophthora root rot can be managed by using resistant varieties. However, Phytophthora root rot is not as common a disease in Mississippi as commonly thought, since it generally occurs only on clayey soils when excess moisture is an issue.

Seed and seedling diseases [caused by numerous fungi that likely comprise a "complex" that includes, but is not limited to, *Cercospora, Fusarium, Phomopsis, Pythium, Phytophthora*, and *Rhizoctonia solani*] can be effectively prevented by using seed treatments. However, this is not to suggest that they will be eliminated with the use of a properly applied seed treatment. Keep in mind that a seed treatment remains effective while the seed and developing seedlings are below the soil surface. Once the developing seedling emerges through the soil surface, the seed treatment can no longer effectively prevent seedlings diseases from occurring.

There are no known resistant varieties [only moderately resistant germplasm and some tolerant varieties] or fungicides for charcoal rot management. Additionally, it is likely that the majority of germinating soybean seed are infected with the causal organism *Macrophomina phaseolus*, and infection likely occurs shortly after the cotyledon emerges from the seed. Charcoal rot will manifest itself in infected plants if and when a condition such as drought or poor irrigation management causes stress to plants.

Foliar fungicides can be applied to prevent several prominent soybean diseases. Preventive fungicides [i.e. quinone outside inhibitor (QoI) or strobilurins such as azoxystrobin (Quadris) or pyraclostrobin (Headline)] are most effective when applied prior to or at the earliest appearance of a disease. However, in the past, strobilurin fungicides have been suggested to manage such diseases as frogeye leaf spot [FLS] even when the disease was present. The general view was that a strobilurin fungicide could prevent additional spread of the disease to non-infected plants.

Soybean rust can be managed with preventive and curative [i.e. demethylation inhibitors (DMI) or triazoles such as flutriafol (Topguard) or tetraconazole (Domark)] applications of foliar fungicides timed according to occurrence of rust in sentinel plots. Based on past years' experience, rust may be avoided in the Midsouth by planting early-maturing varieties early so that R6 or full seed stage is reached before about Aug. 1. Additionally, the R3/R4 fungicide application utilized in Midsouth production systems has likely provided some prevention of soybean rust in areas where the disease might have occurred.

Scouting should be used to detect the first occurrence of disease(s) or to accurately determine the reproductive stage recommended for the most effective preventive fungicide application prior to disease presence. A May 2016 Plant Management Network (PMN) webcast entitled "Integrated Approaches to Fungicide Applications in Soybean" by Dr. Hillary L. Mehl of Virginia Tech Univ. provides coverage of the when's and how's of scouting for foliar diseases.

Click here for a comprehensive scouting guide on this website. This reference provides guidance on scouting practices, details about common disease and nematode pests of soybeans, and information that will help identify and treat disease problems that occur in Midsouth soybean fields.

Cost and effectiveness of fungicide products should be evaluated when choosing options for disease management. Resistant varieties should be chosen based on level of pest tolerance and yield, and grown in those areas with a known history of a particular disease.

Fungicide Resistance (FR) and Management

For almost two decades, foliar fungicides that are effective against myriad diseases that infect soybeans have been available and applied to an increasing soybean acreage. Concurrent with this widespread use of these products has been the development of resistance to several classes of these fungicides occurring over the last several years.

Fungicide-resistant fungal populations generally result from the continuous use of a fungicide or fungicides with the same mode of action (MOA). This overuse of these fungicides results in the selection of traits that allow fungal species to withstand fungicide applications that otherwise would suppress or kill them.

Subsequent generations of the resistant fungi inherit the ability to survive and reproduce following a fungicide application. Thus, FR fungi are the product of intensive selection pressure from the continuous use of a fungicide or fungicides that target a specific physiological or biochemical process. Examples follow.

The continued use of the strobilurin [quinone outside inhibitor or QoI] class of foliar-applied fungicides whether needed or not [these fungicides have long been touted for enhancing "plant health"] over the last decade and a half has resulted in the selection for strobilurin resistance in the pathogen that causes frogeye leaf spot [FLS] in soybean. Iowa data collected in 2019 further confirm that foliar fungal diseases such as FLS and Septoria brown spot continue to develop resistance to the QoI class of fungicides. In fact, in the Iowa trials, application of fungicides with a sole QoI component did not provide a profitable yield increase. Thus, the unnecessary use of foliar fungicides should be minimized and an integrated approach to disease management that employs foliar fungicides with multiple modes of action only when necessary to control a particular disease that is present should be adopted. This disease management strategy must become the norm to ensure the continued sustainability of high-yield soybean production in the U.S.

Furthermore, there is now evidence of resistance in other pathogenic fungi such as *Corynespora cassicola* [causal agent of target spot] to this fungicide class. This is likely an inadvertent happening that resulted from the continued exposure of this pathogen to this fungicide class during this past extended period of its widespread application. Obviously, any fungi that are susceptible to the strobilurins would have selected for resistant types during this time. It is likely, then, that these other foliar pathogens, which previously had not been problematic, will become so in the near future.

Fortunately, there are other fungicide classes that can be applied to control FLS in soybean to avoid yield reduction. Regrettably, this may not be the case for target spot. Hopefully, it is not too late to start rotating fungicides that have different modes of action or apply fungicide mixes that have more than one mode of action to prevent further resistance development within fungal populations.

Drs. Tom Allen, Ext. Plant Pathologist at MSU-DREC, and Trent Irby, MSU Ext. Soybean Specialist, address this issue in a June 3, 2017 article titled "Considering the R3/R4 Automatic Application in Soybean: Time to Apply Two Modes of Action Instead of One" on the MCS blog site. In this article, they state that for the better part of a decade farmers have applied foliar fungicides as a necessary management practice in high-yield environments. They further state that "data from more than 10 years of trials suggested that in approximately 50-60% of the situations, a modest 3-5 bu/acre return could be expected" (notice the word modest) when a QoI fungicide product was applied at either the R3 or R4 growth stage. These fungicide applications "were made based on growth stage timing generally in the absence of disease and independent of the long-range forecast". In studies they conducted in 2015 and 2016, a stand-alone QoI product provided a -0.4 bu/acre response, whereas pre-mix fungicides (more than one mode of action) provided a +3 bu/acre response. This leads to their recommendation "that individuals wanting to continue to receive the same benefit from the R3/R4 automatic fungicide application should apply either a pre-mix or tank mix that contains at least two modes of action." This recommendation still relies on the automatic fungicide application concept, which may lead to further selection for resistance among fungal populations.

Producers have a choice of fungicides, with different modes of action, that have similar/equal efficacy against the same disease. There is general acknowledgment that resistance development in the targeted fungi will be delayed by either rotating the application of these fungicides or by applying them together in a tank-mix. In general, both methods will delay resistance development; however, there is a general consensus that tank mixing will be the better of the two. This is simplified for producers by their having a choice of premixes that contain fungicides with at least two modes of action to accomplish this. See Table 2 below for a compilation of premixes and the pathogens they control.

There is research evidence (Orlowski et al, Crop Sci. Vol. 56, 2016; Lindsey, CFTM Mar. 2018) that the present-day automatic application of a foliar fungicide may not provide a profitable yield enhancement, or the yield enhancement will be small when the environment is conducive to pathogen development. Thus, prophylactic applications of fungicide are unlikely to increase soybean yield in many cases; however, these applications will hasten the development of FR in susceptible pathogens. This provides further impetus to use IPM strategies that consider disease history of a field, susceptibility of the soybean variety, and environmental conditions when applying fungicides to soybeans.

Knowledge of the MOA categories described by the Fungicide Resistance Action Committee [FRAC] will subsequently result in application of fungicides with different MOAs. This should reduce, if not prevent, the selection for FR fungi, and will aid in managing fungi that are resistant to the fungicides that are currently available. Selecting and using fungicides with different MOAs should be a primary tool for preventing and/or managing resistance.

Selecting fungicides with different MOAs must be combined with choosing fungicides within those MOA Groups that are effective at managing the targeted fungi in individual fields. In other words, merely selecting fungicides from a different MOA Group will do little to reduce selection pressure if those fungicides are not effective at managing targeted fungi.

The numerical classification system developed by the FRAC (**Table 2**) currently appears on fungicide labels. Near the top of the label, a box labeled "Group Fungicides" contains the number or numbers that indicate the MOA of the product's active ingredient(s). Multiple numbers in the box indicate that the fungicide is a premix that has more than one MOA.

Examples are the labels for:

Quadris,

GROUP	11	FUNGICIDES

Quilt,

GROUP	3 11	FUNGICIDES

Topsin XTR,

GROUP	1 3	FUNGICIDES

and Priaxor

GROUP	7 11	FUNGICIDES

Important points are:

- Producers, consultants, and professional crop practitioners should select fungicides that are best suited to manage specific resistant fungi, or that can be used in rotation to prevent or delay resistance.

- Knowing and using fungicide MOAs should be an important component for managing the potential development of resistance to fungicides.
- Fungal species present in individual fields should be documented each year so that MOA knowledge and level of control by individual fungicides can be coupled when making fungicide decisions.
- If resistance to a particular fungicide is not documented in a particular field or fields, then its use is a viable option when used in rotation with other fungicide(s) with a different MOA.
- Selecting a different fungicide that has an active ingredient with the same MOA as a previously-used product will not contribute to resistance management.

Any disease management strategy that is adopted to minimize selection pressure for resistance will delay or block the emergence of fungicide resistance. Thus, the MOA strategy should be viewed as just one of several management tools that can be used by producers and advisors to choose fungicides. This tool should be used in conjunction with other resistance management practices to delay the evolution of resistance to fungicides.

Dr. Tom Allen, Extension Plant Pathologist at MSU-DREC, provides considerations for soybean fungicide management. Major points from that article follow.

- An R3/R4 strobilurin or strobilurin + triazole fungicide application is made at that time regardless of the presence of disease. The timed application produces the best results when applied to a soybean crop with high yield potential such as continuous soybean that is irrigated.
- Applying products that contain a stand-alone triazole should be saved for when foliar disease is present. They should be relied on for managing against yield loss as a result of FLS or soybean rust infestations.
- Fungicides in the strobilurin class are best suited for when diseases are not present; i.e., used on a preventive basis. The residual effect in this case should be about 21 days.
- Even though triazole fungicides have the ability of being curative and can be applied to manage a present disease, they perform best when applied prior to the onset of visible disease symptoms. Their residual effect generally lasts about 14 days.
- The systemic activity of both strobilurin and triazole fungicides is limited to movement around the area of the leaf where a spray droplet is deposited. Fungicides in both classes should not be considered to move throughout the plant from the point of entry.
- Growing varieties that are susceptible to FLS may increase the likelihood of developing FR FLS biotypes.
- If an FLS-resistant variety is grown, relying on a stand-alone strobilurin fungicide is an acceptable practice.
- If an FLS-susceptible variety is grown and FLS has been detected, applying a labeled triazole fungicide could reduce yield loss.
- With the onset of strobilurin-resistant FLS, triazoles should be considered to manage the disease.

Current FR Information

PMN's Soybean Fungicide Resistance Hub is a central destination for up-to-date information on soybean fungicide use and management practices that should be considered to ensure the prolonged effectiveness of present and forthcoming fungicide products. The hub includes a "Featured Webcasts" section with open-access videos on FR management, a "Fungicide Resistance Tracking" section with maps of yearly distribution of FR plant diseases, and a "Fungicide Resistance Resources" section which contains information on FR management in soybean. The following posts are especially noteworthy.

Fungicide Classification is a poster developed by the USB that shows the FRAC code and mode of action of soybean fungicides and fungicide premixes presented by the Fungicide Resistance Action Committee [FRAC].

Fungicide Resistance in the Cercospora Leaf Blight and Purple Seed Stain Pathogen of Soybean is a webcast presented by Dr. Trey Price with the LSU AgCenter. In his presentation, Dr. Price discusses the symptoms of the disease caused by *Cercospora* *kikuchii* pathogen, and how the symptoms are manifested in the foliar and mature seed stages. Severe infections in soybean can result in defoliation (Cercospora leaf blight) and poor seed quality (purple seed stain) that will result in dockage at the elevator. He also shows how fungicide efficacy against this pathogen has declined over the years to the point that the various classes of fungicides that are available now provide only limited efficacy against the pathogen, and no yield protection. Finally, he states that control measures consist of choosing tolerant varieties based on ratings taken in field trials (there are no resistant varieties) and early planting.

Principles of Fungicide Resistance is authored by Dr. Carl Bradley (Univ. Of Kentucky), Dr. Clayton Hollier (LSU AgCenter), and Dr. Heather Kelly (UT Extension). The authors define fungicide resistance, and describe how disease resistance to fungicides develops followed by the subsequent loss of fungicide efficacy. They also discuss the factors associated with fungal pathogens and fungicides that affect resistance development. They show the primary chemical classes of fungicides commonly applied to soybean, and how the FRAC code can be used to distinguish these different fungicide classes as well as determine the risk level of fungicide resistance developing to each of the fungicide groups (**Table 3**). And finally, they present management practices that will prevent or delay development of fungicide resistance in order to retain fungicide efficacy over a long period of time.

The United Soybean Board has expanded its Take Action Program to include fungicide resistance management. This is being done to provide resources that can be used to prevent or delay fungal pathogens developing resistance to available fungicides. Taking a proactive approach to managing fungicide resistance will help preserve the effectiveness of existing crop protection products. The contents of this program include the following steps or practices that should be used to ensure the long-term efficacy of these products.

- Properly identify the type of disease to ensure that it is in fact caused by a fungal pathogen.
- Practice a diversified approach; i.e., consider non-chemical control methods such as planting tolerant or resistant varieties and rotating crops.
- Apply fungicides only when necessary so that selection of fungicide-resistant pathogens is minimized.
- If a fungicide application is justified, apply a product with multiple MOAs, and rotate MOAs.
- If a fungicide with two MOAs contains an ingredient that a targeted pathogen has developed resistance to, then that product effectively has only a solo active ingredient that will affect the targeted pathogen. This will hasten development of resistance to that lone effective ingredient.
- Scout fields prior to application to ensure correct application timing; e.g., know the soybean growth stage at the onset of disease development.
- Ensure that the disease being treated is an economic threat to yield.
- Apply labeled rates of fungicides.
- A Soybean Disease Risk Score Sheet was developed to provide producers a tool that can be used to determine the risk of disease development in a soybean field so that a fungicide application can be planned only if its need is anticipated. Remember, fungicides should be applied on an as-needed basis rather than as an automatic blanket application at a particular soybean growth stage in order to slow development of fungicide resistance in the myriad soybean foliar pathogens that plague the crop.

Click here for a comprehensive scouting guide on this website. This reference provides guidance on scouting practices, details about common disease and nematode pests of soybeans, and information that will help identify and treat disease problems that occur in Midsouth soybean fields.

Table 1. Mechanism of action (MOA) classification for fungicides used for managing soybean diseases and diseases controlled according to CPN fungicide efficacy ratings of Good to Excellent and MP 154.

FRAC Code	MOA*	Chemical group	Active Ingredient	Trade names**	Diseases controlled***
1	Mitosis disrupters	thiophanates	thiophanate-methyl	Topsin	FLS, SR
3	Cell membrane disrupters	triazoles	cyproconazole	Alto	BS, SR
			difenoconazole	Component of Quadris Top, Miravis Top	See Table 2 below
			flutriafol	Topguard	AN, BS, FLS, SR
			mefentrifluconazole	Component of Revytek	See Label
			propiconazole	Tilt etc.	AN, BS, SR
			prothioconazole	Proline	FLS, SR
			tetraconazole	Domark	AN, BS, FLS, SR
7	SDHI's	pyridinecarboxamide	boscalid	Endura	BS
		pyrazole-4-carboxamides	benzovindiflupyr	Component of Trivapro	See Table 2 below
			bixafen	Component of Lucento	See Table 2 below
			fluxapyroxad	Component of Priaxor, Revytek	See Table 2 below
			pydiflumetofen	Adipidyn, component of Miravis Top	See Table 2 below
11	QoI/strobilurins	methoxy-acrylates	azoxystrobin	Quadris	AB, AN, BS, SR
			picoxystrobin	Aproach	AB, AN, BS, SR
		methoxy-carbamates	pyraclostrobin	Headline	AB, AN, BS, SR
		dihydro-dioxazines	fluoxastrobin	Evito, Aftershock	AB, AN, BS

*See FRAC (Fungicide Resistance Action Committee) for detailed description of MOAs.
**See MP 154 (Arkansas Plant Disease Control Products Guide) for a complete list of fungicide products in each Group.
***AB = aerial blight; AN = anthracnose; FLS = frogeye leaf spot; PSB = pod and stem blight; PSS = purple seed stain; SR = soybean rust. This is a general guide. There are no efficacious fungicides for control of Cercospora leaf blight and Target Spot. See MP 154 and individual labels at CDMS for specific fungi controlled, level of control, time of application, and preharvest interval for the listed fungicides.

Table 2. Mechanism of action (MOA) classification for fungicide premixes used for managing soybean diseases and diseases controlled according to CPN fungicide efficacy ratings of Good to Excellent and MP 154. Diseases controlled by Overrule and Evito T are according to their labels.

FRAC Code	Trade Name	Active Ingredients	Diseases controlled at G to E level*
1 + 3	Overrule	thiophanate-methyl + tebuconazole	AB, AN, BS, FLS, PSB, PSS, SR (by label)
11 + 3	Affiance	azoxystrobin + tetraconazole	AN, BS, FLS
11 + 3	Aproach Prima	picoxystrobin + cyproconazole	BS, SR
11 + 3	Evito T	fluoxastrobin + tebuconazole	AN, BS, FLS, PSB, SR (by label)
11 + 3	Quadris Top SBX, Mogul	azoxystrobin + difenoconazole	BS, FLS, SR
11 + 3	Quilt Xcel	azoxystrobin + propiconazole	AB, AN, BS, SR
11 + 3	Stratego YLD	trifloxystrobin + prothioconazole	AB, AN, BS, FLS, SR
11 + 7	Priaxor	pyraclostrobin + fluxapyroxad	AB, AN, BS, SR
3 + 7	Lucento	flutriafol + bixafen	BS, FLS
3 + 7	Miravis Top	difenoconazole + pydiflumetofen	BS, FLS, PSB
11 + 7 + 3	Trivapro	azoxystrobin + benzovindifjupyr + propiconazole	AB, BS, FLS, PSB , SR
11 + 7 + 3	Priaxor D	pyraclostrobin + fluxapyroxad + tetraconazole	BS, FLS, PSB, SR

*AB = aerial blight; AN = Anthracnose; BS = Brown spot; FLS = frogeye leaf spot; PSB = Pod and stem blight; PSS = purple seed stain; SR = soybean rust. This is a general guide. There are no efficacious fungicides for control of Cercospora leaf blight and Target Spot. See MP 154 and individual labels at CDMS for specific fungi controlled, level of control, recommended time of application, and preharvest interval for the listed fungicides.

Table 3. FRAC determination of risk level of fungicide resistance development to commonly used fungicide groups applied as foliar fungicides to soybean.

FRAC code	Fungicide Group	Risk of Resistance Development
1	Methyl benzimidazole carbamates (MBC)	High
3	Dimethylation inhibitors (DMI, includes triazoles)	Medium
7	Succinate dehydrogenase inhibitors (SDHI)	Medium to High
11	Quinone outside inhibitors (QoI, includes strobilurins)	High
29	Oxidative phosphorylation uncouplers	Low
33	Phosphonates	Low
M5	Chloronitriles	Low

For over twenty years, soybean producers have been planting soybean seed that were treated with a fungicide seed treatment. One of the fungicide components of all seed-applied products was and still is metalaxyl or mefenoxam, both FRAC Code 4 fungicides. These materials are very effective against *Pythium spp.*, a pathogen that is capable of severely reducing soybean emergence and stand establishment. There is no present or forthcoming varietal resistance to *Pythium*, so the current soybean production system is totally dependent on this fungicide to prevent damage from this pathogen. Fortunately, there have been no reported stand failures where the present seed treatments were used to control *Pythium*. It remains to be seen if this long-term use of this very effective fungicide class will lead to resistant types within the *Pythium* complex.

Vayantis is a systemic fungicide seed treatment that has activity against *Phytophthora* and all isolates of *Pythium*. It contains a new active ingredient, picarbutrazox, that belongs to the chemical group of fungicides with a new mode of action (FRAC code U17). Its use in combination with mefenoxam (FRAC Code 4) will enhance/complement the protection against oomycetes through overlapping effective modes of action. This should thwart the potential development of resistance to the widely used FRAC Code 4 seed treatment fungicides mentioned above.

There are several classes of fungicides in present seed treatments that are effective against *Fusarium*, *Rhizoctonia*, and *Phomopsis* fungi, all of which can contribute to poor emergence and stand loss. Therefore, it is likely a good practice to choose seed treatment products that at least rotate the classes of fungicides that are effective against the non-*Pythium* pathogens. Unfortunately, most seed suppliers/dealers pretreat their soybean seed with a proprietary product that the recipient has little or no choice about, or may not even know the components of. Thus, it behooves soybean producers to become familiar with what protectant materials are applied to their seed, and even insist that these products be rotated so as not to use the same FRAC class of fungicide(s) year after year.

Take-Home Message

The no or infrequent small yield enhancement by foliar fungicides when only low levels of foliar diseases were present confounds recommendations. First, sound IPM practices dictate that pesticides only be applied when the targeted organism is present at a yield-limiting level. Second, repeated use of the fungicides when not needed to control diseases increases the selection pressure on fungal pathogens, and this will hasten resistance development such as that now occurring in several fungal pathogens.

Foliar fungicides should only be considered as an input component for soybeans growing in a high-yield environment when diseases are present at yield-limiting levels. The small yield and/or economic gain realized from their use when only low levels of diseases are present will hasten resistance development in fungal organisms. The long-term negative effect from this latter occurrence far outweighs any small short-term yield/economic gains realized from their annual use as a touted "plant health" enhancer.

In the Midsouth, foliar diseases frequently are present at yield-limiting levels. Thus, applying foliar fungicides is likely to be a common practice for Midsouth soybean producers. This will entail using a thorough scouting protocol to ensure that the anticipated yield gain from controlling these diseases is worth the possible hastening of resistance development that may occur from the increased frequency of their application.

The potential for the development of pathogen resistance to a pesticide should be given priority consideration whenever the blanket use of any pesticide is considered or promoted. The development and release of soybean varieties that are resistant to pests, both fungal and insect, is the true long-term solution for dependable pest management. Until that happens [may or may not for some pests], the use of pesticides should be reserved for situations where there is a documented case for significant yield loss if they are not used.

If fungicides continue to be applied just because they are perceived to provide only slight or even unknown benefit, resistance to these fungicides will continue to evolve in targeted pathogens, and the end result will be a decrease in products that can be used to thwart serious outbreaks of diseases caused by these pathogens. There will come a time when farmers will need these chemistries to defend against these serious disease outbreaks that will truly threaten yield potential. Overusing them now for limited economic gain is not a prudent long-term strategy for soybean disease management.

Composed by Larry G. Heatherly, Updated July 2022,
larryheatherly@bellsouth.net