
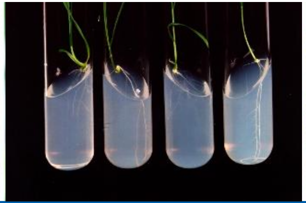


Integrated Pest Management: Science and Practice
Disease control in cereals

Neil Paveley and Frank van den Bosch

A video series funded by Defra and produced by ADAS

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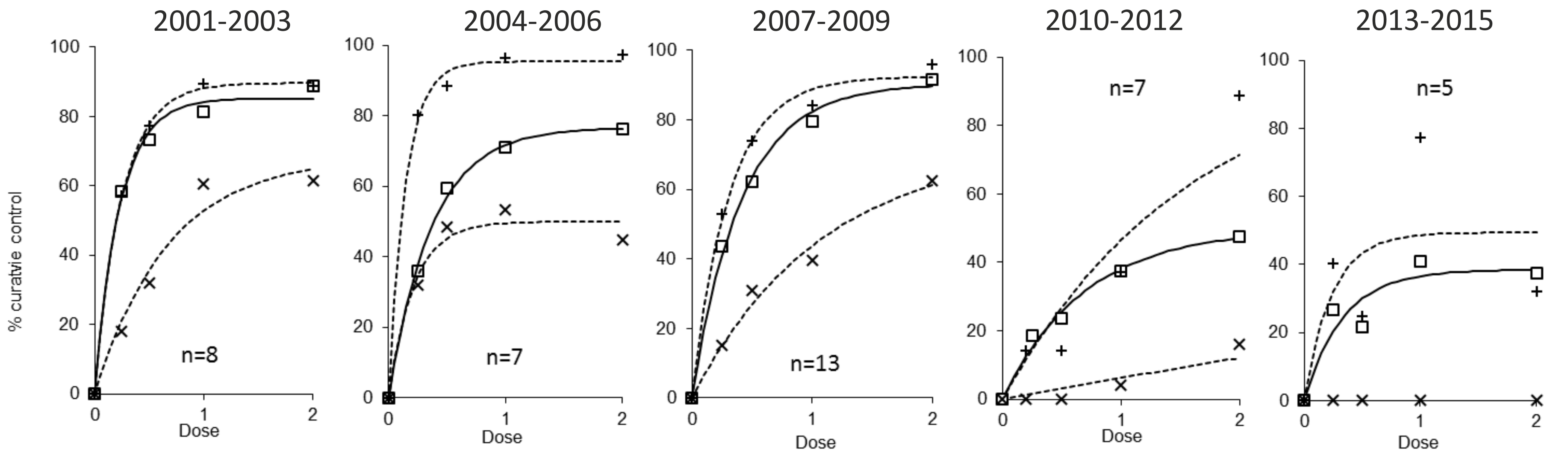
How to manage fungicide resistance?

Broad-spectrum fungicide modes of action:

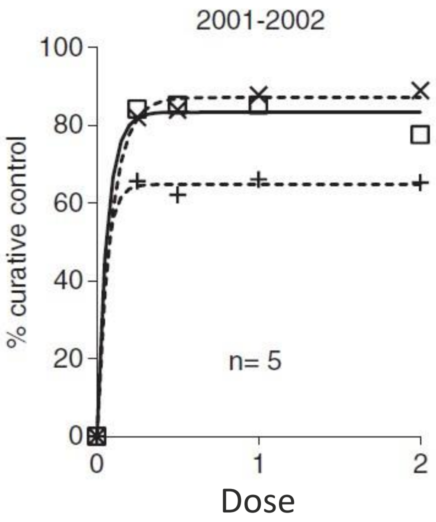
Azoles (demethylation inhibitors; DMIs)	1970s
Strobilurins (quinone outside inhibitors; QoIs)	1990s
Succinate dehydrogenase inhibitors (SDHIs)	2010s
Quinone inside inhibitors (QiIs)	2020s
Next new mode of action	?

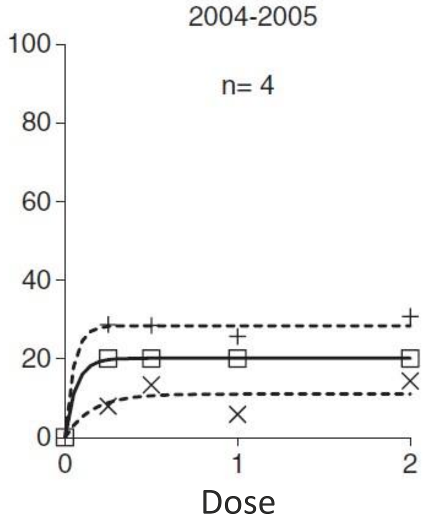
Azole (prothioconazole)



Source: Blake et al. (2018) Plant Pathology

QoI/strobilurin (trifloxystrobin)





Source: Blake et al. (2018) Plant Pathology

How to manage fungicide resistance?

How to manage resistance – Part A (this video)

Number of fungicide applications

Dose per application

Mixtures of fungicide modes of action

Integrated pest management

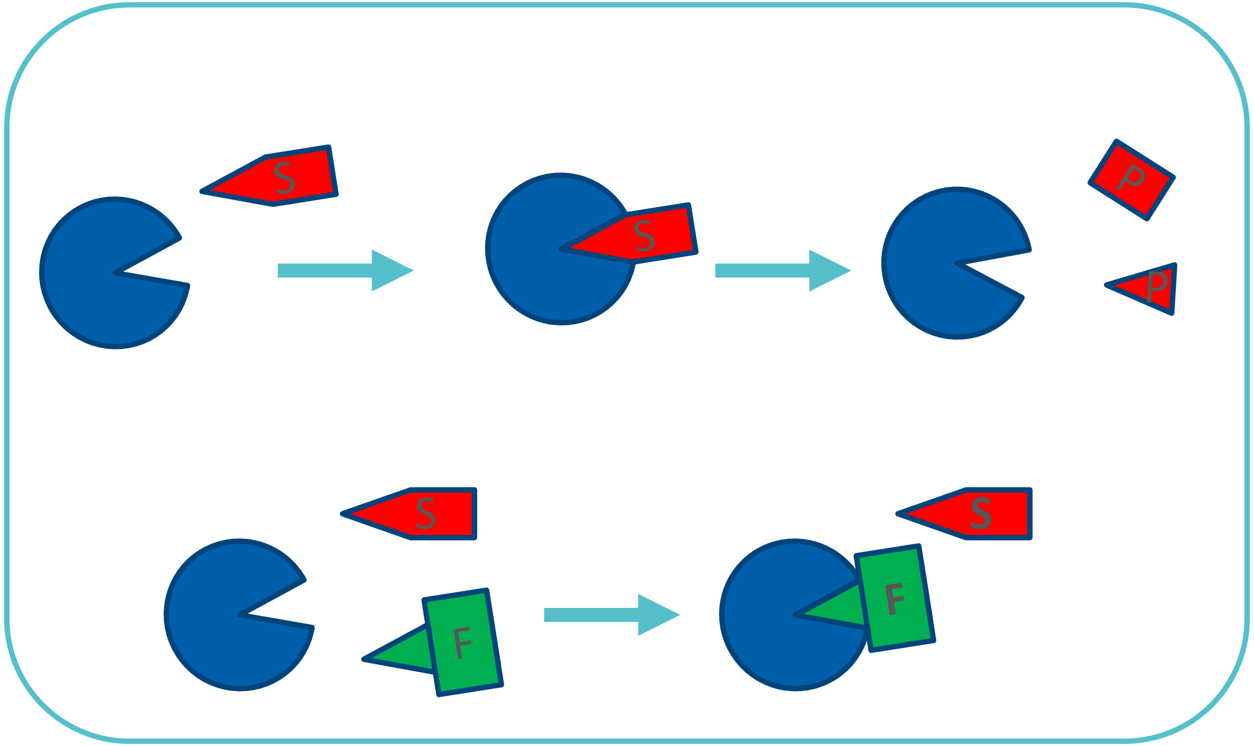
How to manage resistance – Part B (next video)

Alternating modes of action

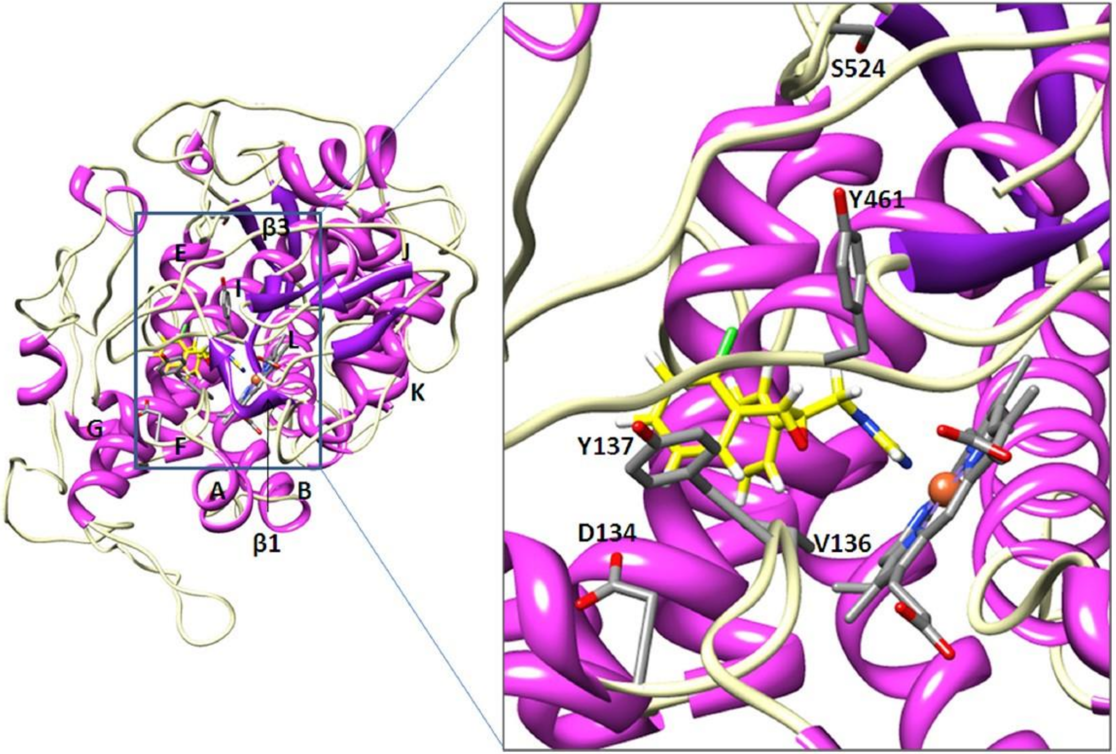
Alternation or mixtures?

Spray timing

Fungicide blocking enzyme in biochemical pathway

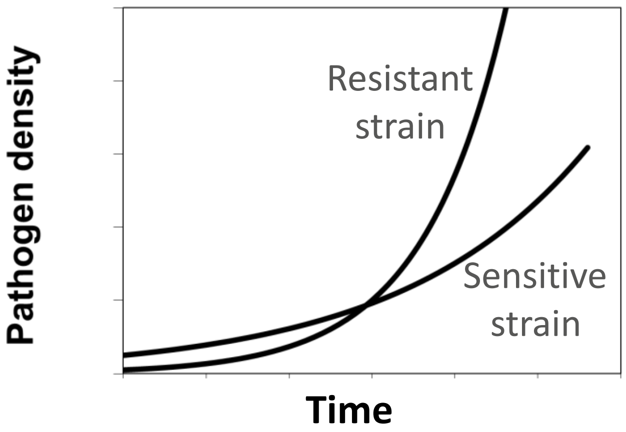


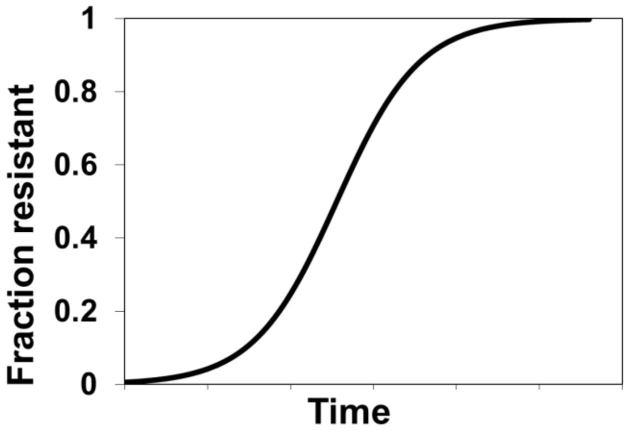
Target enzyme for a mode of action



Source: Cools et al. (2011) Applied and Environmental Microbiology

Resistance evolution





$$\text{Selection} = (r_R - r_S)T$$

*r*R: *per capita* growth rate of the fungicide resistant strain.

*r*S: *per capita* growth rate of the fungicide sensitive strain.

Selection is the increase in the fraction resistant.

Resistance management strategies

$$\text{Selection} = (r_R - r_S)T$$

Strategy 1: Reduce growth rates of resistant and sensitive strains

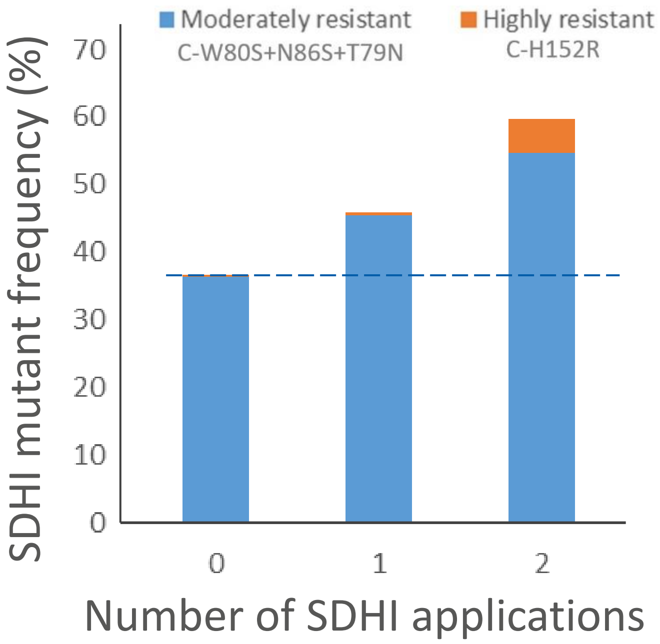
Strategy 2: Reduce growth rate of resistant strain relative to sensitive strain

Strategy 3: Reduce time pathogen exposed to fungicide

Source: Milgroom & Fry, 1988. *Phytopath.;* van den Bosch *et al*., 2014. *Ann. Rev. Phytopath.*

Number of fungicide applications

SDHI + azole mixture. Mean of 4 field trials



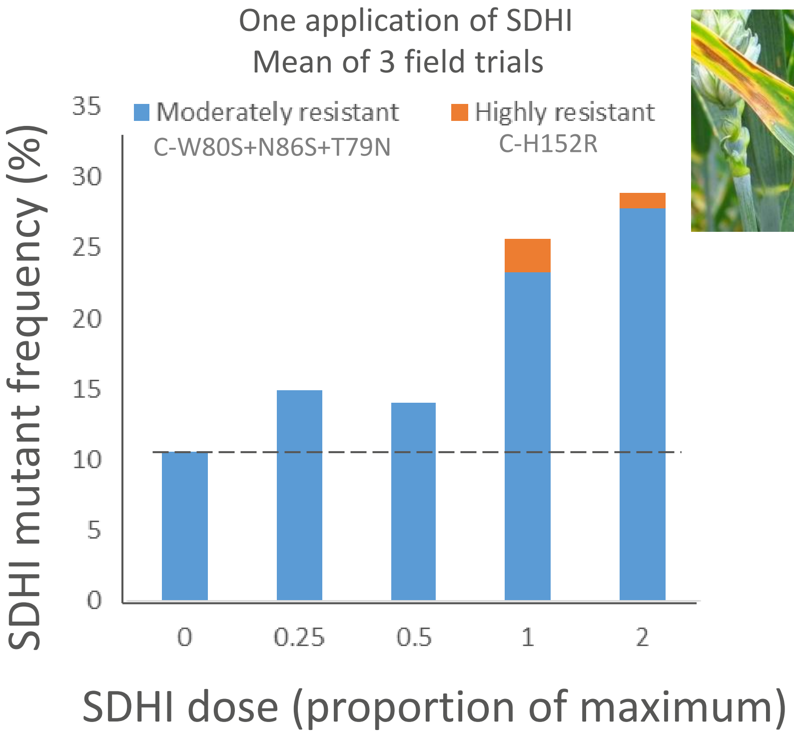
Increasing number of applications increases exposure time

Global evidence across pathogens and modes of action:

	Increases selection	No effect	Decreases selection
Spray number	**6**	0	0

Source: Paveley et al. 2019 Reinhardsbrunn proceedings; van den Bosch et al. 2014 *Ann. Rev. Phytopath.*

Dose per application



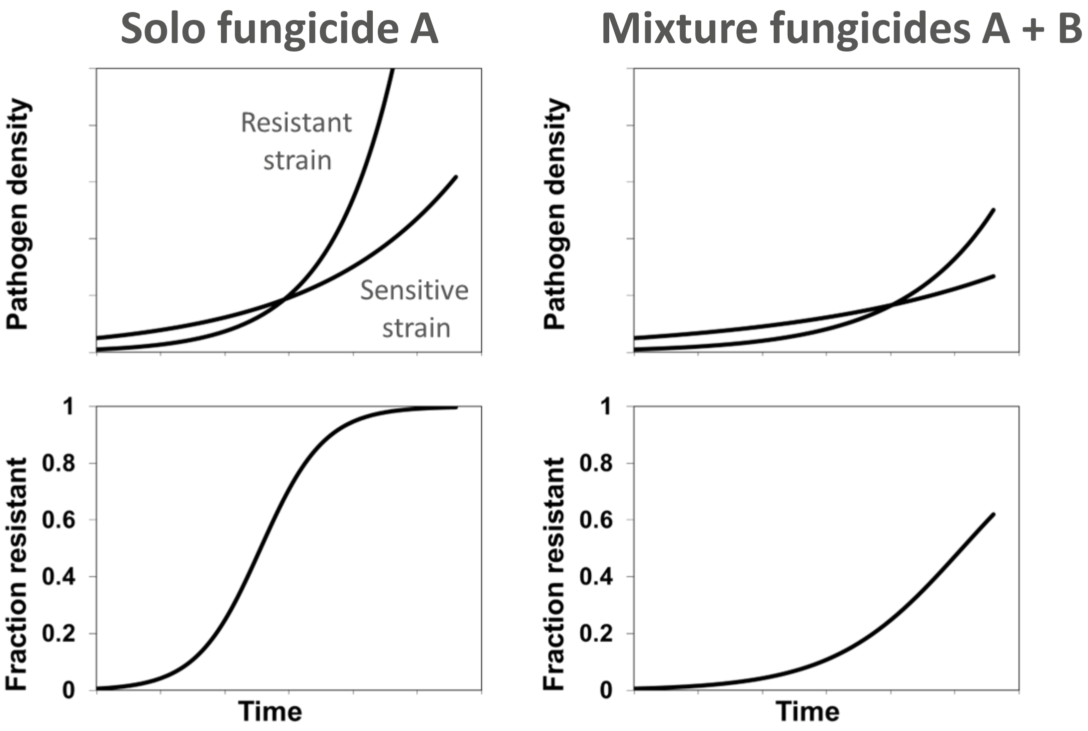
Higher doses affect growth rate of sensitive strain more than growth rate of the resistant strain

Global evidence across pathogens and modes of action:

	Increase selection	No effect	Decrease selection
Increase dose	**16**	1	2

Source: Paveley et al. 2019 Reinhardsbrunn proceedings; van den Bosch et al. 2014 *Ann. Rev. Phytopath.*

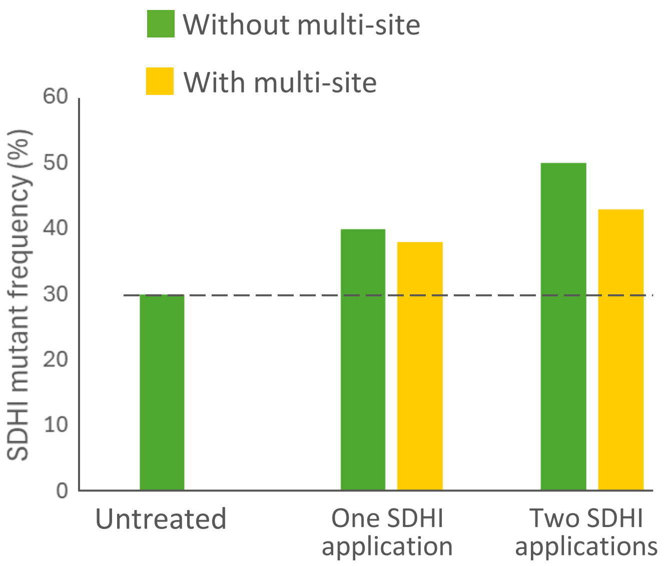
Adding a mixture partner



$$\text{Selection} = (r_R - r_S)T$$

Mixture of fungicide modes of action

SDHI + azole mixture. Mean of 4 field trials



Adding a mixture partner reduces growth rate of the resistant and sensitive strains, i.e. Strategy 1

Global evidence across pathogens and modes of action:

	Increases selection	No effect	Decreases selection
Add a mix partner	1	5	**43**

Source: Young et al. (2021) AHDB project report PR637

What to mix?

- Mixtures of modes of action reduce selection for resistance and increase efficacy
- Choice of mix partners needs to balance minimising resistance with effectiveness and cost
- The reduction in selection is related to the efficacy of the mixture partner
- Multi-site fungicides are low resistance risk
- Single-site fungicides are usually at moderate or high risk
- Mixing a multi-site with a single-site fungicide helps protect the single-site
- Mixing single-site fungicides provides mutual protection. It also creates selection for resistance against both modes of action, but is still good resistance management
- If a cost-effective multi-site is available, use it at the maximum permitted dose and use the minimum amount of single-site needed to achieve effective disease control

Sources: Grimmer et al., Pesticide science (2014); Young et al. (2021) AHDB report PR637

Restrictions on use for resistance management

IMPORTANT INFORMATION FOR USE ONLY AS AN AGRICULTURAL FUNGICIDE

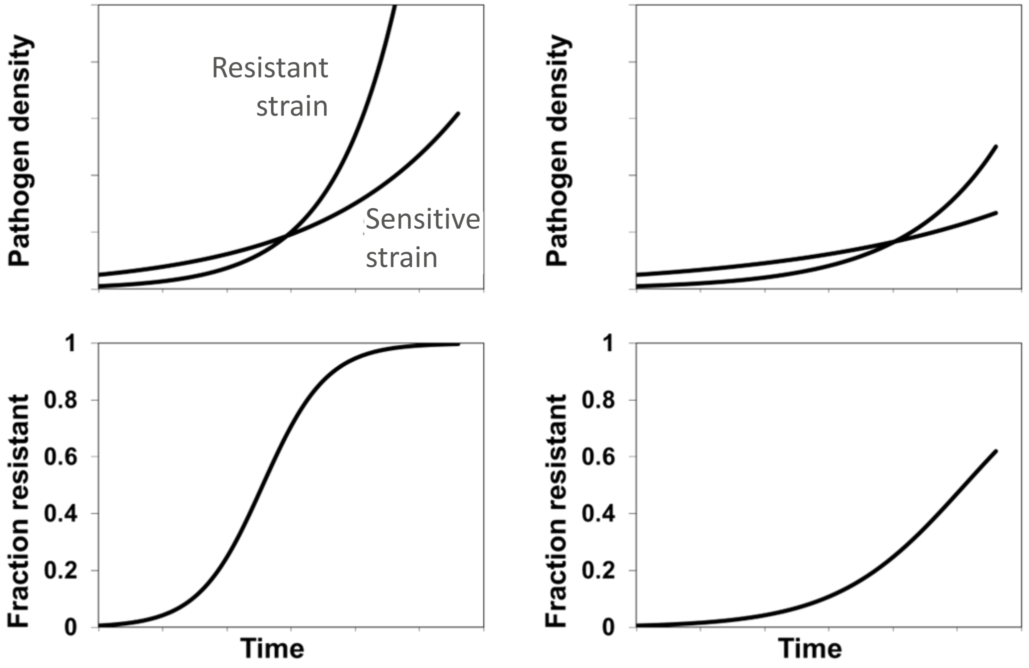
Crops:	Maximum individual dose:	Maximum total dose:	Latest time of application:
Winter and spring barley.	1.0 L product/ha	2.0 L product/ha	Barley: Up to beginning of flowering, first anthers visible (GS 61)

Other Specific Restrictions:
A maximum of 2 foliar applications of product(s) containing SDHIs can be applied to any cereal crop. Apply SDHI fungicides always in mixtures. The mixture partner:
i) should provide satisfactory disease control when used alone on the target disease.
ii) must have a different mode of action

READ THE LABEL BEFORE USE. USING THIS PRODUCT IN A MANNER THAT IS INCONSISTENT WITH THE LABEL MAY BE AN OFFENCE. FOLLOW THE CODE OF PRACTICE FOR USING PLANT PROTECTION PRODUCTS.

Disease resistant variety as a 'mixture partner'?

Susceptible wheat variety **Partially resistant variety**



Selection = $(r_R - r_S)T$

How to manage fungicide resistance?

- Different fungicide modes of action target different enzymes in the pathogen
- Mutations affecting the target site enzyme of a single-site fungicide are usually the major cause of resistance
- Total dose of a single-site mode of action used in a season is a key driver of resistance selection
  - Decreasing the number of fungicide applications decreases selection
  - Decreasing the dose of fungicide per application decreases selection
- Use the amount of fungicide needed for effective disease control, but no more
- IPM practices that reduce the total fungicide dose needed are the basis for resistance management

Further reading

Guides

Guidance from the UK Fungicide Resistance Action Group (FRAG-UK): https://ahdb.org.uk/knowledge-library/the-fungicide-resistance-action-group-frag-uk

Guidance from the industry Fungicide Resistance Action Committee (FRAC): https://www.frac.info/

Book

Understanding and minimising fungicide resistance (2023). Edited by: Lopez-Ruiz FJ. Published by: Burleigh Dodds

Research papers, mainly by the authors, on the theme of this video

Blake, J, Gosling, P, Fraaije, B, Burnett, F, Knight, S, Kildea, N, Paveley, N (2018). Changes in field dose–response curves for demethylation inhibitor (DMI) and quinone outside inhibitor (QoI) fungicides against *Zymoseptoria tritici*, related to laboratory sensitivity phenotyping and genotyping assays. Pest Management Science, DOI 10.1002/ps.4725

Young, C, Boor, T, Corkley, I, Fraaije, B, Clark, W, Havis, N, Kildea, S, Paveley, N (2021). Managing resistance evolving concurrently against two or more modes of action, to extend the effective life of new fungicides. AHDB final report PR637.

Cools, H, Mullins, J, Fraaije, B, Parker, J, Kelly, D, Lucas, J, and Kelly, S (2011) Impact of Recently Emerged Sterol 14 Demethylase (CYP51) Variants of *Mycosphaerella graminicola* on Azole Fungicide Sensitivity. Applied and Environmental Microbiology, doi:10.1128/AEM.00027-11

Van den Bosch, F, Paveley, N, Shaw, M, & Oliver, R (2011) The dose rate debate: does the risk of fungicide resistance increase or decrease with dose? Plant Pathology, 60: 597-606. DOI: 10.1111/j.1365-3059.2011.02439.x

van den Bosch, F, Oliver, R, van den Berg, F and Paveley, N (2014) Governing principles can guide the development of fungicide resistance management tactics. Annual Review of Phytopathology, 52:175–95.

Hobbelen, P., Paveley, N, van den Bosch, F. (2011) Delaying Evolution of Fungicide Insensitivity by Mixing Fungicides at a Low and High Risk of Resistance Development. Phytopathology, 101:1224-1233.

Grimmer, M, van den Bosch, F, Powers, S, and Paveley, N (2014) Evaluation of a matrix to calculate resistance risk. Pest Management Science, 70: 1008–1016.

Carolan K, Helps J, van den Berg F, Bain R, Paveley N, van den Bosch F. Extending the durability of cultivar resistance by limiting epidemic growth rates. Proceedings of the Royal Society B 284: 20170828.http://dx.doi.org/10.1098/rspb.2017.0828

Grimmer M, van den Bosch F, Powers S, Paveley N (2015) Fungicide resistance risk assessment based on traits associated with the rate of pathogen evolution. Pest Management Science 71: 207-215.

van den Bosch F, Lopez F, Oliver R, Paveley N, Helps J, van den Berg F. Cost benefit analysis of fungicide applications: to increase or decrease fungicide dose when resistance is developing. Plant Pathology 67: 549-560.

van den Berg F, Paveley N, van den Bosch F (2016) Dose and number of applications that maximize fungicide effective life exemplified by *Zymoseptoria tritici* on wheat. Plant Pathology 65, 1380–1389

Many excellent papers are available by other authors. The chapters of the fungicide resistance book listed above contain comprehensive bibliographies

If a research paper is not open-access you can request a copy by contacting authors through www.researchgate.net