

Fungicide Resistance for Common Golf Course Diseases

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Learning Objectives

- Know what fungicide classes are at risk for resistance development
- Understand how resistance develops in individuals and populations
- Understand how resistance develops in response to use fungicide use patterns
- Know the major diseases where resistance is a problem
- Develop a strategy to delay & manage resistance development for high risk diseases

Understanding Fungicide Groups

Fungicide Groups

- At least 40 different fungicide groups used in agriculture
- Groups are based on target site and biochemical mode of action (BMOA)
- FRAC is the intra-manufacturer group that oversees the classification of fungicide groups
 - FRAC website provides a lot of information on fungicide mode of action & resistance
 - www.frac.info

Multi-site vs Single-site inhibitors

- ▶ Multi-site
 - ▶ Non-specific mode of action
 - ▶ Preventive, non-systemic
 - ▶ These have a minimal or no risk for resistance
- ▶ Single-site
 - ▶ Affects a specific protein, enzyme or metabolic process
 - ▶ Curative, systemic
 - ▶ These have a resistance risk

Multi-site Inhibitors

FRAC Group	Chemical Group	Fungicide	Example
M1	Inorganics metals	Copper	Junction
M2	Inorganic sulfur	Sulphur	
M3	Dithio-carbamates	Mancozeb Thiram	Fore Spotrete
M4	Phthalimides	Captan	Captan
M5	Chloronitriles	Chlorothalonil	Daconil

Single-site Inhibitors

FRAC Group	Chemical Group	Fungicide	Example
1	Methyl benzimidazole carbamates (MBCs)	Benomyl Thiophanates	Benlate Cleary's 3336
2	Dicarboximides	Iprodione Vinclozlin	Chipco 26GT Curalan
3	Demethylation-inhibitors (DMIs)	Metconazole Myclobutanil Propiconazole Triadimefon Triticonazole	Tourney Eagle Banner Bayleton Triton/trinity
4	Phenylamides	Metalaxyl	Subdue
7	Succinate dehydrogenase inhibitors	Flutolanil Boscalid	Prostar Emerald

Resistance issues have been seen with groups highlighted in orange

Single-site Inhibitors

FRAC Group	Chemical Group	Fungicide	Example
11	QoI-fungicides	Azoxystrobin Fluoxastrobin Pyraclostrobin Trifloxystrobin	Heritage Disarm Insignia Compass
12	Phenylpyrroles	Fludioxonil	Medallion
14	Aromatic hydrocarbons	PCNB Etridiazole	PCBN Terrazole
19	Polyoxins	Polyoxin-D	Endorse
21	Qil-fungicides	Cyazofamid	Ranman
28	Carbamates	Propamocarb	Banol

Resistance issues have been seen with groups highlighted in orange

Single-site Inhibitors

FRAC Group	Chemical Group	Fungicide	Example
33	Phosphonates	Fosetyl-Al Phosphor. Acid	Aliette/Signature Alude
43	Benzimidides	Fluopicolide	Stellar
44	Microbials	<i>Bacillus subtilis</i>	Rhapsody

Resistance issues have been seen with groups highlighted in orange

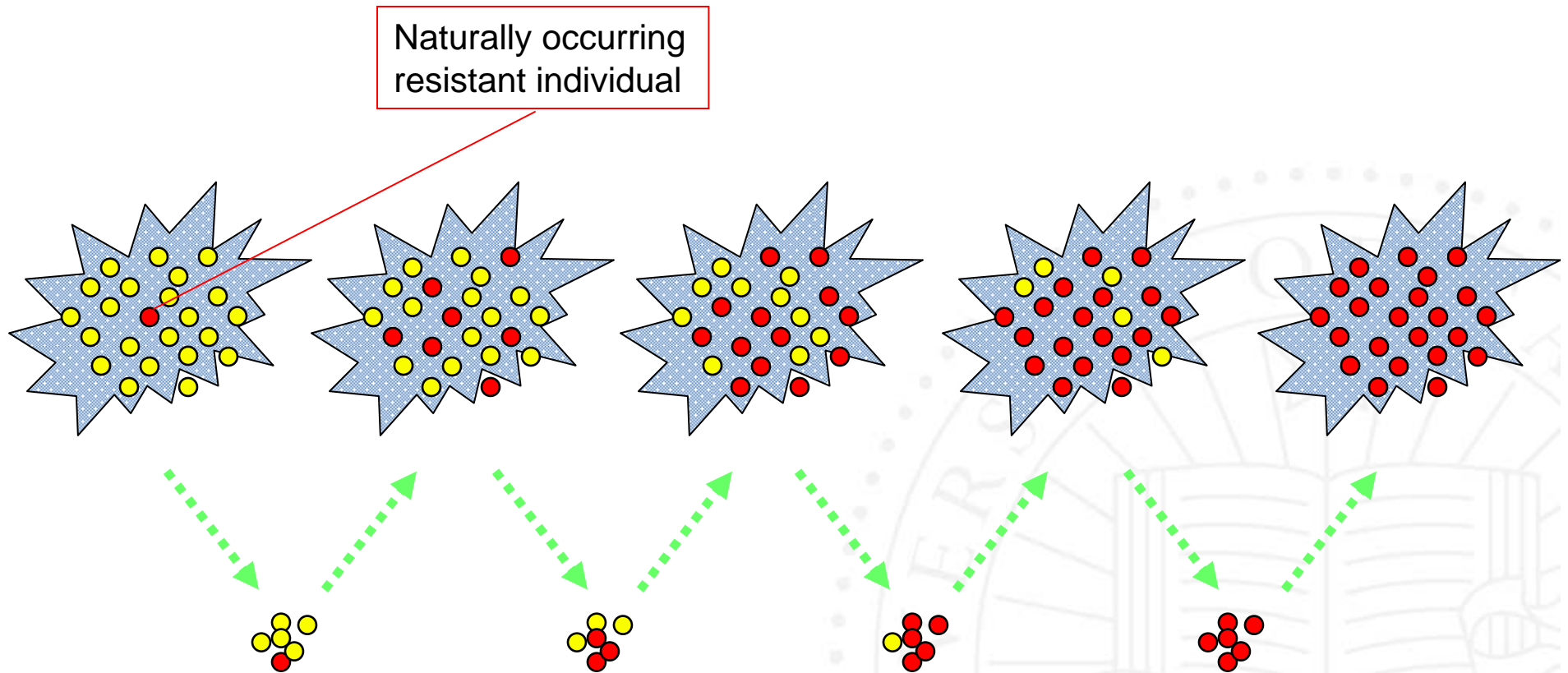
Fungicide Resistance Development



Fungicide Resistance Development

- Random mutations result in proteins that are changed in the ability to bind to the fungicide resulting in Biochemical Resistance
- These mutations are passed along to the next generation
- Repeated fungicide applications select for these mutants in a population
- When the frequency in the population is high enough you get Practical Resistance

Selection for Practical Resistance



The development of *Practical Resistance* is a step-wise process

Cross Resistance

- Fungicides in the same group have the same BMOA and target site
- The biochemical mechanism of resistance will affect the binding of all fungicides from the same fungicide group to the target site
 - For example: azoxystrobin resistant individuals are resistant to other Qols like pyraclostrobin, fluoxastrobin or trifloxystrobin

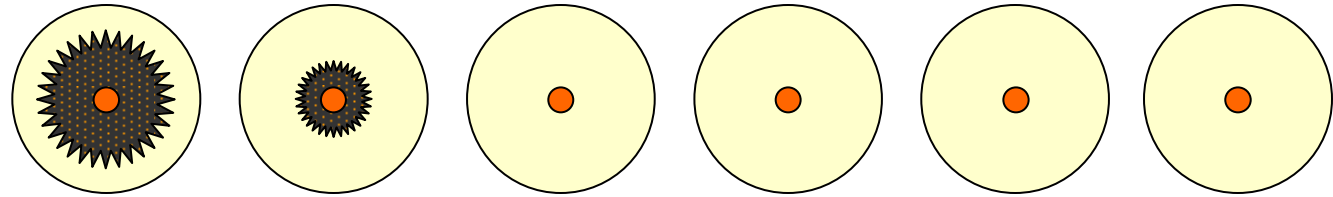
Cross Resistance

- However, cross resistance does not affect fungicides in different fungicide groups
- For example: an azoxystrobin (QoI) resistant individual may still be sensitive to thiophanate-methyl (MBC)
- Resistance develops independently for different fungicide groups
- Double, triple, quadruple resistance can happen, but each is independent

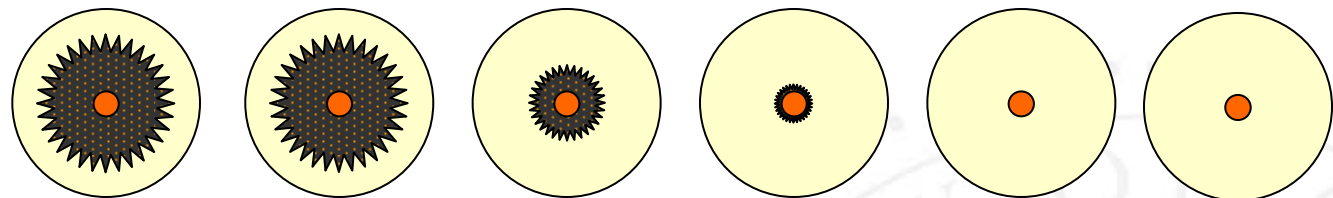
Resistance Development

- There are two kinds of resistance phenotypes
- Qualitative
 - Individuals are immune to the fungicide group
 - i.e. MBCs, Qols, phenylamides
- Quantitative
 - Individuals are tolerant to the fungicide group
 - i.e. dicarboximides, DMIs

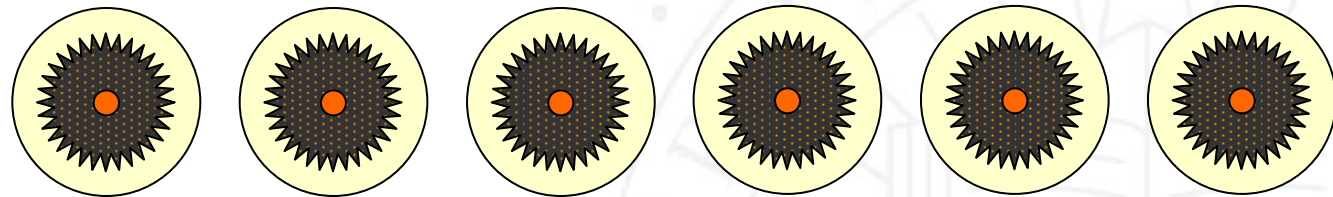
Sensitive



Tolerant



Immune



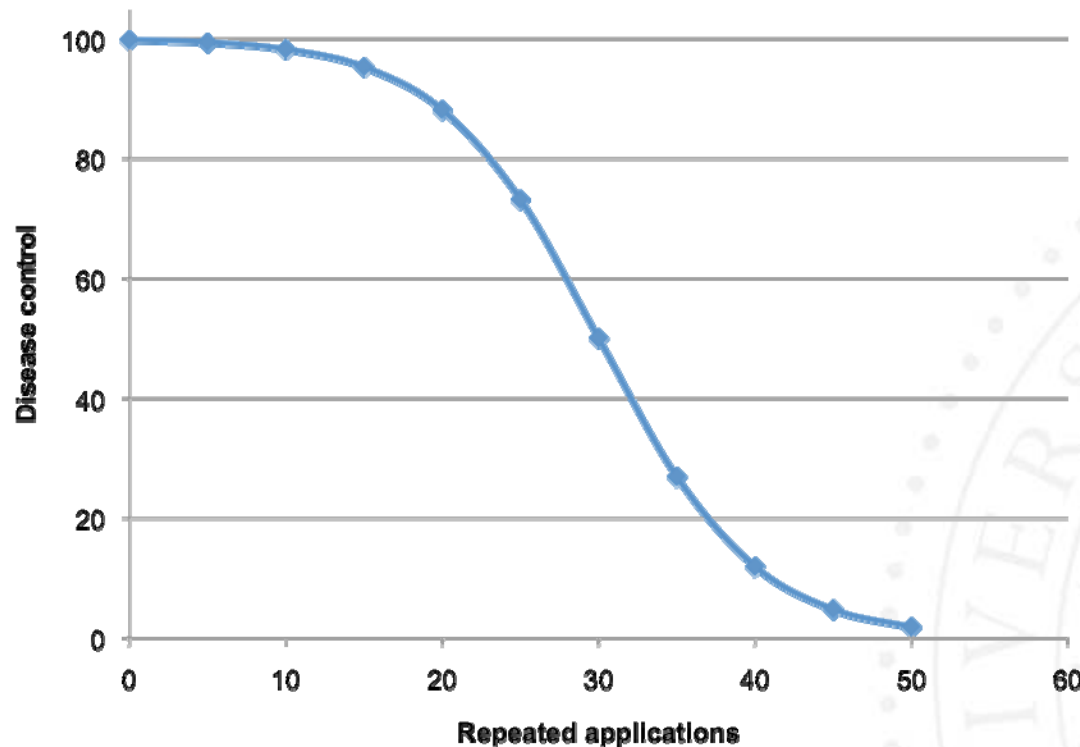
0 ppm

10 ppm

1000 ppm

increasing fungicide concentration

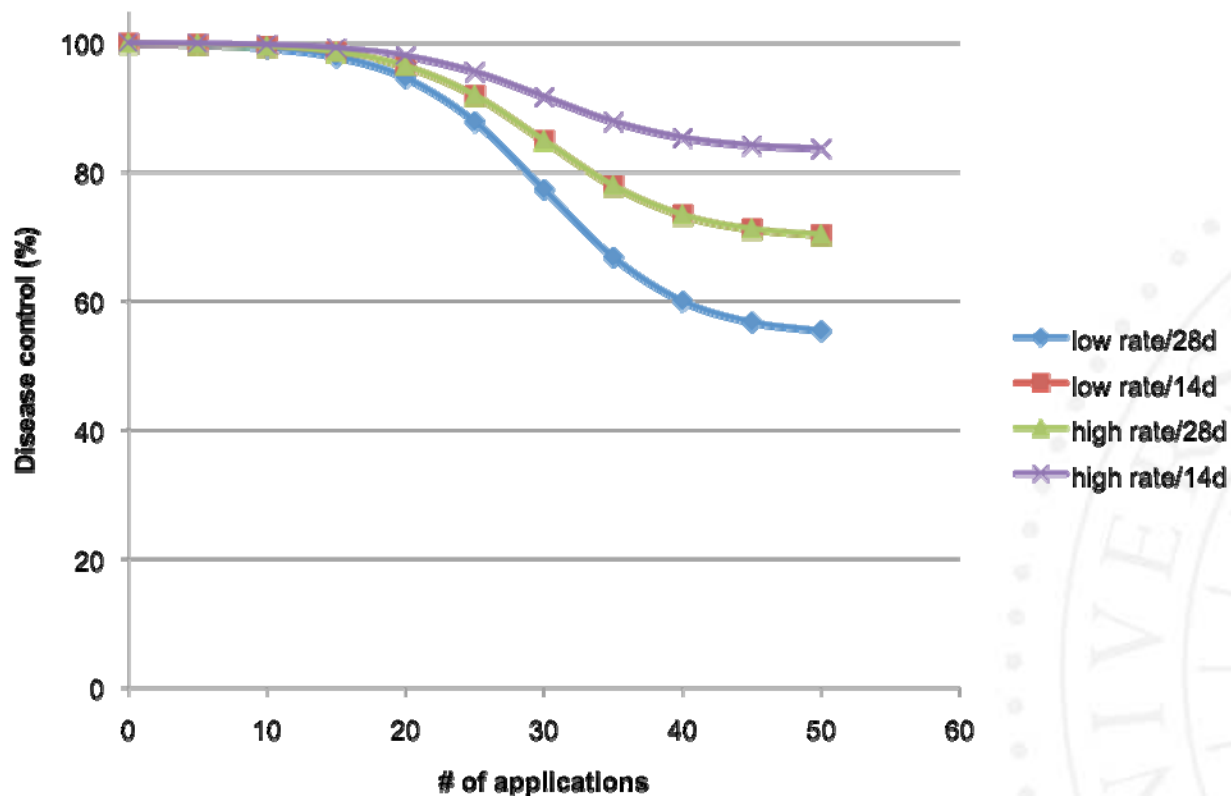
Theoretical Pattern of Qualitative Resistance Development



This pattern would be typical for MBC, QoI and phenylamide resistance

Increasing rates or applications has no effect on control of resistant isolates

Theoretical Pattern of Quantitative Resistance Development



This pattern would be typical for DMI and dicarboximide resistance

Increasing rates or shortening application intervals can decrease the impact of resistance

Fitness of Resistant Fungi

- Once a high frequency of resistance is established, resistance is usually permanent within the population
- Resistant isolates in the field are just as “fit” as the rest of the population
- Once selection pressure is applied, resistance may return quickly

Delaying & Managing Resistance

Resistance Risk

- Many factors contribute to the risk of resistance for any given fungicide

***Mode of
Action***



***Pathogen
Biology***

Use Patterns

Resistance Risk

- Mutations that result in no normal change in function to the target are at the highest risk of practical resistance development
 - MBCs, Qols, phenylamides
- Mutations that result in some change in function of the target by fungicide are moderately at risk
 - DMIs and dicarboximides
- Some fungicides have not had issues; mutations affecting these may result in less fit individuals that do not survive to become trouble makers

Relative Resistance Risk

LOWER RISK

Spring Dead Spot
Take-all Patch
Summer Patch

MODERATE RISK

Pythium Root Rot
Brown Patch
Yellow Patch
Southern Blight

HIGHEST RISK

Anthracnose
Dollar Spot
Grey Leaf Spot
Pink Snow Mold
Pythium Blight

Resistance occurs more frequently in pathogens that:

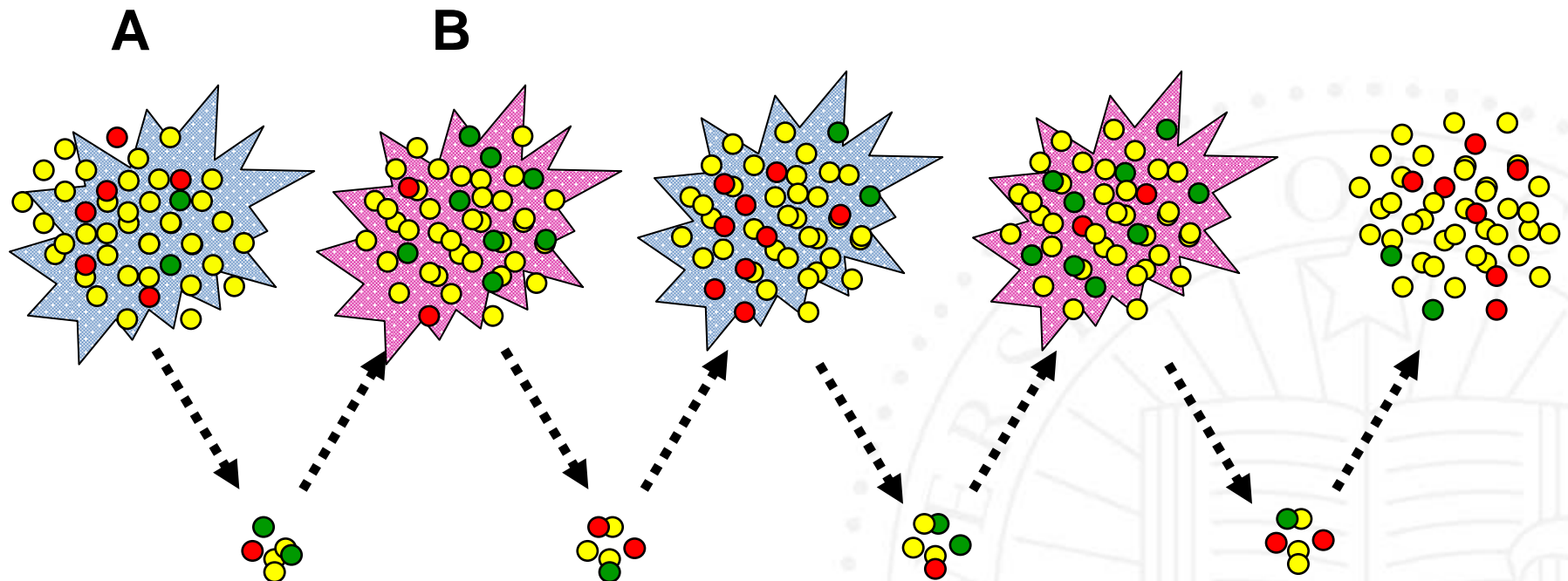
- Have a short generation time
- Have a high frequency of reproduction
- Have long periods of conditions favorable for disease development

Risk: Use Patterns

- Every application is a selection event
- The fastest way to resistance is repeated applications
- Late curative and reduced rate applications are worse:
 - Incomplete control & selection against a larger population
- Limit total applications from a fungicide group by alternation or reducing overall use by using cultural controls

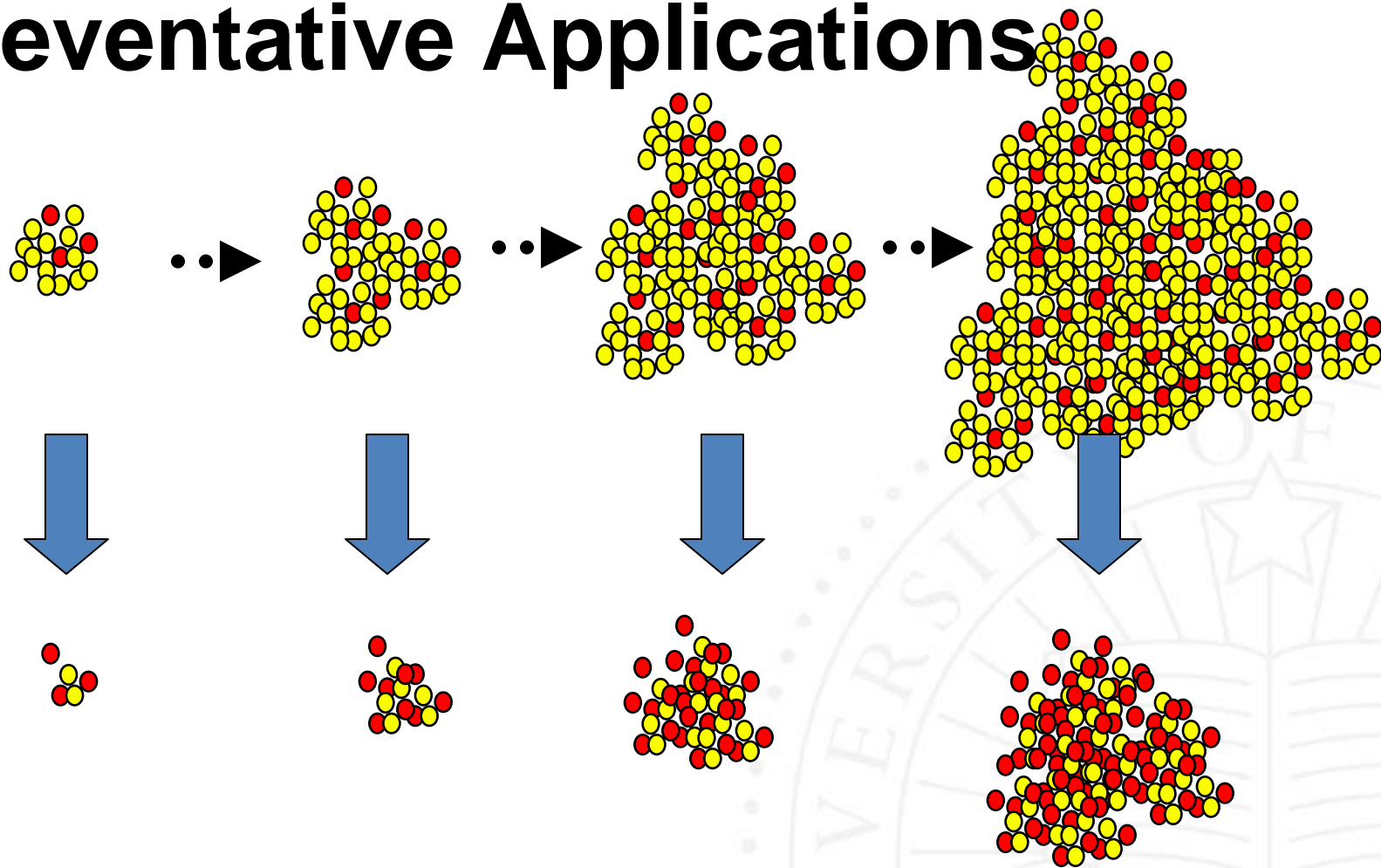
Fungicide Alternation

Prevents repeated selection for resistant individuals



Fungicide B indiscriminately controls Fungicide A - resistant individuals and vice-versa

Preventative Applications



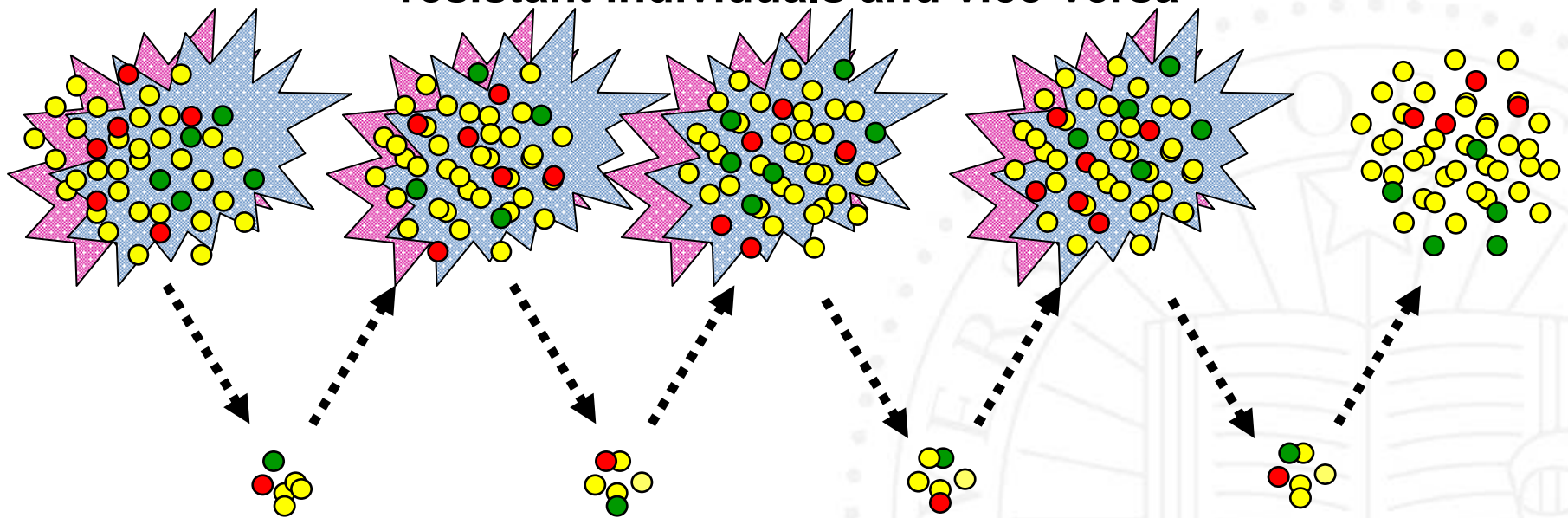
Minimize late curative applications against large populations

What About Mixtures???

- Mixtures are supposed to help delay resistance by exposing pathogens to multiple modes of action
- Two or more fungicides decreases the chance that one of them will fail completely
- But if any of the mixing partners is site specific, it is still a selection event
- Multi-site fungicides are preferred mixing partners as they carry no resistance risk

Fungicide Mixtures

**Prevents control failure caused by resistant individuals by exposure to multiple modes of action.
Fungicide B indiscriminately controls Fungicide A - resistant individuals and vice-versa**



You are more likely to get control with a mixture, but some selection for resistance can still occur

Assessing Resistance

- Keep good records
 - what worked & what didn't work
 - environmental conditions
 - equipment condition
- Make sure calculations are right
- Communicate well with crew
- If all checks out – send samples for testing
- Resistance can be confirmed by University and manufacturer labs

Managing Resistance

- Once resistance is confirmed – you are officially managing it
- Due to cross resistance – the whole fungicide class is affected
 - ex – Heritage resistant GLS is also Compass and Insignia resistant
- Resistance does not mean to give up a fungicide class just yet....

Managing Resistance

- ▶ Fungicide resistance development is independent for pathogens
 - ▶ example: losing Qols on anthracnose doesn't mean you've lost it for brown patch
- ▶ Resistance can be localized
 - ▶ Within greens
 - ▶ Within fairways
 - ▶ Within courses
- ▶ Resistant pathogens that disperse well may be able to spread to other parts of the course

Managing Resistance: General Strategies

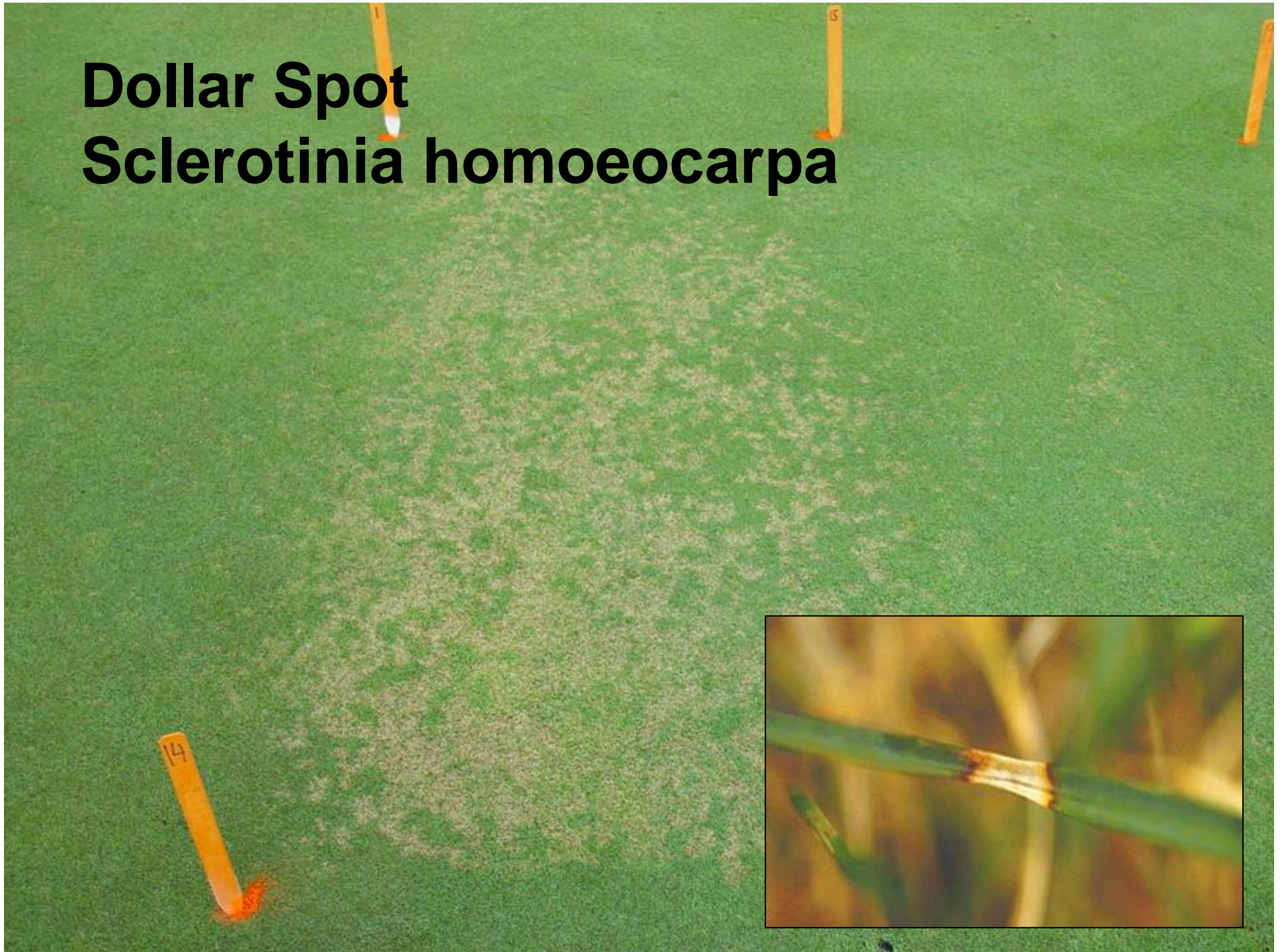
- Qols, MBCs, Phenylamides
 - Resistance to these = immunity
 - Switch to another fungicide class
- DMIs
 - Bump up rates and shorten intervals
- Dicarboximides
 - Bump up rates and shorten intervals
 - Reserve use for a few years from now
- Incorporate multi-site fungicide use
- Decrease disease pressure by using cultural controls

Resistance Issues for Specific Diseases and Suggested Strategies



Dollar Spot

Sclerotinia homoeocarpa



Dollar Spot

- Dollar spot is the most commonly occurring disease of turfgrass in the U.S.
- The “800 pound gorilla” for fungicide resistance for turf pathogens
- Major issues:
 - Benzimidazole resistance
 - Dicarboximide resistance
 - DMI resistance

Dollar Spot: MBCs

- MBC resistance is fairly widespread
- Courses with a long history of MBC use can no longer get good control with this fungicide
- Limit the number of seasonal applications of MBC fungicides
- Tank mixes with a multi-site can still provide good control
- example: Daconil + 3336, Spectro (a chlorothalonil/t-methyl premix)

Dollar Spot: Dicarboximides

- Current impact and distribution not well documented
- High rates and shorter application intervals are recommended
- Dicarboximide resistance appears to recede over time
- Michigan populations appeared to regain some sensitivity when removed from rotation for 3+ yrs (Vargas)

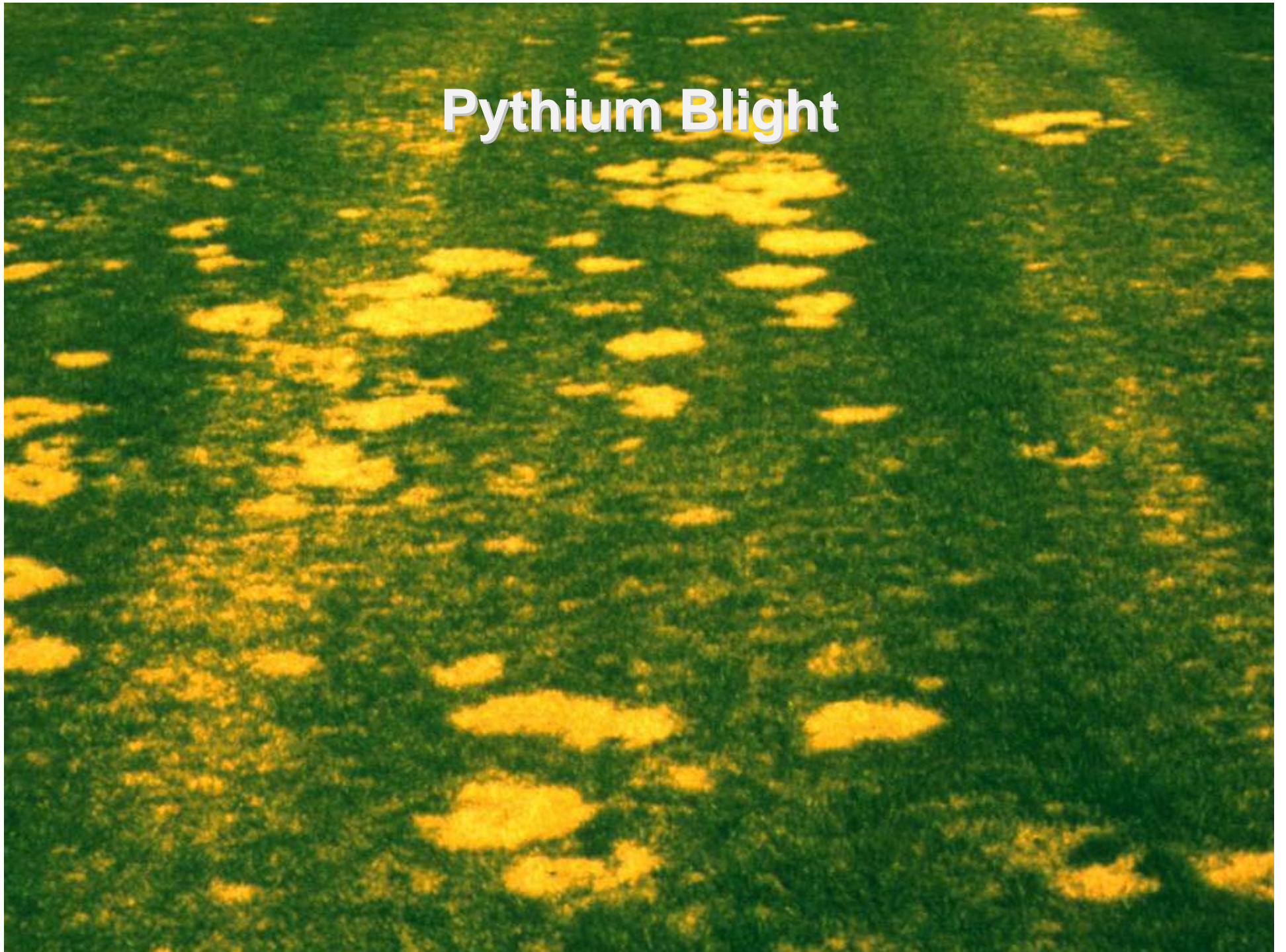
Dollar Spot: DMIs

- Mainly a problem on fairways when low rates and long application intervals are used
- When reduced effectiveness is observed, increase rate or shorten application interval
- Tank mixes with a multi-site will help control the disease

Dollar Spot: Alternatives

- Increased nitrogen, leaf wetness management, other cultural controls
- Multi-site fungicides
 - Chlorothalonil
 - Be aware of seasonal restrictions
- Single site fungicides
 - Boscalid (Emerald)
 - Biologicals

Pythium Blight



**Pythium Blight on Ryegrass and
Poa trivialis overseeded on Bermuda**



Fungicide Resistance: Pythium

- Resistance to metalaxyl/mefenoxam (Subdue) is probably the biggest issue for Pythium
 - Cases reported from multiple sites since 1980s (P. L. Sanders 1984)
 - Mefenoxam still used frequently for control
- Impact is the greatest for protection of seedlings during the overseeding process
- Driven by multiple, repeated applications (seed treatment, foliar)

Fungicide Resistance: Pythium

- QoI resistance has not been detected on courses, but has been in laboratory tests
 - No more than 2 sequential applications
 - Use high rates of azoxystrobin, fluoxastrobin or pyraclostrobin for best control

Fungicide Alternatives: Pythium

- For seedling blight where mefenoxam resistance is present, azoxystrobin, chloroneb, etridiazole, or phosphorous acid fungicides may be effective
- On established turf, pyraclostrobin, fluoxastrobin, fosetyl-Al, mancozeb and propamocarb can also be used
- Fluopicolide and cyazofamid are effective on established turf, but there is not enough data on seedling protection

Pythium Alternatives

- ▶ Since seedlings are so vulnerable, overseeding must be performed outside of the danger window
 - ▶ avg RH + min Temp > 150 = danger
 - ▶ night time > 68F = danger
 - ▶ Delay overseeding to be outside of the window
- ▶ Time preventive applications for Pythium on established turf for the danger window

Grey Leaf Spot *Pyricularia grisea*

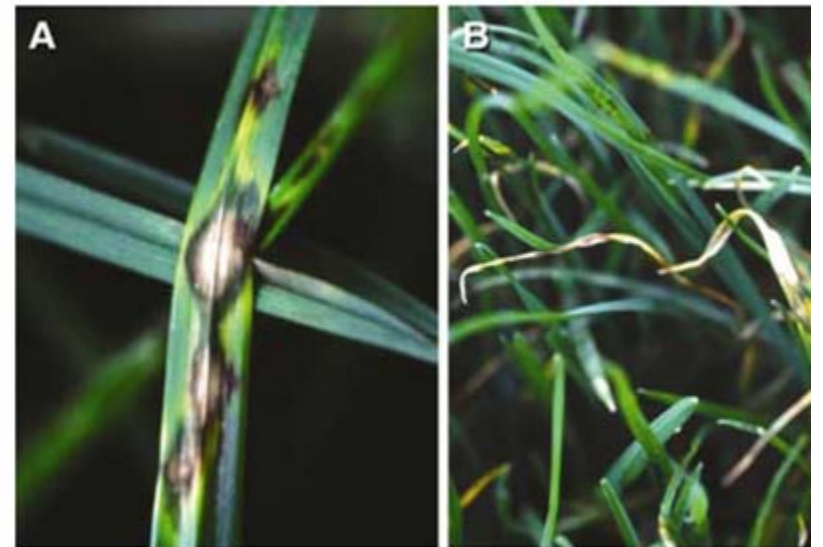


Fig. 3. Gray leaf spot symptoms on perennial ryegrass. A, Characteristic lesion. B, Flagging of leaf blade.

Courtesy Paul Vincelli, Univ. of Kentucky
Uddin Viji and Vincelli (2003) Plant Disease 87:880-889

Fungicide Resistance: Gray Leaf Spot

- Issues were reported just a few seasons after Qols were used widespread for GLS control
- Likely due to the speed of the disease and its ability to sporulate profusely
- Unlike most cases of Qol-resistance, two phenotypes were found
 - G143A cytb mutants: immune
 - F129L cytb mutants: tolerant
- Unfortunately, immune isolates appeared to dominate resistant locations

QoI Resistance Management: GLS

- ▶ Limit QoI applications for GLS control
 - ▶ Labels say no more than 2 – 4 sequential applications
 - ▶ Conservatively, rotate to another fungicide group after QoI application
 - ▶ Use no more than 2 applications per season for GLS
- ▶ Tank mixing with a contact (chlorothalonil) will help reduce the impact of resistance development

GLS Fungicide Alternatives

- Deploy resistant varieties of perennial ryegrass to reduce the impact of GLS
- Modify conditions that promote prolonged leaf wetness periods
- Reduce nitrogen fertility during summer periods of GLS activity
- Don't increase mowing heights

GLS Fungicide Alternatives

- ▶ Chlorothalonil & mancozeb
 - ▶ Both products are effective for GLS control and carry no resistance risk
 - ▶ Due to the explosiveness of the disease, applications may be not be effective >14 days
 - ▶ Be aware of chlorothalonil restrictions
 - ▶ Tank mixing with site specific fungicides will help reduce the impact of any fungicide resistance

GLS Fungicide Alternatives

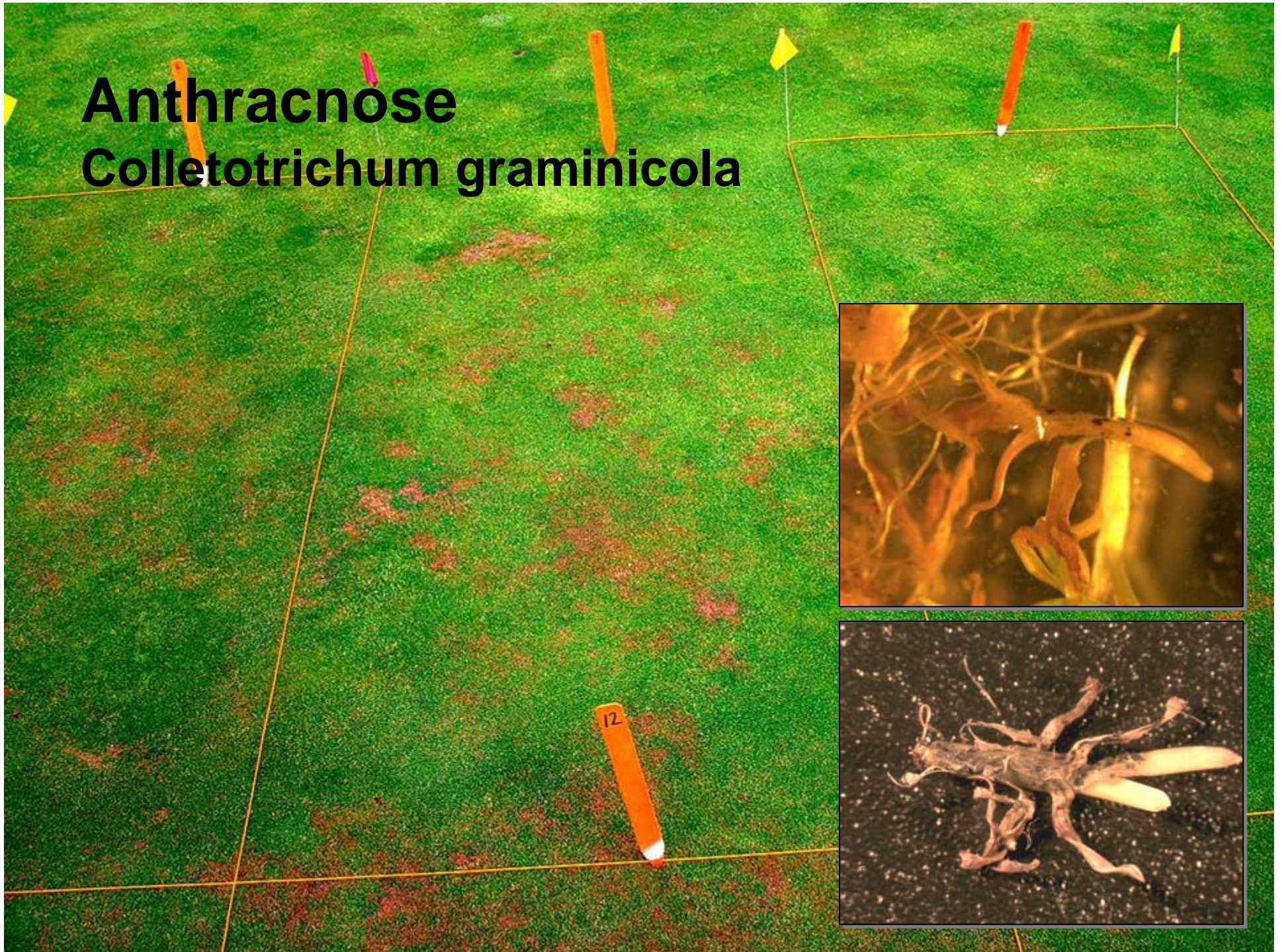
- ▶ Thiophanate-methyl (3336)
 - ▶ MBC-resistance has not been an issue
 - ▶ Reduced rates (4 to 6 oz vs 8 oz) may shorten length of effectiveness
 - ▶ Use 1 to 2 applications/yr for GLS; rotate between applications
 - ▶ Tank mix with chlorothalonil or use a premix product (Spectro 90)

GLS Fungicide Alternatives

- DMI fungicides
 - Can provide good control of GLS, especially when tank mixed with a multi-site fungicide
 - No resistance issues have been identified with these products for GLS control

Anthracnose

Colletotrichum graminicola



Fungicide Resistance: Anthracnose

- Resistant isolates detected starting 2002-2003
- Qols
 - New York, New Jersey, Pennsylvania, Georgia, California, Connecticut
- MBCs
 - New York, New Jersey, Pennsylvania, Georgia, California, Connecticut, Massachusetts, Ontario
- Resistance to both is considered fairly widespread by now

Fungicide Resistance: Anthracnose

- Resistance development is likely due to
 - Frequent curative applications with site-specific fungicides
 - Activity of the fungus throughout the year = exposure to greens fungicide applications even when symptoms are not present

MBC Resistance: Anthracnose

- Fairly common at locations where it's been used repeatedly
- Very poor to no control on resistant greens
- Limit use on greens where the product is still performing well
- Curative applications are not recommended

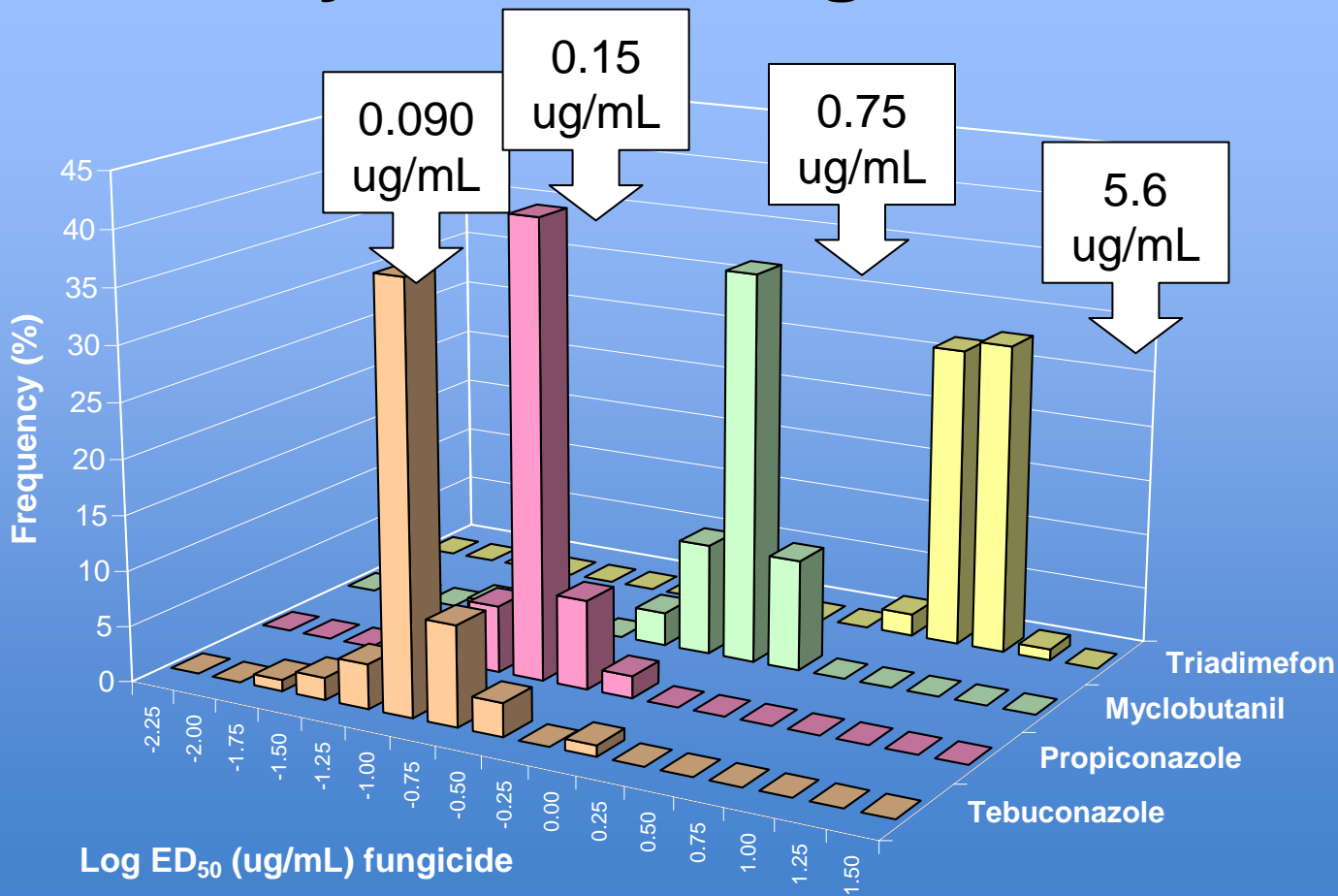
QoI Resistance: Anthracnose

- Fairly common at locations where it's been used repeatedly
- Very poor to no control on resistant greens
- Curative applications are not recommended
- Maintain use against other summer diseases
 - Summer Patch
 - Rapid Blight
 - Brown Patch

DMI Resistance: Anthracnose

- So far, DMI resistance has not been a true problem for anthracnose management
- High rate use of DMIs on greens is a likely factor
- However, differences between DMIs have been detected that are correlated with disease control

Sensitivity to DMI-Fungicides:



Intrinsic Activity of DMIs

- Propiconazole (Banner MAXX) appeared 7X more active than myclobutanil (Eagle) and 35X more active than triadimefon (Bayleton)
- Tebuconazole (Lynx) was very active, but it is in registration limbo right now
- Differences in intrinsic activity are reflected in actual field control; less active DMIs give poorer control

Rutgers 2002 Anthracnose Data (Dr. Bruce Clarke)

Treatment	% Area Diseased		
	18 Jul	14 Aug	10 Sep
Eagle 40W (1 oz)	3.3	10.0	32.8
Banner MAXX (1 fl oz)	0.8	1.3	7.5
Lynx 45W (1.1 oz)	0.0	0.0	0.8
Bayleton 50DF (1 oz)	7.3	60.3	78.5

All treatments applied at 14 day intervals, 2 gal/M

Intrinsic Activity of DMIs

- Right now, Banner MAXX appears to be the most active DMI vs anthracnose
- Other DMIs are being examined right now, and not enough data exists to make a clear recommendation on these
 - Triticonazole (Trinity or Chipco Triton)
 - Metconazole (Tourney)



Fungicide Strategies: Anthracnose

- Use cultural controls & don't stress grass
- Use high labeled rates of DMIs for early season control
- Propiconazole appears to be the most active
- Use QoIs and MBCs for other summer diseases, but don't rely on them for anthracnose control
- Use other fungicides preventively for mid summer programs

Fungicide Strategies: Anthracnose

➤ Chlorothalonil

- Very useful when applied preventively at 14 day intervals
- Save chlorothalonil applications for anthracnose when other fungicides can be used for other diseases
- Tank mix low rates with other fungicides if possible

➤ Fludioxonil

- 0.33 to 0.5 oz Medallion can be used effectively on 14 day intervals
- Limited to 1.5 oz/yr; rotate with other fungicides

Fungicide Strategies: Anthracnose

- ▶ Polyoxin-D
 - ▶ Use 4 oz preventively at 14 day intervals
 - ▶ Rotate with other fungicides
- ▶ Fosetyl-AI (Chipco Signature)
 - ▶ Use 4 to 8 oz of the pigmented form to tank mix with other fungicides
 - ▶ Apply tank mix at 14 to 28 day intervals; if used every 28 days, rotate another fungicide at 14 days
 - ▶ The tank mix partner must also be effective
 - ▶ Chlorothalonil, fludioxonil & polyoxin-D are good choices

Microdochium Patch/Pink Snow Mold



Fungicide Resistance: Pink Snow Mold

- MBC and dicarboximide resistance have been known to be present since the 1980s, as first reported in Washington State.
- Resistance to Qols has been observed in California; likely in other locations
- Resistance development is likely due to
 - Long application intervals under snow cover
 - Curative applications without snow cover

Fungicide Resistance: Pink Snow Mold

- In cold weather locations, the impact of resistance may be low
- PCNB can be used effectively and no resistance issues have been reported
- In areas with PSM issues where PCNB cannot be used safely, the impact will be higher

Resistance Management: Pink Snow Mold

- Limit applications of MCB, dicarboximide, or Qols for PSM control to 1 to 2 applications per season
- Dicarboximide applications are the least risky of these fungicides
- Tank mix these with a contact or a DMI fungicide for best control
- Use high labeled rates if conditions favorable for PSM without snow cover are prolonged (cool, wet weather)

Fungicide Alternatives: Pink Snow Mold

- Chlorothalonil, mancozeb and thiram are all multi-site fungicide that can be used/tank mixed with other applications
- Fludioxonil
- Polyoxin-D
- DMI fungicides
- Chlorothalonil + Fludioxonil + Propiconazole

Developing Resistance Management Strategies

Developing a Management Strategy

- Dollar spot, gray leaf spot, Pythium, anthracnose and pink snow mold are the diseases with the most significant resistance issues
- Each disease has a different group of fungicides where resistance is an issue
- These fungicides may not be affected by resistance at your course, but should be monitored closely
- Performance issues should be correlated with laboratory tests to confirm resistance

Developing a Management Strategy

- Because of cross-resistance, it is very important to not use the same fungicide group repeatedly
- Limiting the use of fungicide applications by rotating fungicides will not stop resistance, but will prolong the usefulness of the fungicides
- Limit the use of single-site fungicides by
 - Incorporating other control measures
 - Keeping multi-site fungicides in the program
- Use mixtures to improve disease control, but they will not stop resistance development

Developing a Management Strategy

- Minimize the use of late curative applications
- High rate strategies will improve DMI and dicarboximide effectiveness
- High rates may be useful for other fungicides where resistance has not yet been a problem (e.g. where resistance mechanisms are not fully understood)
- Even though some single-site fungicides do not currently have resistance issues, we should not overuse and abuse them

The Future for Fungicide Development

- New fungicide registrations are becoming harder and harder
 - Development is expensive (\$100s of millions)
 - New fungicides must be extremely safe
 - Effective multi-site fungicides will be extremely rare
- Legislation like the Food Quality Protection Act may cancel/restrict some older fungicides
- It is extremely important to prolong the longevity of what we have now

Summing it All Up



Summary

- Fungicide resistance is an issue that affects site-specific fungicides
- Multi-site fungicides have no resistance risk
- Fungicide groups are based on target site and mode of action
- Each group affects a specific target in the host
- Mutations in the host target result in fungicide resistance (biochemical resistance)

Summary

- Target site mutations affect all fungicides in a fungicide group (cross resistance)
- Fungicide applications select for individuals with naturally occurring target site mutations
- Repeated applications increase the frequency of these individuals to a point where disease control is reduced (practical resistance)
- Resistance is usually not an issue that goes away once it develops

Summary

- Resistant individuals are either immune or tolerant
 - Increasing fungicide rates can still control tolerant fungi but not immune fungi
- The best way to select for resistance is repeated applications
- Late curative applications are worse because they allow a larger population to be selected against

Summary

- Alternating and rotating fungicides delays the development of practical resistance
- Fungicide mixtures can give increased control and limit the impact of resistance, but can still select for resistance development
- Once resistance is observed and confirmed, you can manage resistance by choosing alternative control measures
 - Resistance must be delayed to other fungicides that are used as alternatives

Summary

- Five disease are the most impacted by resistance
- Dollar spot – MBCs, dicarboximides, DMIs
- Pythium - mefenoxam
- Gray leaf spot – Qols
- Anthracnose – Qols and MBCs
- Pink Snow Mold – Qols, MBCs and dicarboximides

For More Information

- FRAC website: www.frac.info
- McGrath, M.T. 2004. What are Fungicides. The Plant Health Instructor.
 - <http://www.apsnet.org/education/introplantpath/topics/fungicides/default.htm>
- ‘Chemical Approaches to Managing Plant Pathogens’ by W. Koeller in the Handbook of Pest Management edited by John R. Ruberson, CRC Press, 1999.
- Fungicide Resistance in North America, edited by C.J. Delp, APS Press, 1988

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