Fungicide Resistance Management of Turfgrass Diseases

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Fungicides have been used to control turf diseases for many years and as a result fungicide resistance has developed to various fungicide classes in several diseases with dollar spot being the poster child of fungicide resistance. Understanding fungicide properties and their resistance mechanisms is necessary for effective disease management and delaying the development of resistance. The Fungicide Resistance Action Committee (FRAC) has classified active ingredients based on their biochemical mode of action and number of target sites affected in fungi to help practitioners make educated decisions regarding fungicide applications (Table 1). Fungicides that inhibit the same or very similar metabolic processes are placed in the same fungicide class. Fungicides can impair one or more metabolic sites within fungi, defining them as either **single-site** or **multi-site** mode of action respectively. Mutants with resistance to fungicides generally occur at very low frequencies in a natural population. Moreover, mutations to a single metabolic site occur more readily in a population than mutations to multiple metabolic sites, thus putting single-site fungicides at a higher risk of developing resistance.

Fungicide Rotation and Tank Mixes

Repeated back to back applications of the same active ingredient or the same FRAC code allow for resistant mutant isolates to thrive while sensitive isolates are inhibited leading to greater numbers of resistant isolates over time. Also, fungicide applications made to large fungal populations increase the likelihood of resistant isolates being selected, therefore well-timed preventative fungicide applications are recommended for resistance management. Once resistant isolates constitute a significant percentage of the population, reduced control becomes evident by the need for shorter spray intervals.

The best fungicide resistance management strategy minimizes disease damage by maximizing cultural practices, however, when disease pressure is high, fungicides may be necessary. Fungicide rotation/tank-mix is used to delay the onset of resistance by avoiding continuous selection pressure to the pathogen population. Rotate between FRAC codes and use multi-site fungicides as a tank-mix or rotation partner with single-site high-risk fungicides as much as possible. The resistance risk of a fungicide also varies depending upon type of disease and fungicides labeled for use on that disease. For example, resistance to strobilurins (FRAC #11) has been reported in gray leaf spot (*Pyricularia grisea*) and anthracnose (*Colletotrichum cereale*) but not in dollar spot (*Sclerotinia homoeocarpa*)(Kim *et al*., 2003; Wang et al., 2007).

Dollar Spot Case Study

Dollar spot (*Sclerotinia homoeocarpa*) is a major turfgrass disease in which fungicide applications are required to maintain acceptable conditions for golf. Cultural practices such as: planting a resistant cultivar, minimizing leaf wetness (morning dew removal), reducing thatch, maintaining adequate nitrogen fertility and water, promoting good air circulation, and reducing compaction provide some level of reduction in disease severity, but do not provide complete control under high disease pressure. Therefore, a disease such as dollar spot is controlled by multiple fungicide applications throughout the growing season. Currently, there are five different fungicide classes commonly used for control of dollar spot (Figure 1).

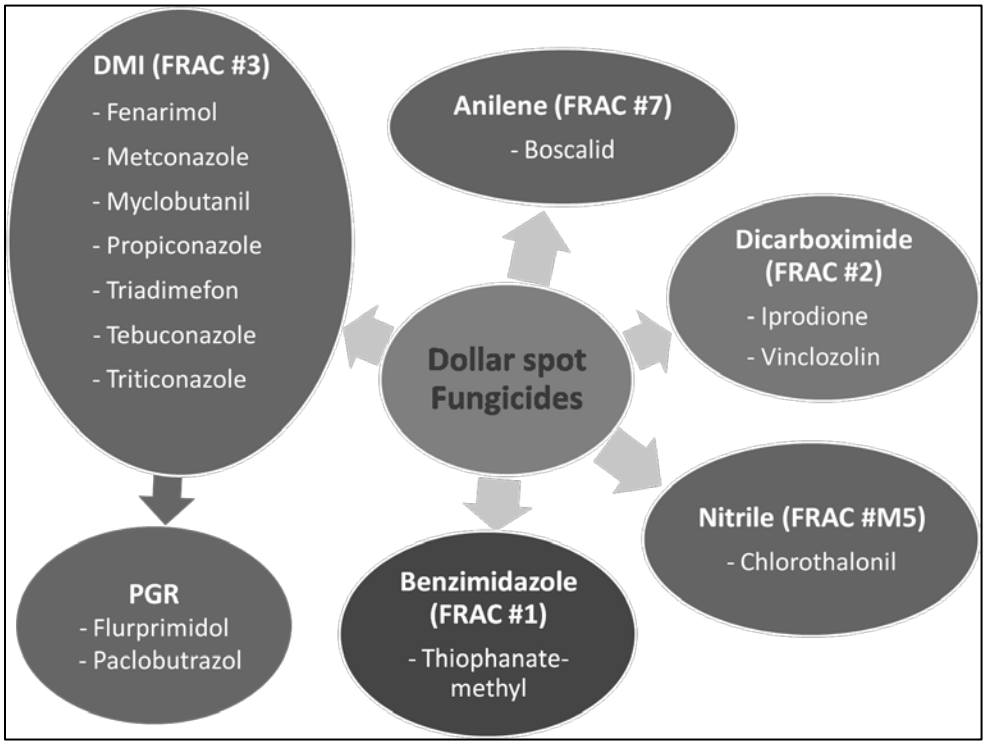

Figure 1. Fungicide classes commonly used to control dollar spot organized by FRAC code.

Benzimidazole (FRAC #1)

The benzimidazole class has been used in turfgrass since the early 1970's and many different formulations with the same active ingredient are available (Table 1). Resistance was first reported in 1974 and is widespread across the country (Bishop *et al*., 2008; Jo *et al*., 2006; Koch *et al*., 2009 and Putman *et al*., 2010). Benzimidazole resistance can be rapidly selected by only a few repeated curative applications (Jo *et al*., 2008). Preventative applications may take longer to select for resistance than curative applications; however, fungicide rotation/tank-mix is shown to delay resistance (unpublished data, Geunhwa Jung). Resistant isolates selected by repeat benzimidazole applications are likely to remain within populations for many years.

Dicarboximide (FRAC #2)
The dicarboximide class has been used in turfgrass since the 1970's and resistance was first reported in 1983 (Detweiler *et al*., 1983). The frequency of resistance occurrence appears to be significantly less than the benzimidazole and DMI classes according to fungicide resistance survey results (Jo *et al*., 2006 and Putman *et al*., 2010). Resistant population development remains poorly understood with the exception of Detweiler *et al*. (1983) reporting development after three years of frequent use. The lower occurrence of dicarboximide resistant populations in surveying studies may be due to low persistence of resistant isolates, however, this facet is poorly understood.

Demethylation Inhibitor (DMI)(FRAC #3)
The DMI class has been used in turfgrass since the early 1980's and many active ingredients (seven for turfgrass) and formulations are available (Table 1). Resistance was first reported in 1992 and reduced sensitivity has been widely reported (Jo *et al*., 2006; Koch *et al*., 2009; Putman *et al*., 2010 and Golembiewski *et al*., 1995). DMI resistance is described as reduced efficacy or shortened control intervals. Residual control can be as short as seven days for fungicides meant to provide 21 days of control (Popko *et al*., 2009). Field efficacy can also be influenced by the pre-existing dollar spot population structure, susceptibility of turf species, and favorable environment present at the particular site. Selection of insensitive populations (field resistance) appears to take longer than the benzimidazole class (unpublished data, Geunhwa Jung) but depend on initial population structures. Cross-resistance among active ingredients within the DMI class has been observed *in vitro* as well as under field conditions in limited studies. Because there are seven DMI active ingredients and many premixed products containing DMIs, great care should be taken to ensure proper fungicide rotation/tank-mix is practiced due to cross-resistance among DMI active ingredients. In addition, our recent findings (Ok *et al*., 2010 in review) show that plant growth regulators (flurprimidol and paclobutrazol) have a fungistatic effect on *S. homoeocarpa* similar to that of DMI fungicides. The high correlation of *in vitro* sensitivities among plant growth regulators and DMI fungicides suggests that plant growth regulators can contribute to the selection of DMI resistant isolates or facilitate decreased sensitivity to DMI fungicides. Persistence of resistant isolates without applications of DMI fungicides remains poorly understood. Our lab has currently been conducting long-term research on reversion of DMI resistant population using non-DMI fungicides at golf course.

Anilene (FRAC #7)
The anilene class is relatively new to turfgrass and only one active ingredient (boscalid) is currently registered for use on turfgrass. Resistance has not been reported in turfgrass, however, there have been reports of resistance in the pistachio pathogen *Alternaria alternata* (Avenot and Michailides, 2007). Resistance is likely to develop in turfgrass if boscalid is used continuously.

Nitrile class (FRAC #M5)
The nitrile class containing chlorothalonil is the only multi-site mode of action fungicide commonly used for controlling dollar spot. Resistance to chlorothalonil has not been reported in turfgrass or any other crop. Chlorothalonil is a contact fungicide that coats

the leaves of turfgrass and is not taken up by the plant. Use of chlorothalonil is restricted in zone 2 sections of turf in Massachusetts and provides 10-14 days control.

Premixed Fungicides

Recently more fungicide products come premixed with multiple active ingredients. This can be useful for broad-spectrum control, however, it is important for practitioners to read the label for the active ingredients mixed before application so as not to make two back to back applications containing the same active ingredient. When using premixed fungicides, make sure to select a fungicide with a different FRAC code number in the next application.

Diagnosing Fungicide Resistance

Fungicide failure should always be recorded and analyzed to determine if a factor besides resistance could have affected fungicide efficacy (misdiagnosis, alkaline hydrolysis, calculation error, excessive post-spray rainfall, expired product, ineffective product from manufacturer, nozzle type, sprayer malfunction, water volume, etc.). For situations in which you are not certain if resistance has developed, the UMass Turfgrass Pathology Lab can analyze the dollar spot population at your site. This service will test resistance to all four single-site mode of action fungicide classes and provide a comprehensive written recommendation specific to that site. Since past management affects the dollar spot population, areas that have been treated differently (i.e. greens, fairways and tees), should also be tested separately. Overall, because resistance level varies from site to site, there is no single blanket recommendation that can be given to all sites. However, practicing all cultural methods and fungicide rotation/tank-mix by FRAC codes when managing dollar spot will delay the onset of resistance as long as possible. Some sites may be severely limited by the effects of fungicide resistance and extra care must be made to rotate the fungicide classes that are non-resistant.

If you have experienced reduced efficacy or fungicide failure to dollar spot and believe that fungicide resistance is a problem at your golf course, please contact the UMass Turfgrass Pathology Lab to set up a fungicide screening for dollar spot resistance. For more detailed information, visit:http://www.umass.edu/turfpathology/services.html.

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Table 1. Chemical classes and modes of action of fungicides registered for use on turfgrasses.

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Common Name	FRAC #	Group Name	Trade Name(s)	Mode of action
thiophanate- methyl	1	Benzimidazole	Absorb TM, Allban, Andersons Systemic Fungicide 2.3G, ArmorTech TM462, Cavalier 2G (4.5F, 50WSB), Cleary's 3336 (2G, 4F, 50WSB, 70EG), Fungo Flo 4.5F, Fungo 50WSB, Lesco T-Storm 50WSB, Proturf Systemic Fungicide, Systec 1998 85WDG, T-Bird WDG, Tee-Off 4	Acropetal Penetrant
iprodione	2	Dicarboximide	Andersons Fungicide X, ArmorTech IP 233, Chipco 26 GT, Chipco 26019, Iprodione Pro, Lesco 18 Plus, Proturf Fungicide X, Raven	Localized Penetrant
vinclozolin	2	Dicarboximide	Curalan 4F (50EG, WSB, 50DF), Lesco Touche EG, Vorlan 50DF	Localized Penetrant
triticonazole	3	Demethylation Inhibitor	Trinity, Triton	Acropetal Penetrant
fenarimol	3	Demethylation Inhibitor	Rubigan AS	Acropetal penetrant
propiconazole	3	Demethylation Inhibitor	ArmorTech PPZ 143, Banner GL 3.6WSP, Banner MAXX, Kestrel, Lesco Spectator 3.6EC, Propiconazole Pro 1.3MEC, Strider	Acropetal Penetrant
metconazole	3	Demethylation Inhibitor	Tourney	Acropetal Penetrant
myclobutanil	3	Demethylation Inhibitor	Andersons Golden Eagle 0.39G, Eagle 20EW, Siskin	Acropetal Penetrant
triadimefon	3	Demethylation Inhibitor	Accost 1G, Bayleton 50WSP, Andersons Fungicide VII 0.59G, Andersons 1% Bayleton 1G, Lebanon Bayleton 1G, Lesco Systemic Fungicide 50WDG	Acropetal Penetrant
tebuconazole	3	Demethylation Inhibitor	Torque	Acropetal Penetrant
mefenoxam	4	Phenylamide	Andersons Pythium Control 1.2G, Mefanoxam, Quell, Ridomil, Subdue, Subdue MAXX	Acropetal Penetrant
metalaxyl	4	Phenylamide	Subdue2E, Subdue GR, Subdue WSP, Proturf Pythium Control, Apron (seed treatment), Verio	Acropetal Penetrant
boscalid	7	Anilene	Emerald 70EG (WDG)	Acropetal Penetrant
flutolanil	7	Carboximide	ProStar 70WP, Moncut 70-DF	Acropetal Penetrant
fluoxastrobin	11	Strobilurin	Disarm 480SC	Acropetal Penetrant
pyraclostrobin	11	Strobilurin	Insignia 20WDG	Localized Penetrant
trifloxystrobin	11	Strobilurin	Compass 50WDG	Localized Penetrant
azoxydtrobin	11	Strobilurin	Heritage 50WG, Heritage TL, Heritage G	Acropetal Penetrant
fludioxinil	12	Phenylpyrrole	Medallion 50WP	Contact
chloroneb	14	Aromatic Hydrocarbon	Terraneb SP, Teremec SP, Andersons Fungicide V, Proturf Fungicide V	Contact
PCNB	14	Aromatic Hydrocarbon	Andersons FFII 15.4G, Defend 4F, Engage 75W, Fluid Fungicide II, Lesco Revere 4000 4F (10G), Parflo 4F, PCNB 12.5G, Penstar 75WP, Terraclor 400F (75WP), Turfcide 400F (10G)	Contact
etridiazol (ethazole)	14	Aromatic Hydrocarbon	Koban 30WP, Terrazole 35WP	Contact
polyoxin D zinc	19	Polyoxin	Endorse 2.5WP	Localized Penetrant
cyazofamid	21	Cyanoimidazole	Segway	Localized Penetrant
propamocarb HCl	28	Carbamate	Banol 6S	Localized Penetrant
fosetyl-Al	33	Phosphonate	Autograph, Chipco Aliette, Chipco Signature, Lesco Prodigy Signature, Terra Aliette T&O	Systemic Penetrant
phosphites (salts)	33	Phosphonate	Alude 5.2F, Biophos, Fosphite, Magellan 6.69F, Phostrol, Reliant, ReSyst 5F, Vital 4L	Systemic Penetrant
mancozeb	M3	Carbamate	Dithane 37WF, Dithane T/O, Fore Flo-XL 4F, Fore Rainshield 4F, Formec 80W, Junction 61WF, Lesco Mancozeb 75DG, Lesco 4 Flowable Mancozeb 4F, Manzate 200, Pentathlon, Protect DF, WingMan	Contact
maneb	M3	Carbamate	Maneb Plus Zinc F4, Maneb 75DF, Pentathlon 4F (75DG)	Contact
thiram	M3	Carbamate	Defiant 75WDG, Lesco Thiram 75DG, Spotrete 4F	Contact
captan	M4	Thiophthalimide	Captan 80WP, Captec 4L	Contact
chlorothalonil	M5	Nitrile	Andersons 5% Daconil 5G, ArmorTech 825 DF, ArmorTech CLT 720, ChloroStar 6F, Concorde SST 6F, Daconil 5G, Daconil Ultrex, Daconil WeatherStik, Daconil 2787, Daconil Zn, Echo 720F, Equus 500ZN, Manicure 6F, Manicure Ultrex, Lebanon Daconil 5G, Legend 6F, P	Contact

References

Avenot, H.F. and Michailides, T. J. 2007 Resistance to Boscalid Fungicide in *Alternaria alternata* Isolates from Pistachio in California. Plant Disease 91:1345-1350.

Bishop, P., J. Sorochan, B.H. Ownley, T.J. Samples, A.S. Windham, M.T. Windham, and R.N. Trigiano. 2008. Resistance of *Sclerotinia homoeocarpa* to iprodione, propiconazole, and thiophanate-methyl in Tennessee and northern Mississippi. Crop Science 48:1615-1620.

Detweiler, A.R, J.M. Vargas, Jr., and T.K. Danneberger. 1983. Resistance of *Sclerotinia homoeocarpa* to iprodione and benomyl. Plant Disease 67:627:630.

Golembiewski, R.C., J.M. Vargas, Jr., A.L. Jones, and A.R. Detweiler. 1995. Detection of demethylation inhibitor (DMI) resistance in *Sclerotinia homoeocarpa* populations. Plant Disease 79:491-493.

Jo, Y.-K., A.L. Niver, J.W. Rimelspach, and M.J. Boehm. 2006. Fungicide sensitivity of *Sclerotinia homoeocarpa* from golf courses in Ohio. Plant Disease 90:807-813.

Jo, Y.-K., S.W. Chang, M. Boehm, and G. Jung. 2008. Rapid development of fungicide resistance by *Sclerotinia homoeocarpa* on turfgrass. Phytopathology 98:1297-1304.

Kim, Y.-S., E.W. Dixon, P. Vincelli and M. L. Farman. 2003. Fungicides in *Pyricularia grisea* Caused by Mutations in the Mitochondrial Cytochrome b Gene. Phytopathology 93:891-900.

Koch, P.L., C.R. Grau, Y.-K. Jo, and G. Jung. 2009. Thiophanate-Methyl and Propiconazole Sensitivity in *Sclerotinia homoeocarpa* Populations from Golf Courses in Wisconsin and Massachusetts. Plant Disease 93:100-105.

Ok, C., J.T. Popko, Jr, K. Campbell-Nelson, and G. Jung. 2010. In vitro Assessment of *Sclerotinia homoeocarpa* Resistance to Fungicides and Plant Growth Regulators. Plant Disease (submitted)

Popko, J.T., C. Ok, W.R. Autio, M.T. McGrath, and G. Jung. 2009. The effect of demethylation inhibitor fungicides on *Sclerotinia homoeocarpa* population structures. 69th Annual Meeting of the Northeastern Division American Phytopathological Society. Abstract.

Putman, A.I., G. Jung, and J.E. Kaminski. Geographic distribution of fungicide-insensitive *Sclerotinia homoeocarpa* isolates in the northeastern United States. Plant Disease 94:186-195.

Wong, Francis P., Sharon L. Midland, and Karla A. de la Cerda. 2007. Occurrence and Distribution of QoI-Resistant Isolates of *Colletotrichum cereale* from Annual Bluegrass in California. Plant Disease 91:1536-1546.