Using evolutionary principles to optimise deployment of genetic resistance in crops

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Costs of resistance (break-down)

- In Australia alone, average losses to wheat industry of $913M/yr given current control methods (breeding, fungicide, cultural ; > $100M/yr)
- Disease resistance breeding contributes more than 50% of disease control for a range of pathogens
- Disease control is ephemeral – resistance based on genetic approaches generally shows little durability, leading to:
  - continued need for major investment
  - increased use of pesticides and cultural management
  - significant direct yield losses
- Increasing evidence of pathogens evolving increased infectivity and/or aggressiveness in relation to specific types of R genes

Applying eco-evolutionary principles to biotic interactions in agro-ecosystems

- Use of evolutionary principles is not new in agriculture (e.g. breeding of new R cultivars, use of crop mixtures, pyramiding of R genes...)

Epidemiological benefits:
– effective reduction in crop density
– loss of spores to resistant plants
→ Reduced pathogen population size

Evolutionary benefits:
– disruptive selection
– preventing "super-race" appearance
→ Reduced evolutionary potential

BUT….

- Only rarely considered in a broader spatial or systems context...
- Very few situations where it has happened proactively and collectively (e.g. managing pest resistance to Bt cotton)
- Some investigation of broader effects (e.g. community ecology of beneficial insects and pests in relation to landscape structure)
- Many more examples where it has not happened, or is only now happening reactively (e.g. herbicide tolerance in weeds, bio-control agents)

Resistance deployment options

Genetics

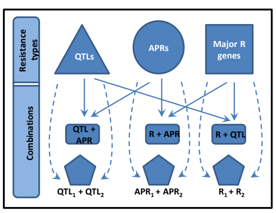
		Genetic control	Characteristics	Evolutionary implications
Genetics	Specific	Major R genes	Single gene – isolate specific – mostly full resistance	'Hard' selection on pathogen – evolution for increased infectivity
Genetics	Non-specific	APR genes	Single gene – isolate non-specific – partial resistance	'Soft' selection on pathogen – evolution for increased aggressiveness [?]
Genetics	Non-specific	Quantitative R	Multi-genic – isolate non-specific – partial resistance	'Soft' selection on pathogen – evolution for increased aggressiveness

Deployment

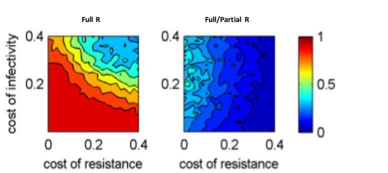
		Within field	On farm	Region
Deployment	Spatial	• Single genes • Pyramided R genes • Pyramided APR genes • Combined R & APR • QTL combinations • Mixed lines	• Row cropping • Alley cropping • Varietal diversity	• Regional gene separation
Deployment	Temporal	• Sequential replacement and reuse of resistance genes	• Crop rotation	

Epidemiological vs. evolutionary control of plant pathogens

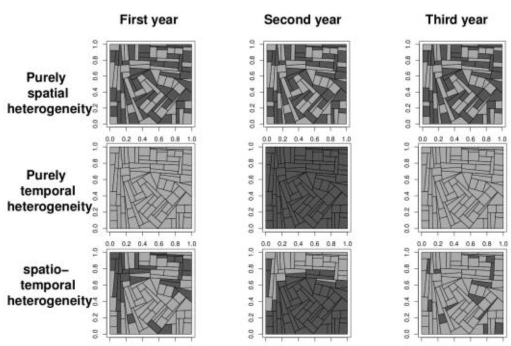
Resistance gene combination options



Prevalence of super infective pathotype

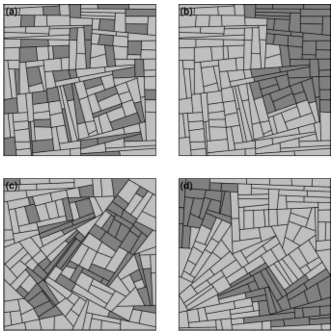


Environmental heterogeneity in agro-ecosystems



Papaix, Lannou & Monod 2012 unpublished

Simulation models of epidemiological and evolutionary management of R gene deployment

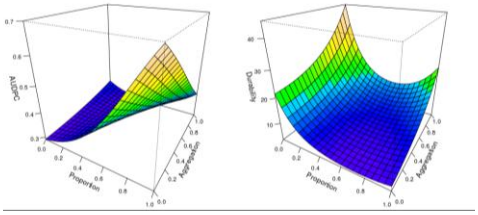


- 2 varieties: an established (susceptible) variety and a new (resistant) variety
- 4 levels of spatial aggregation
- 5 proportions (10%, 30%, 50%, 70%, 90%)

Epidemiological vs. Evolutionary Disease Control

Proportion of crop remaining healthy during epidemics

Durability of a new resistant crop variety



- ➢ **Short and long-term management objectives potentially in conflict**
- ➢ **Spatial deployment of R genes matters**

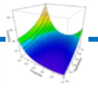
New science opportunity

Problem: ***How to prevent rapid loss of effectiveness in disease resistance genes***

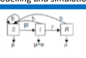
Solution: ***Evolutionary management of diseases for durable resistance***

- Applying eco-evolutionary principles to managing diseases in agricultural systems
  e.g. Deployment of seedling R and APR genes separately / combined
  Spatial deployment strategies
- Integrating modeling, experimentation & molecular approaches

How can ecological and evolutionary principles be applied to better manage disease?



Modelling and simulation



A conceptual framework for predicting disease emergence and better engineering long-term, sustainable solutions to rapidly evolving plant pathogens

R-gene deployment strategies that minimize potential for pathogen evolution and the breakdown of resistance

Using theoretical studies

Develop spatially explicit models simulating pathogen evolutionary change under different R-gene deployment scenarios

with specific application to

- wheat – stripe rust
- canola – blackleg

Phenotyping experiments to

Identify key components of pathogen aggressiveness

Serial passaging to

Identify potential for rapid evolution of aggressiveness

leading to

Field testing and validation of experimental and model predictions

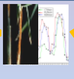
Managing epidemiological & evolutionary trajectories of pathogens in agriculture

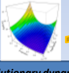
Components of integrated approach

- Modeling & simulation
- Epidemiology
- Pathogen & host physiology
- Agronomy & breeding

Fundamental research needs

Epidemiological interactions
Understanding fitness effects on pathogens in complex resistance environments





Evolutionary dynamics
Understanding how to exploit evolutionary processes (disruptive selection) to achieve resistance durability

Research outcomes

- Interaction between selection against unnecessary virulence & for increased aggressiveness understood
- Impact of resistance [R, APR, QTLs] management on epidemic development understood
- Predictive models developed to assess effect of genetic & spatial deployment strategies on resistance durability

Applied endpoints

Environmental & production benefits

a) Reduced inputs [e.g.: reduced breeding effort; reduced pesticides]

b) Increased longevity of R genes

c) Improved strategies for epidemiological & evolutionary management of disease resistance [durability]