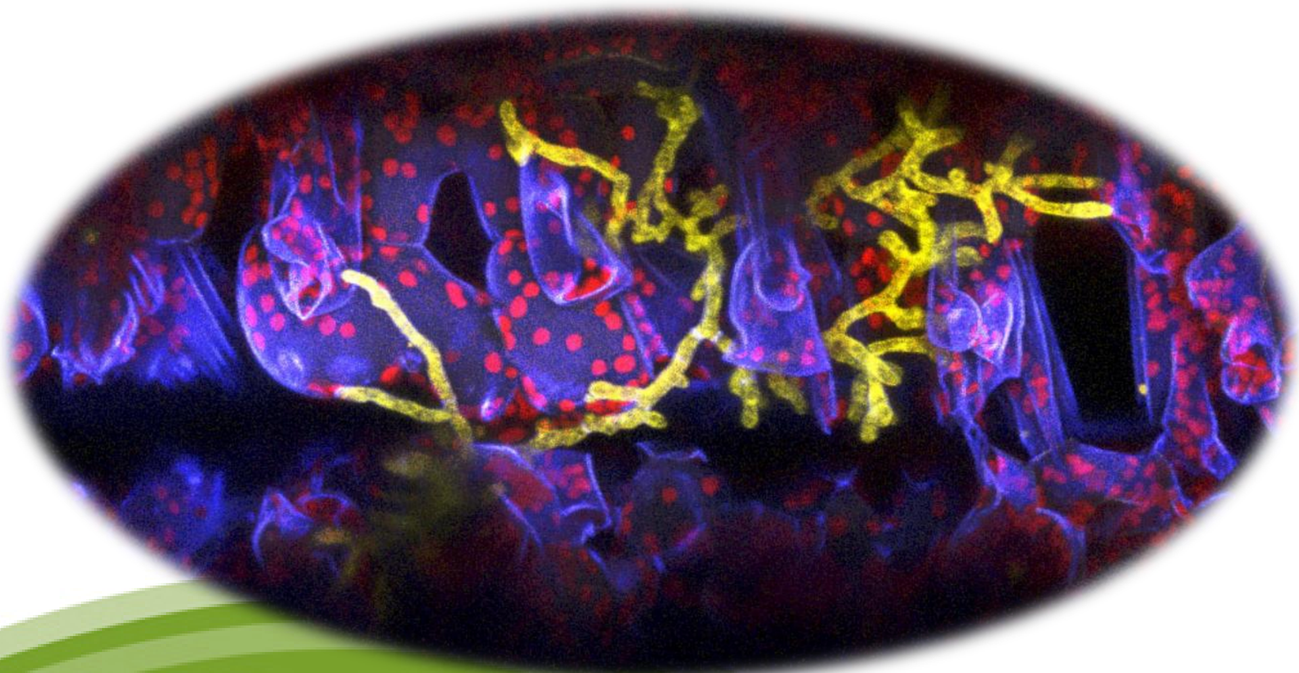
Climate change, plant disease and food security: an overview

Adrian C Newton



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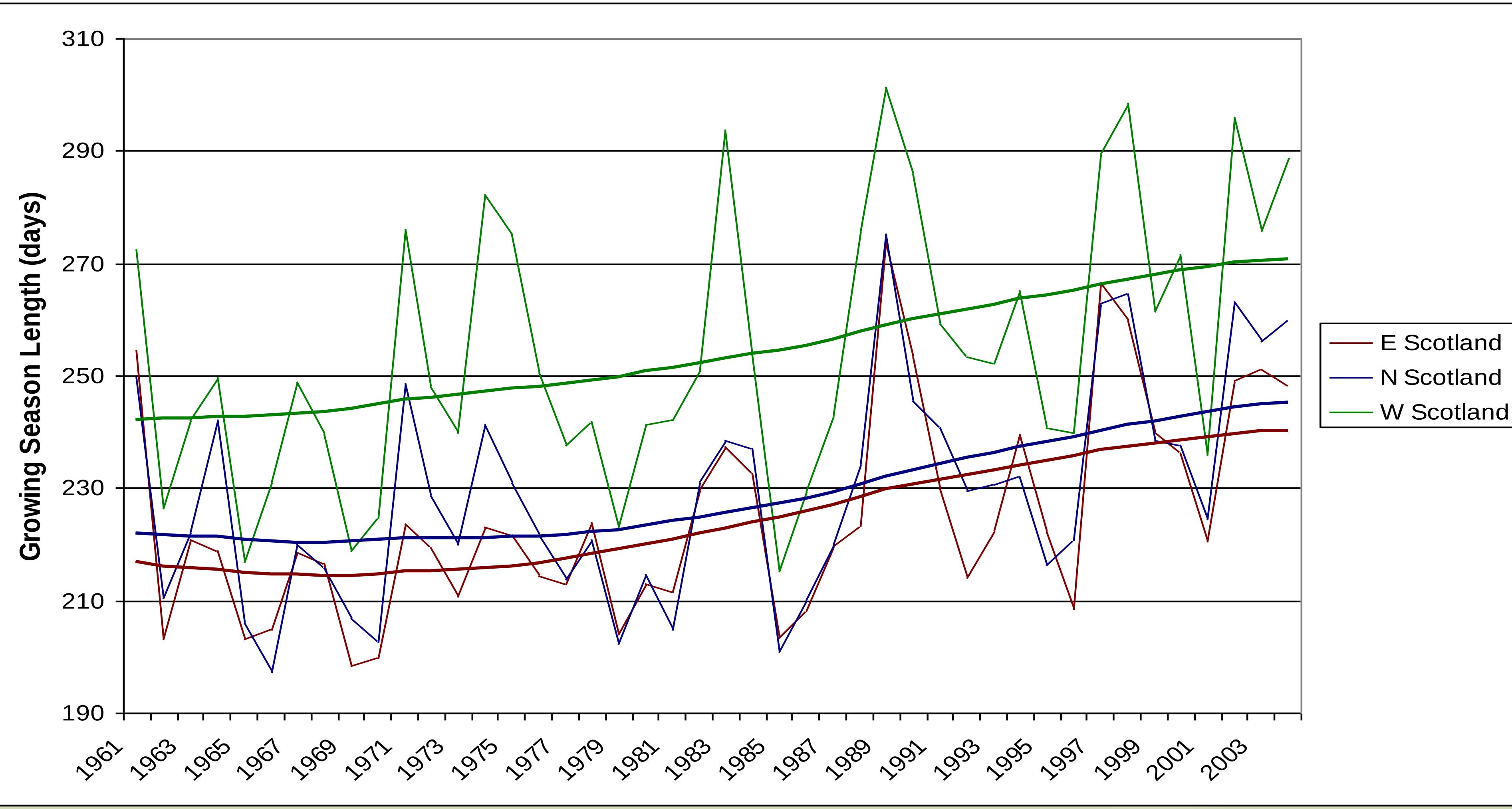
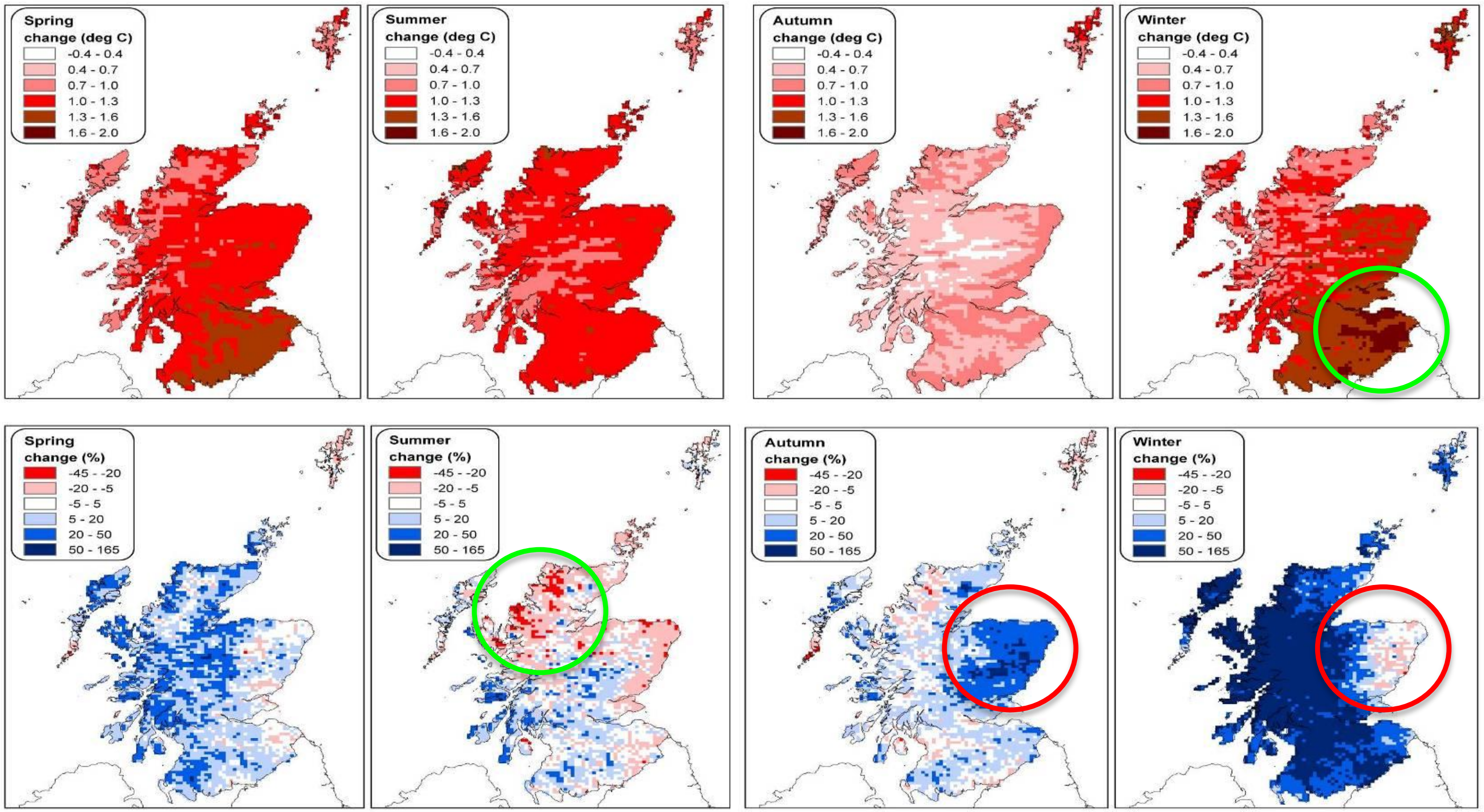
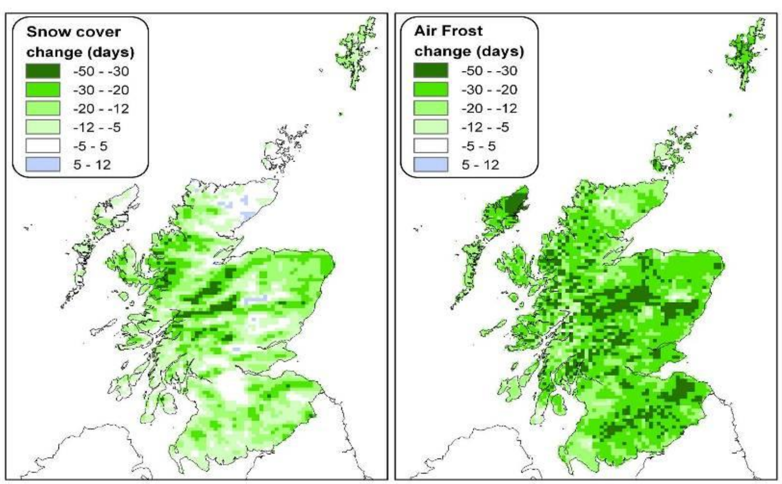
Ian Toth, Nicola Holden, Lesley Torrance

Change in length of growing season in Scotland: 1961-2004 (Barnett *et al.*, 2006)







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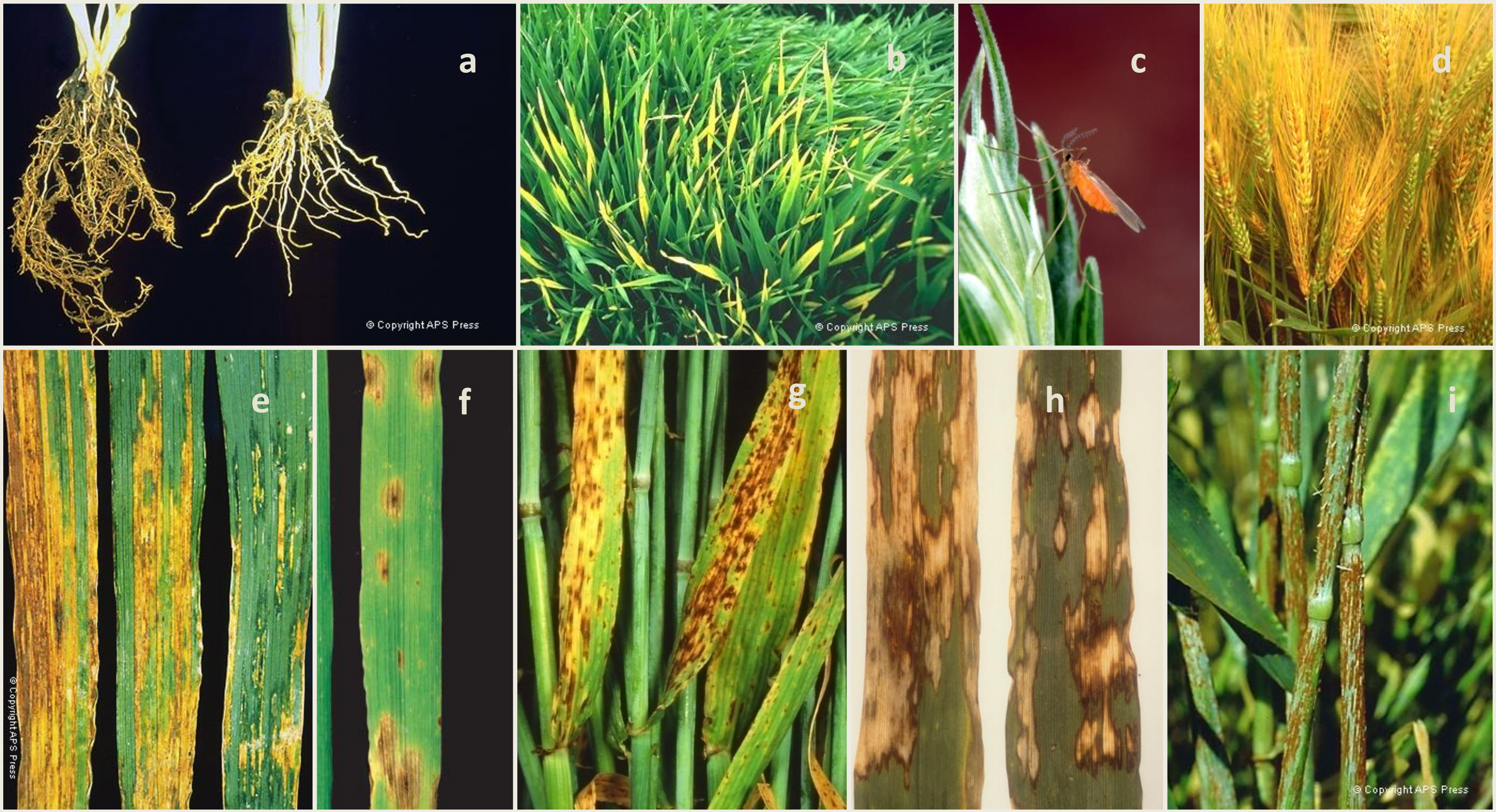
Changes in: temperature rainfall, frost and snow cover in Scotland 1961-2004

(Barnett et al., 2006)

Global importance of crop loss due to disease, pests and weeds

Potato – actual losses 24% N Europe to 50% in Central Africa (Oerke, 2006)



Representative current and emerging pest and disease problems that could threaten barley food security.
a) cereal cyst nematode, b) Barley Yellow Dwarf Virus,
c) orange blossom midge, d) Fusarium head blight
e) cereal bacterial leaf streak, f) rice blast (on barley), g) Ramularia Leaf Spot
h) rhynchosporium or scald, i) stem rust (on barley)

Journal: Food Security 3, 141-178.

Crops that feed the world 4.

Barley

Barley: a resilient crop? Strengths and weaknesses in the context of food security.

Adrian C Newton, Andrew J Flavell, Timothy S George, Philip Leat, Barry Mullholland, Luke Ramsay, Cesar Revoredo-Giha, Joanne Russell, Brian Steffenson, J Stuart Swanston, William T B Thomas, Robbie Waugh, Philip J White, Ian J Bingham

Image a courtesy R Cook, b courtesy B Cunfer, d and i courtesy B Steffenson, e courtesy M Peterson, all reproduced by permission from Compendium of Barley Diseases, 2nd Ed., 1997, American Phytopathological Society, St. Paul, MN, USA; image c courtesy and copyright of Rothamsted Research Ltd, Harpenden, UK. Image f courtesy of B. Steffenson; image g courtesy of Dr Neil Havis at SAC, Edinburgh, UK; image h by permission, from Paulitz, T. C., and Steffenson, B. J. 2011. Biotic Stress in Barley: Disease Problems and Solutions. Pages 307-354 in: Barley: Production, Improvement, and Uses. S.E. Ullrich, Ed. John Wiley & Sons, Inc., Ames, IA.

Soft fruit pest and pathogens

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Potato pest, patho… …ses

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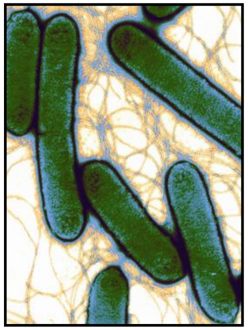
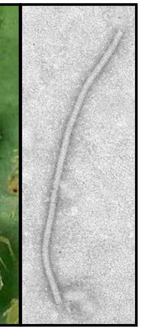
Pests and pa…





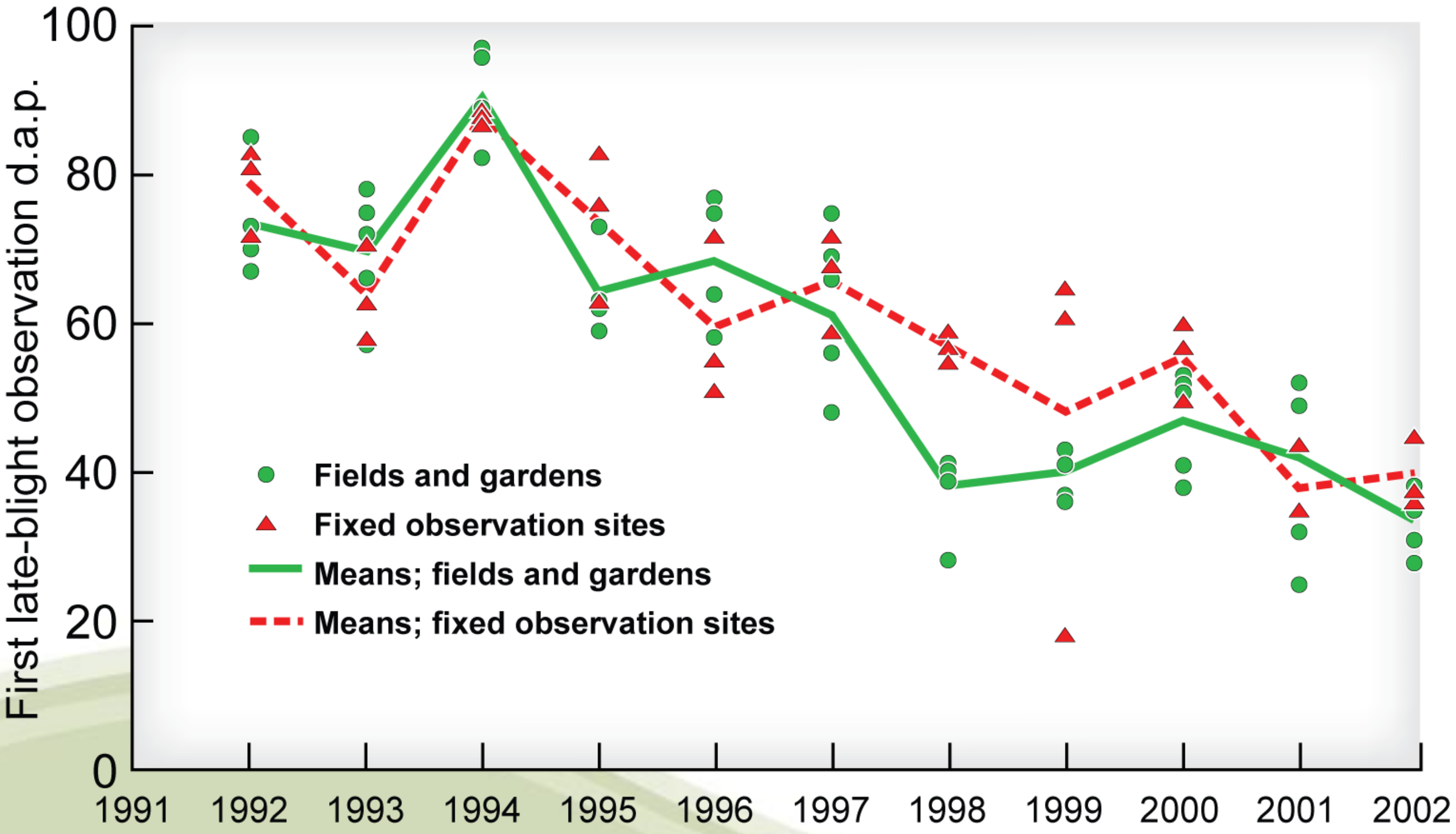
Impact of Climate Change on Pests and Diseases of Potatoes in Scotland: Risks and Recommendations (2008)

RERAD Work Package 1.5 (Potato Pathology)

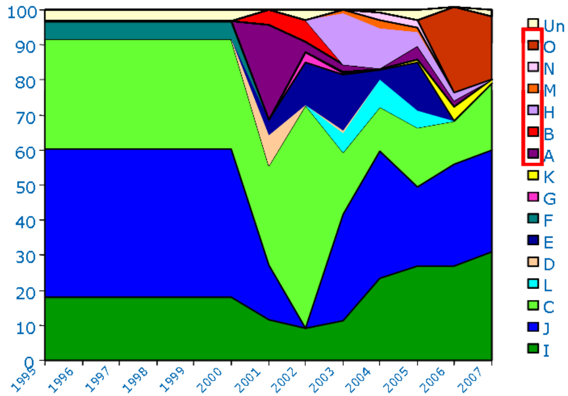
Understand … respond to key climate chang… …arameters

Potato

Earlier outbreaks of late blight in Finland
(Hannukkala et al., 2007)



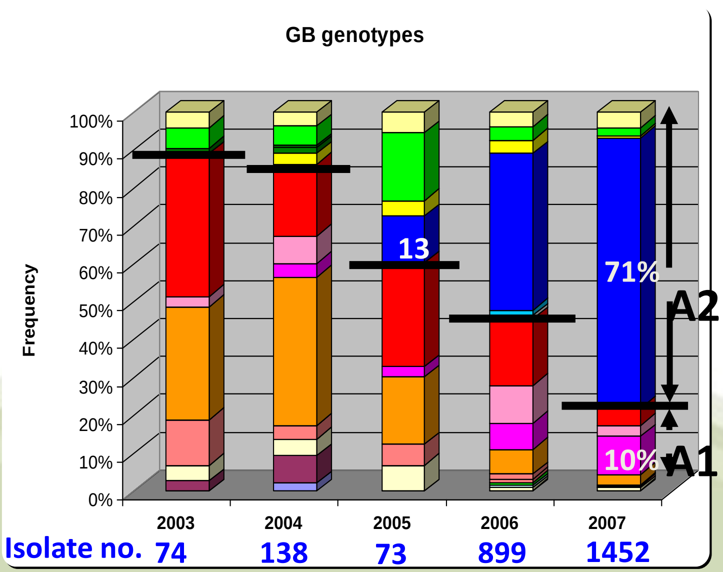
Pathogen population change



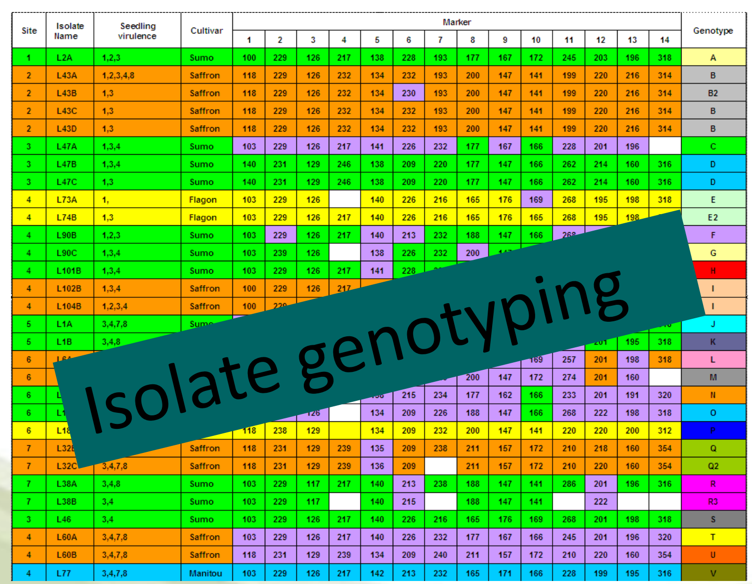
Peach-potato aphid

Driven by:

- Variety resistance
- Local population
- Fungicide treatments
- **Climate change**
- Trade – new pests & pathogens



Potato late blight

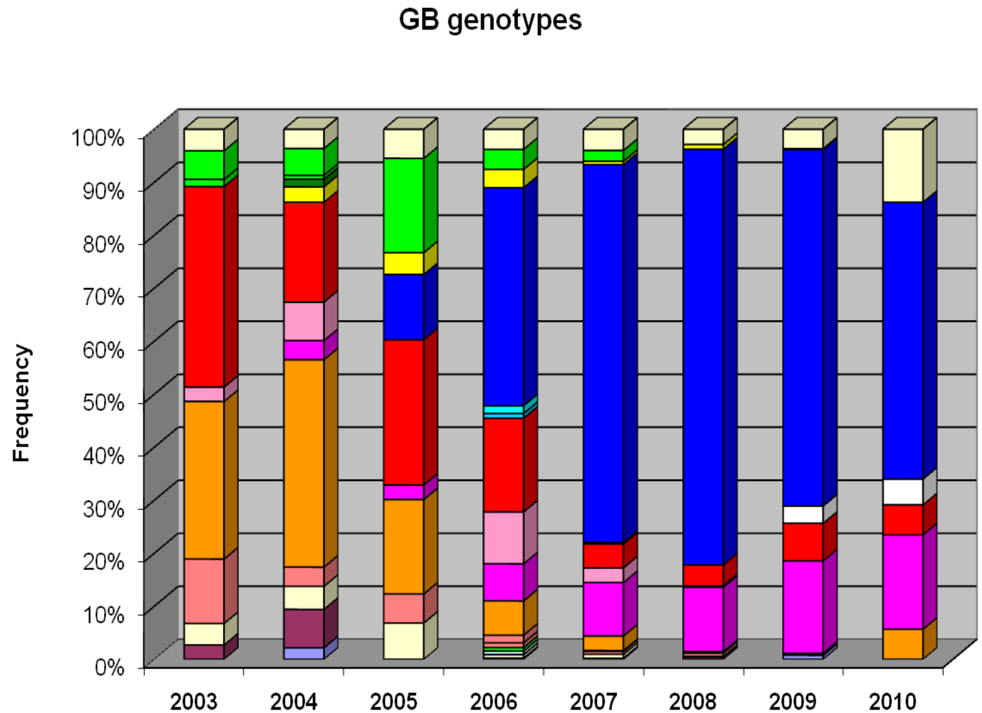


Rhynchosporium on barley

A changing population

SSR markers used to genotype 24,000 isolates across Europe

A new dominant A2 strain 13_A2 (blue)



Isolate no. 74 138 73 899 1452 1118 522 247

More aggressive, faster generation time, phenylamide R

David Cooke & Alison Lees, JHI

Major consequences of the population change on host resistance

Pathogenicity and resistance genes affected by stress

- Pathogens have stress-responsive mechanisms for generating variation

(mutation hot-spots, recombination control, retrotransposon activity control, mutant instability mechanisms, mRNA alternate splicing control mechanisms...)

- Temperature sensitive expression of rust resistance (stem rust, leaf rust)

- Drought stress and drought stress-relief

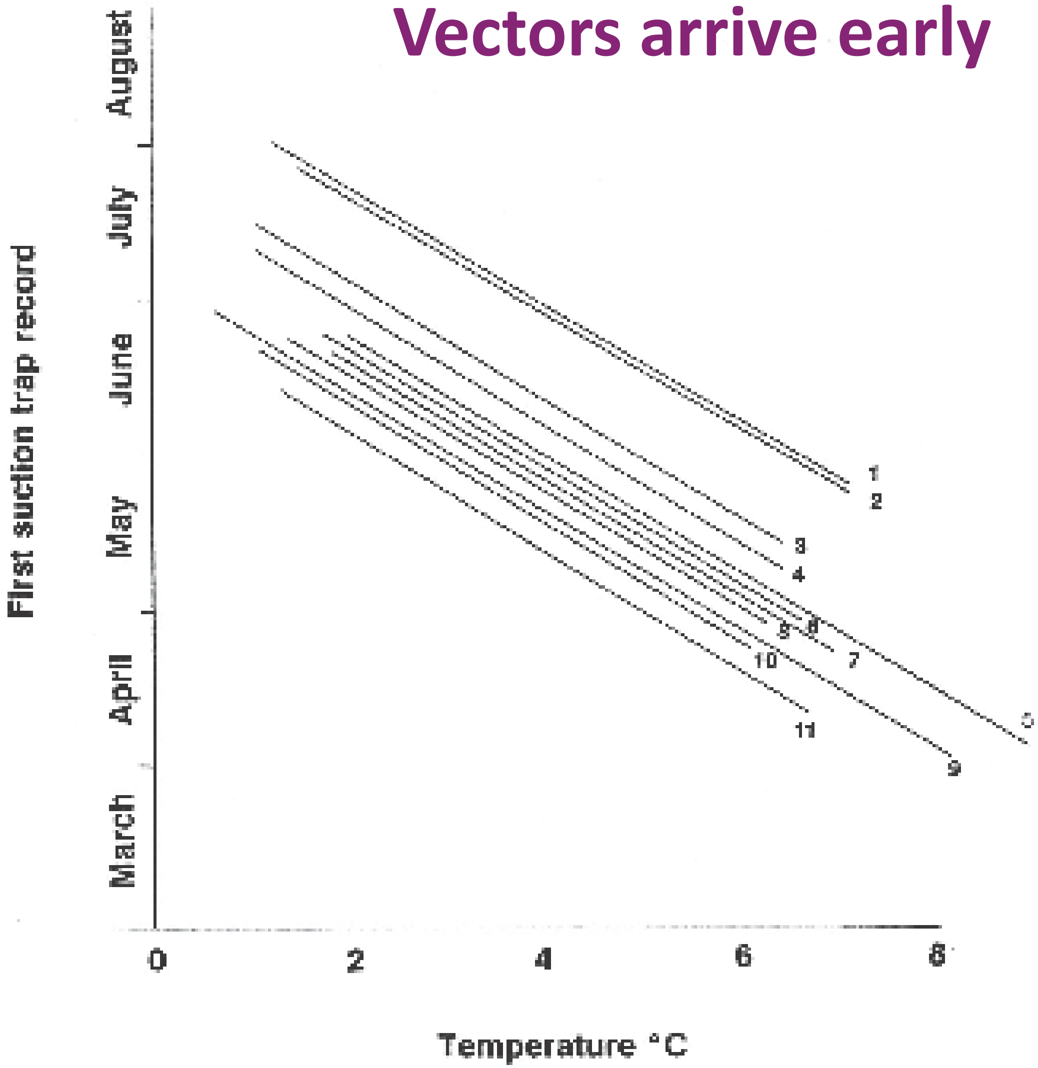
	Atem ***mlo11***	**Apex** ***mlo9***
Non-stressed	0	0
Stress-relieved: water	23%	10%
Stress-relieved: nutrients	62%	19%

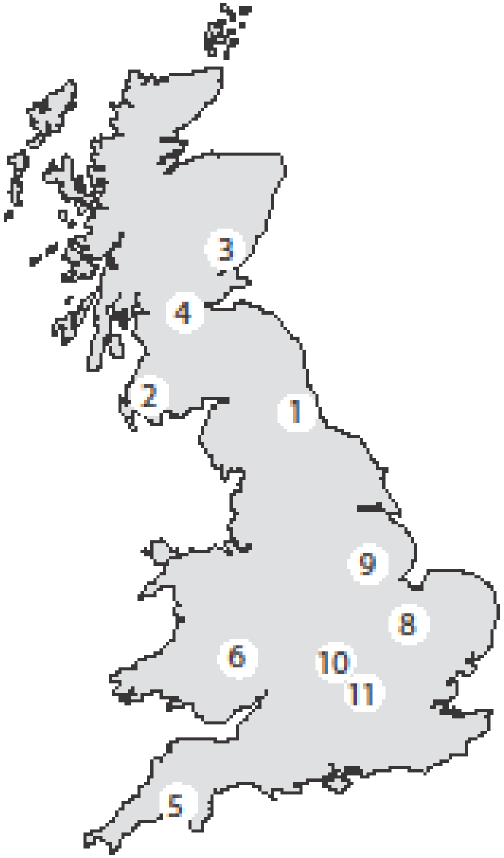
Host resistance is compromised by temperature

- Abiotic stresses (heat, drought) can increase or decrease susceptibility.

- Virus resistance complex - mediated by different mechanisms:
  - lower temperatures (<20°C) RNA silencing less effective
  - whereas high temp (>28°C) inhibit action resistance (R) genes

Vectors arrive early





Date of the first record of *Mysus persicae* (regression lines shown) in relation to mean temperature in January and February at different latitudes across the U.K.

(1) 55.2 Newcastle, (2) 55.5 Ayr, (3) 56.5 Dundee, (4) 55.9 Edinburgh, (5) 50.6 Starcross, (6) 52.1 Hereford, (7) 51.2 Wye (8) 52.3 Broom's Barn, (9) 52.9 Kirkton, (10) 51.8 Rothamsted, and (11) 51.7 Writtle. Reproduced from Harrington *et al*. (1995)

Resistance breakdown in red raspberry

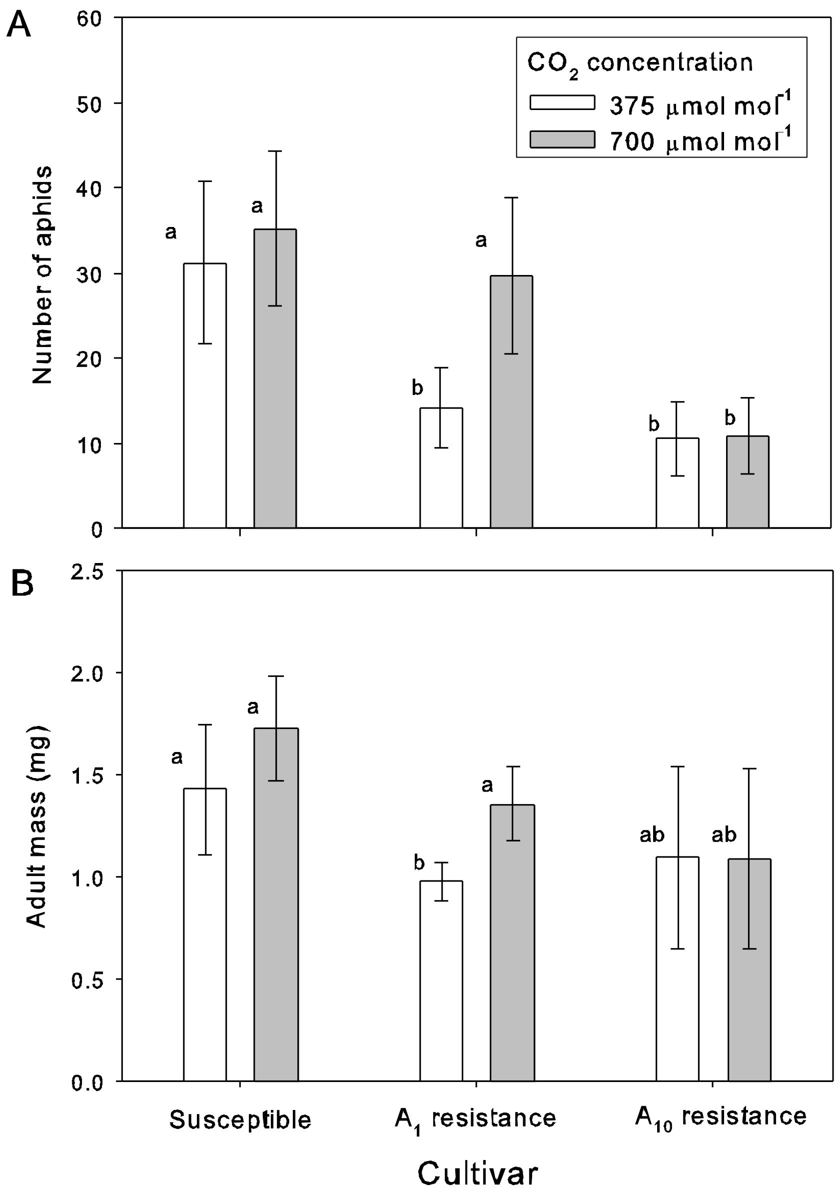
- European large raspberry aphid (*Amphorophora idaei*): most significant insect pest of raspberry
- Vectors of at least four plant viruses that reduce plant vigour and can cause death

Raspberry Leaf Spot Virus

Two resistance genes partially overcome:

- A_1 resistance – weakened in the UK
- A_{10} resistance – weakened in England

Resistance breakdown CO_2 effect



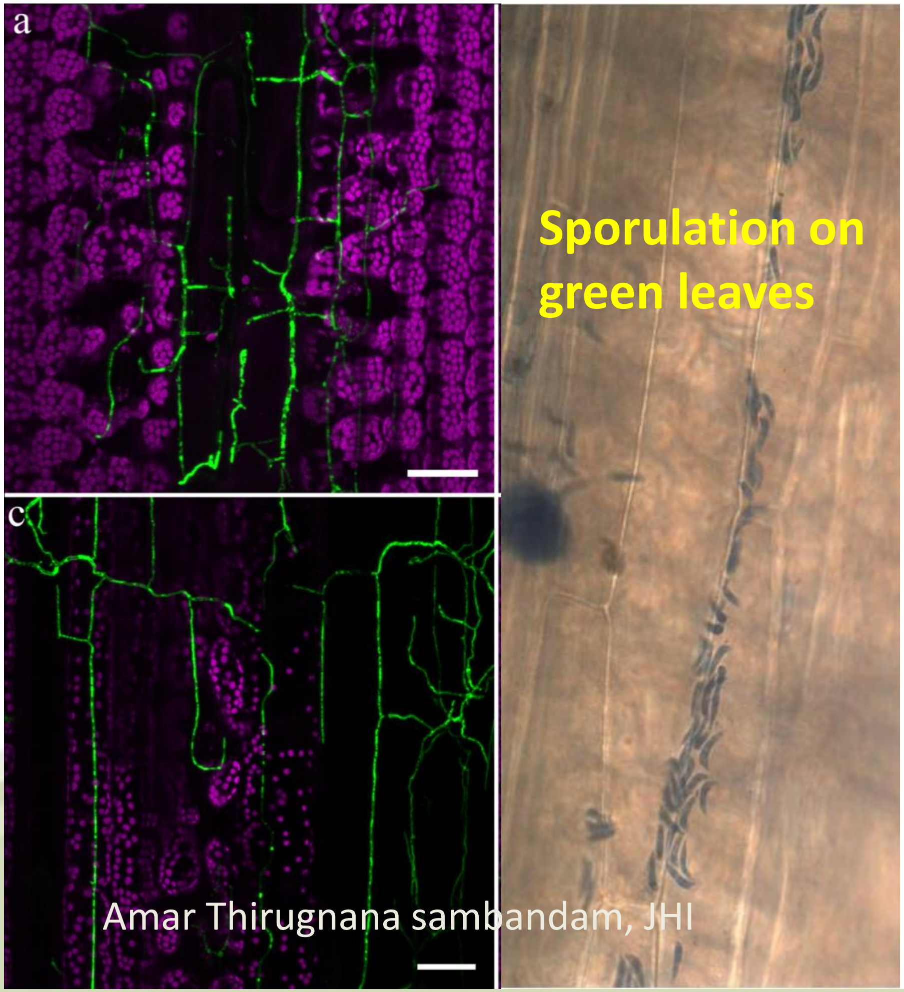
European large raspberry aphid (*Amporophora idaei*) on:

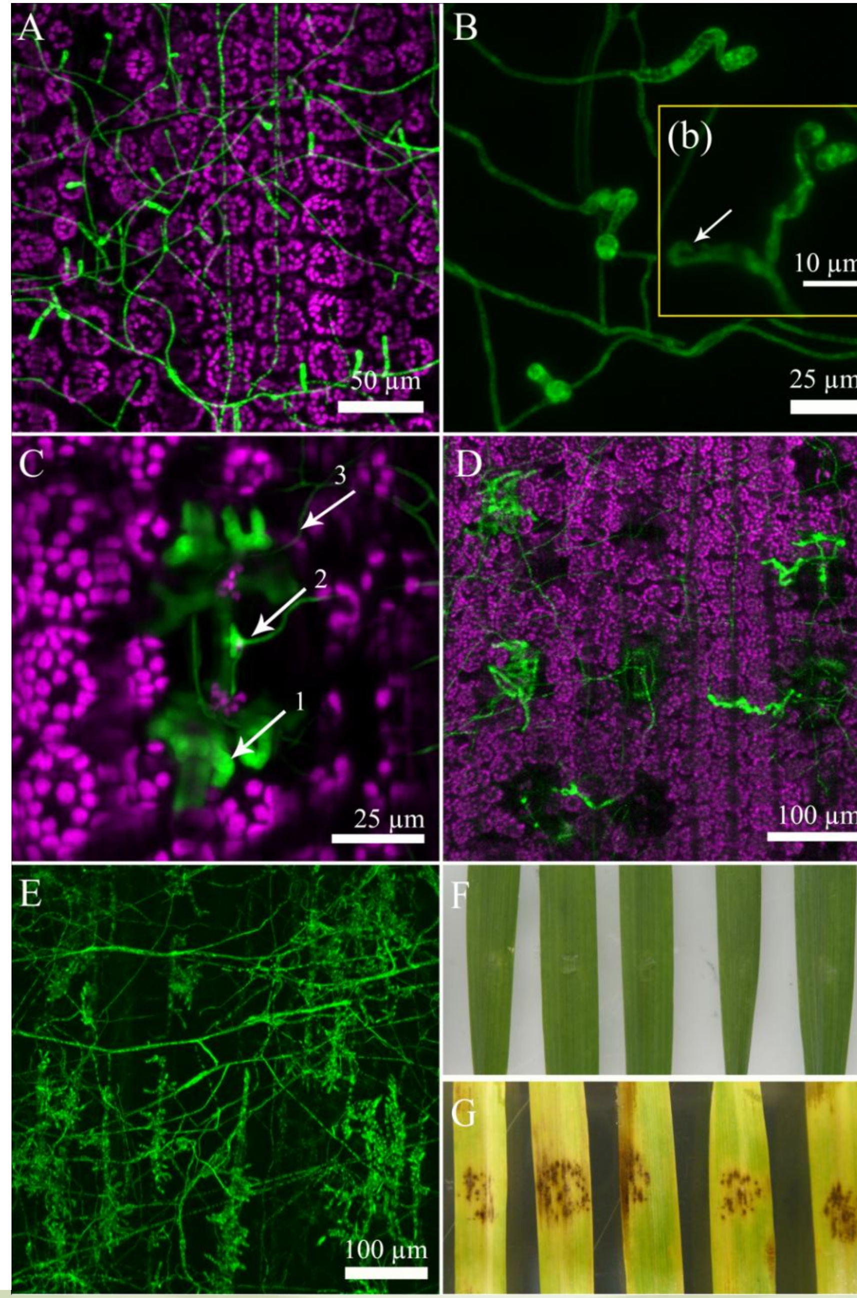
- Susceptible (Malling Jewel)
- A1 gene(Glen Lyon)
- A10 gene (Glen Rosa)

at ambient and elevated CO_2

Mean values ± SE shown (N = 6). Lowercase superscripts indicate statistically significant (P\0.05) differences. (Martin & Johnson, 2010)

Changes in plant-microbe relationships:





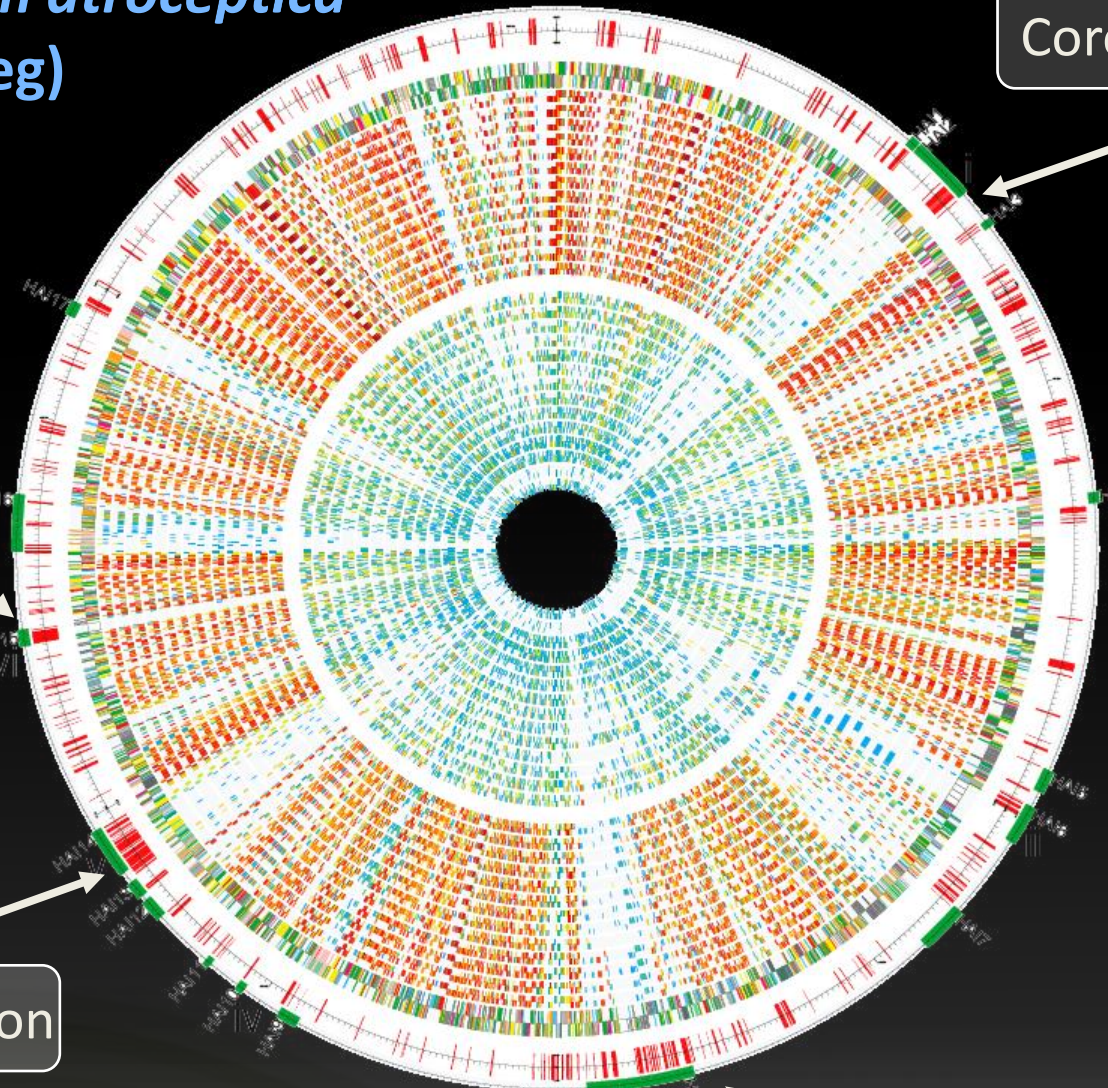
GFP-transformed *Rhynchosporium secalis* and *Ramularia collo-cygni*

Dickeya dianthicola (*Erwinia chrysanthemi*)

Dickeya species spread from Mainland Europe to UK in 1990s

- New species, *Dickeya solani*, spreading rapidly throughout parts of Europe
- Found in ware crops originating from imported NL seed in England 2007 and Scotland 2009
- Causes disease in current climate; more aggressive at warmer temps
- No chemical control – crop management
- Legislation is acting to prevent spread e.g. to Scottish potato seed industry

Pectobacterium atroceptica (potato blackleg)



Coronafacic acid

Brassica Root attachment

Beneficial on brassicas?

Nitrogen fixation

Opportunistic pathogen on potato?

Type III Secretion System

Toth *et al.* (2006) *Ann. Rev. Phytopath.* **44** 305-336

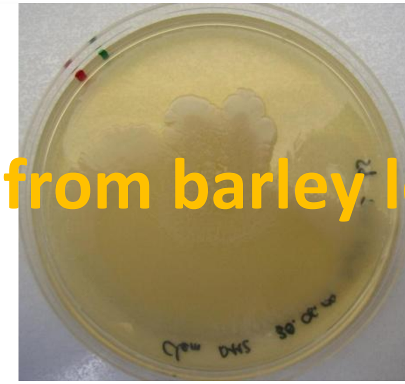
Pectobacterium colonises wild plant species

All plants tested are colonised, although to different extents

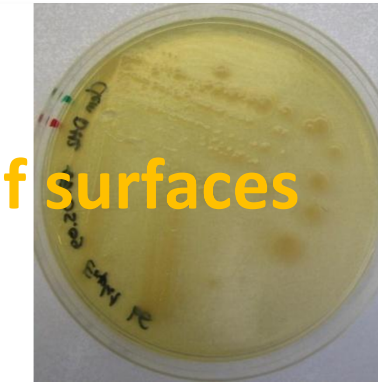
Culturable bacteria from barley leaf surfaces

B3: Pseudomonas poae

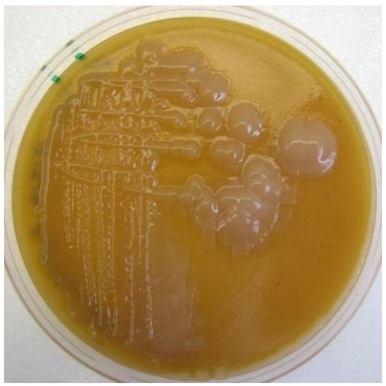
B4: Duganella zoogloeoides or Zoogloea ramigera



B5: Pseudomonas poae



B6: Pseudomonas veronii

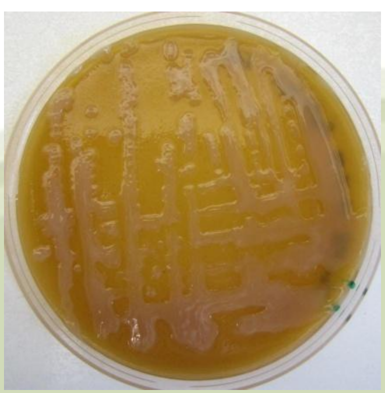


B7: Pseudomonas poae

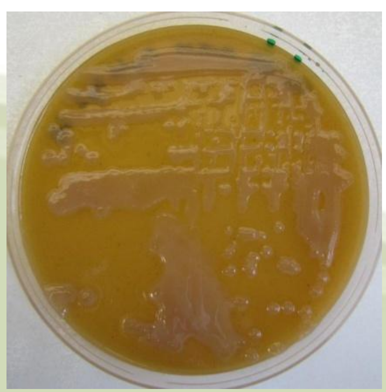
B8: Pantoea agglomerans

B11: Duganella zoogloeoides or Zoogloea ramigera

B12: Pseudomonas veronii



B13: Pantoea agglomerans



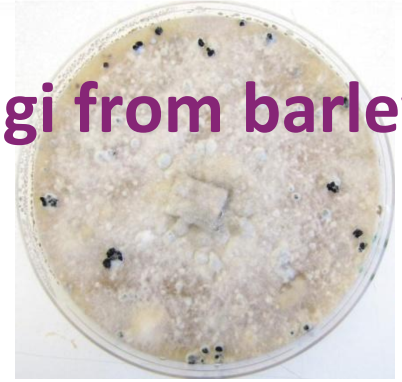
B14: Pseudomonas syringae

B16: Pseudomonas syringae

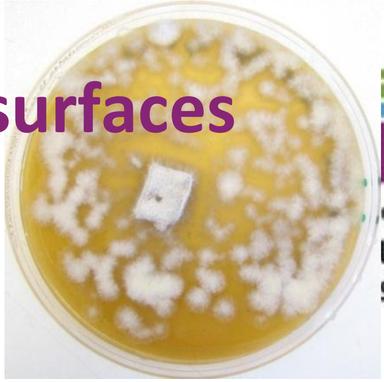
B17: Pseudomonas syringae

Culturable fungi from barley leaf surfaces

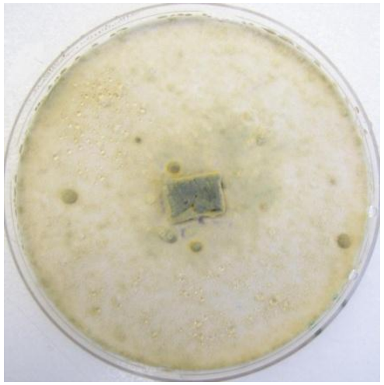
F1 Apiospora montagnei / Arthrinium marii / Arthrinium mediterranei / Arthrinium hispanicum



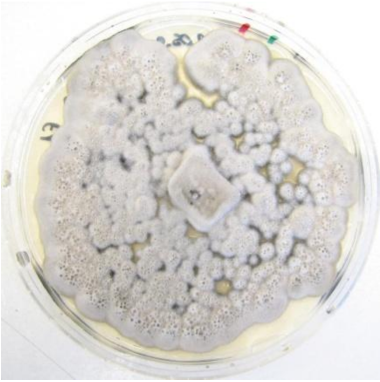
F2 Botryotinia fuckeliana



F3 Humicola fuscoatra var. fuscoatra



F4 Penicillium piceum

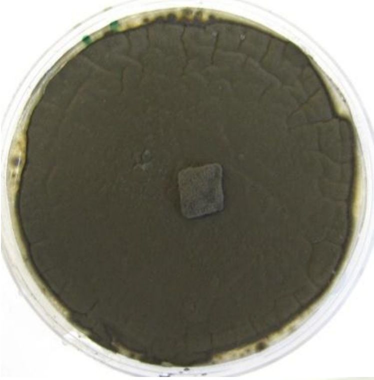


F5 Davidiella tassiana

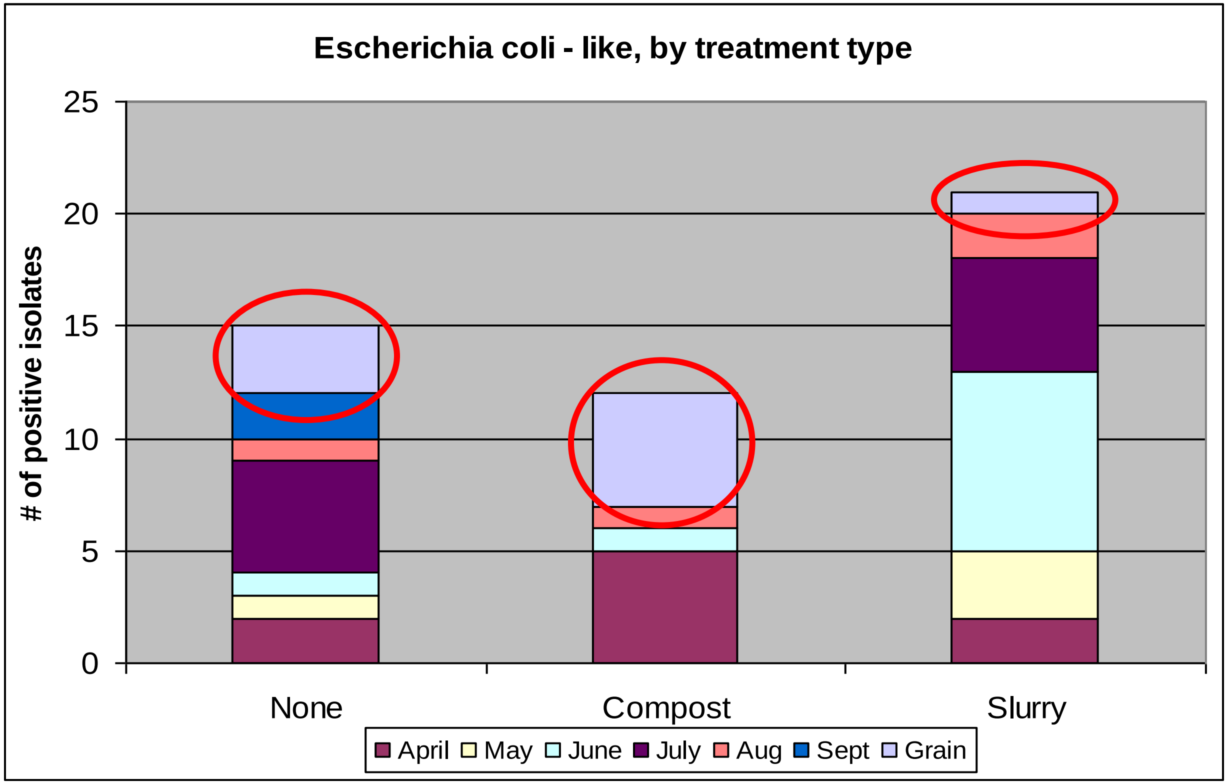
F6 Davidiella tassiana

F7 Davidiella tassiana / D. macrospora / Cladosporium sp. / C. cladosporioides / Zasmidium cellare

F9 Phoma sp. / Phyllosticta phaseolina / Phaeosphaeriaceae sp. / Ascochyta sp. / Didymella bryoniae / dothideomycete sp.



F10 Davidiella tassiana / D. macrospora / Cladosporium sp. / C. cladosporioides / Zasmidium cellare



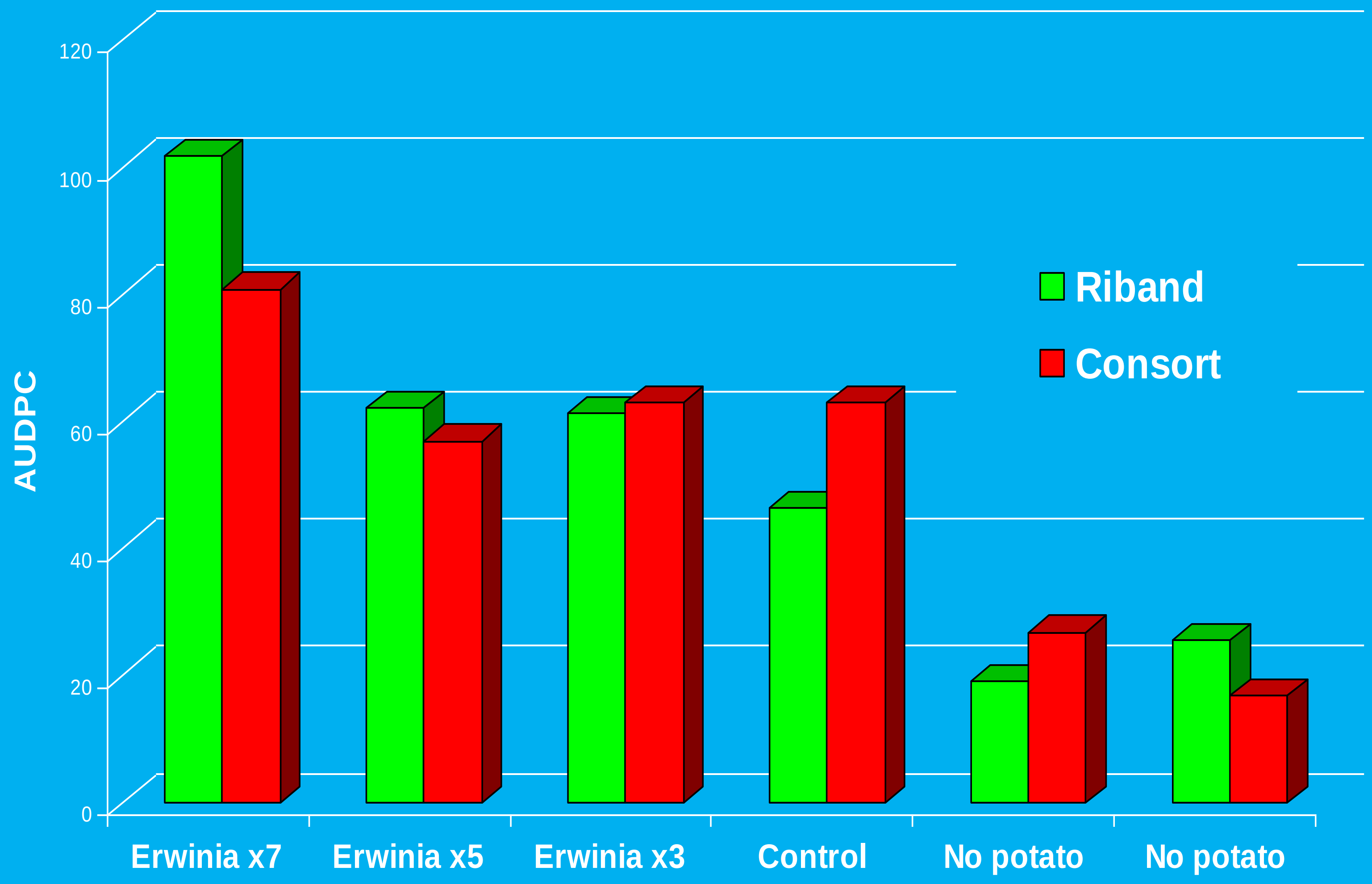
Presence of *E. coli*-like bacteria on barley (cv. Troon)

- Zoonotic bacteria can be transmitted into GROWING plants from animal sources.

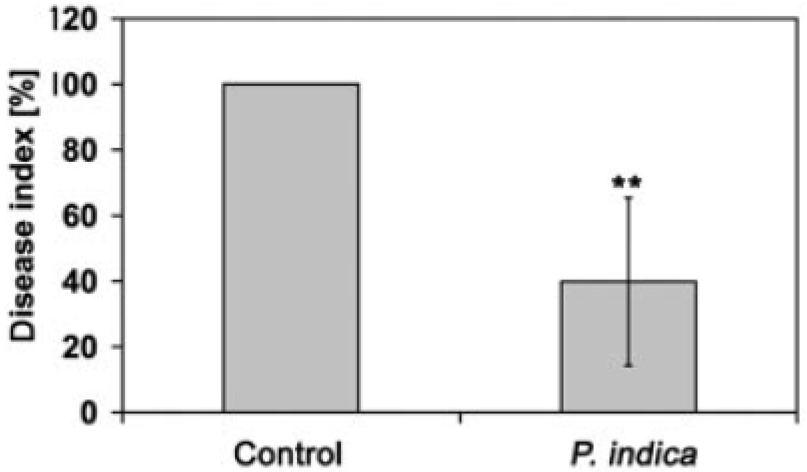
Jay, M. T., Cooley, M. B., Carychao, D. & other authors (2007). *Escherichia coli* O157:H7 in feral swine near spinach fields and cattle, central California coast. *Emerg Infect Dis* **13**, 1908-1911.

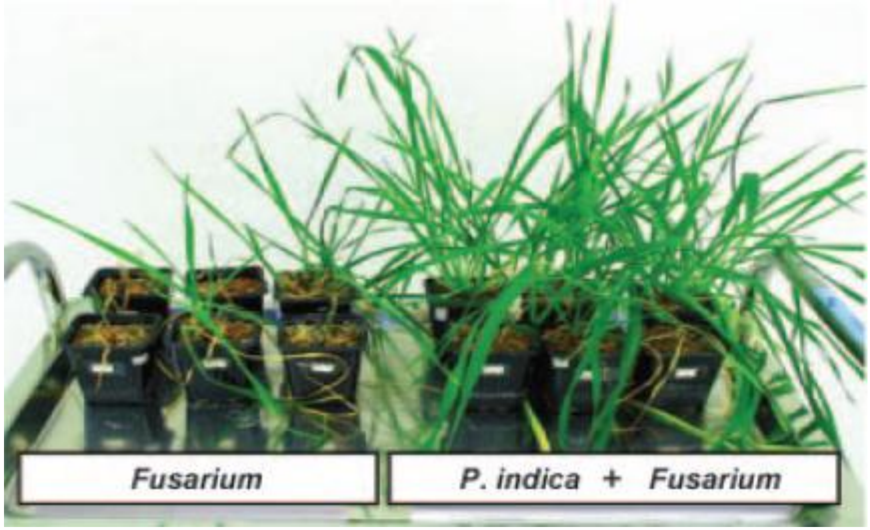
Nicola Holden, JHI

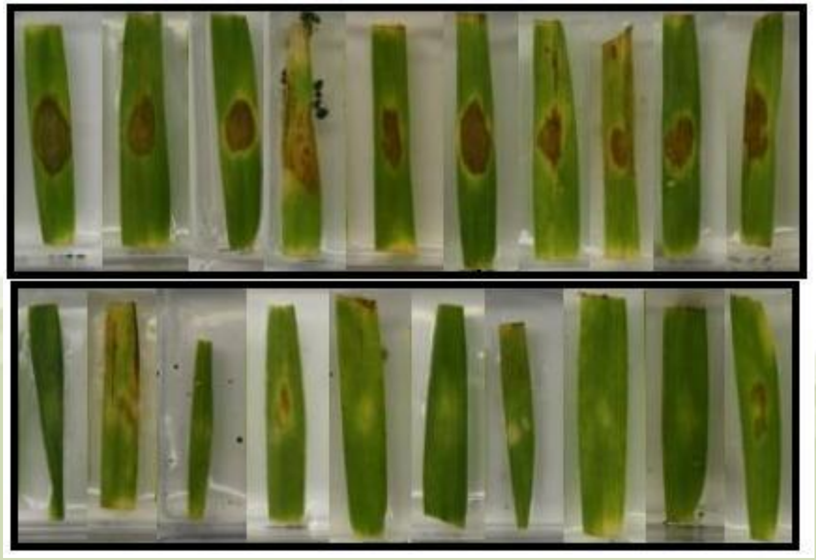
Effect of Blackleg on wheat mildew



Piriformospora indica (Basidiomycetes)







Control

Pi-infected

- Increased biomass
- Salt tolerance
- Mildew resistance

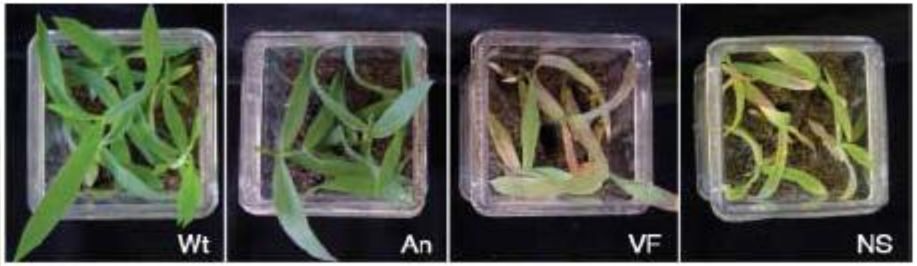
Mutualist/symbiont viruses and complex symbioses

Viruses, normally obligate intercellular parasites, can be beneficial to hosts

BMV infected rice 14d after being re-watered
water withheld for 9d: drought tolerance

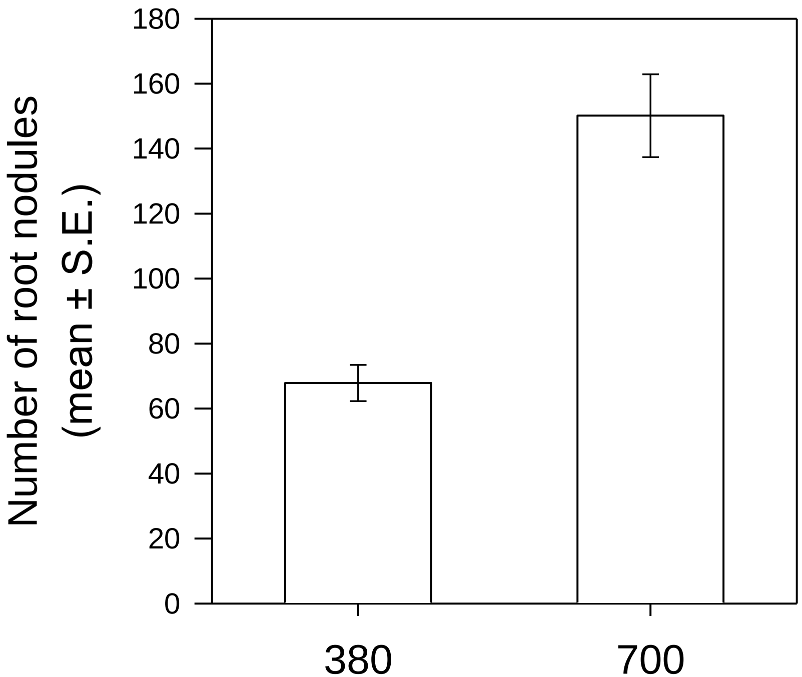
A Virus in a Fungus in a Plant: Three-Way Symbiosis Required for Thermal Tolerance. Márquez et al. 2007. Science 315, 513

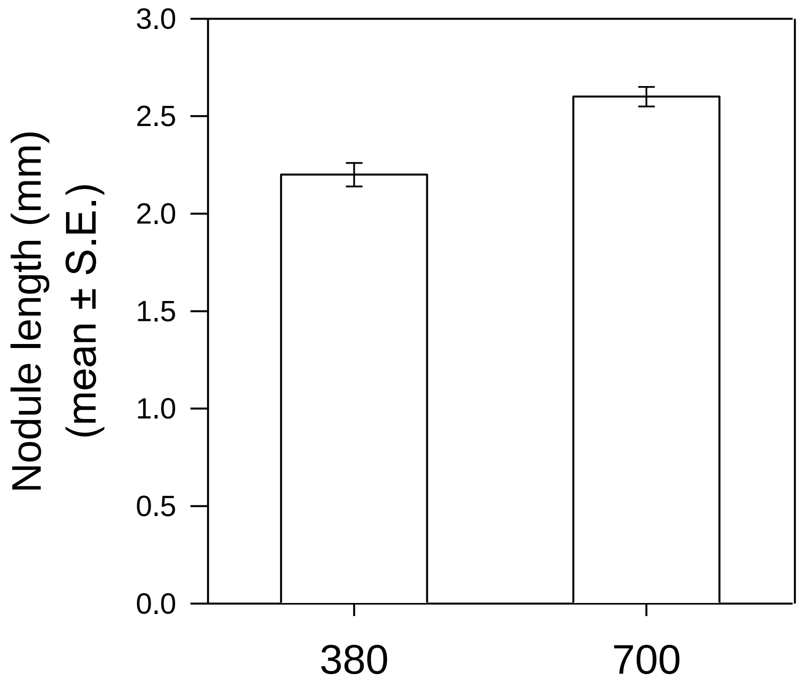
Panic grass from geothermal soils (YNP), *Dichanthelium lanuginosum*, the fungus *Curvularia protuberata* +/- virus. Root zones heated 65°C/10h and 37°C/14 h/day for 14days



Complex interactions... Clover growth

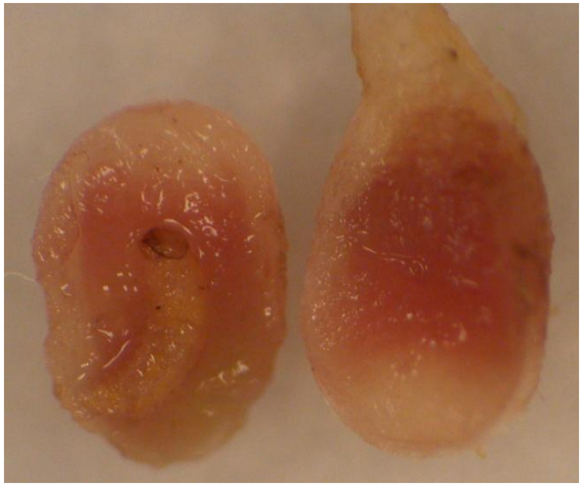
- In general elevated CO_2 widely assumed to increase N fixation in legumes (Soussana & Hartwig, 1996; Zanetti *et al.*, 1996; Hungate *et al.*, 1999)
- One mechanism is that root nodules can become more numerous and bigger = more N fixed

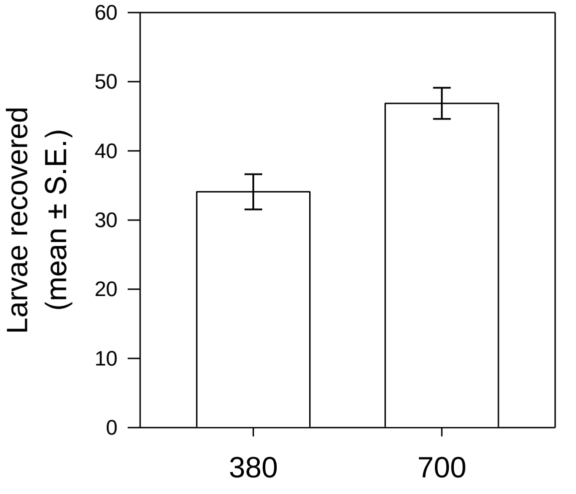


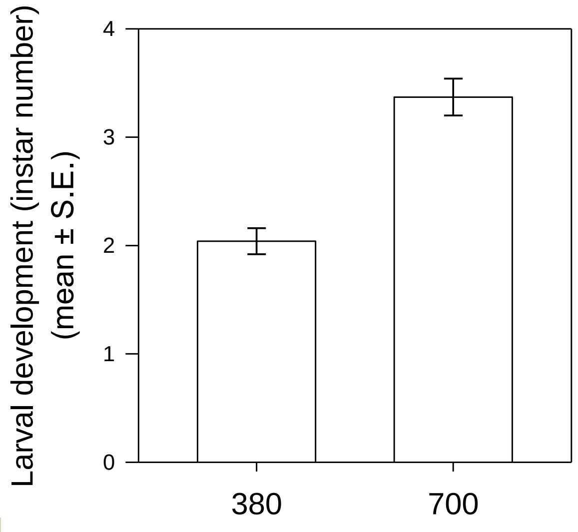


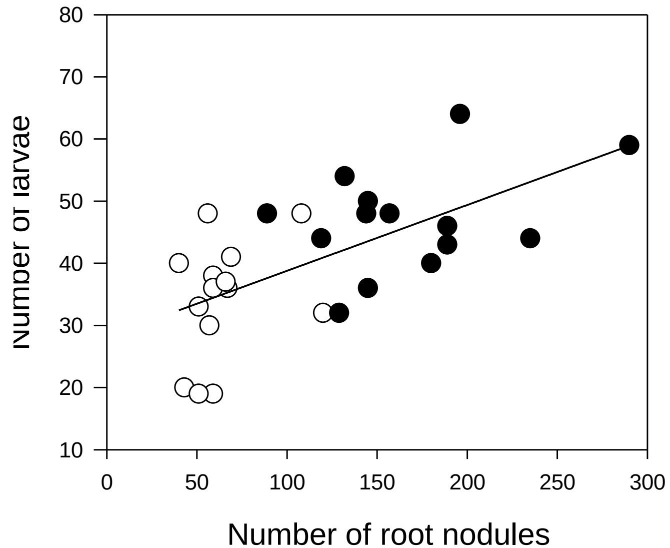
….however more root nodules can cause a surge in root pests

- *Sitona* spp. weevils – new born stages specifically target root nodules
- Elevated CO_2 results in more weevils which develop faster





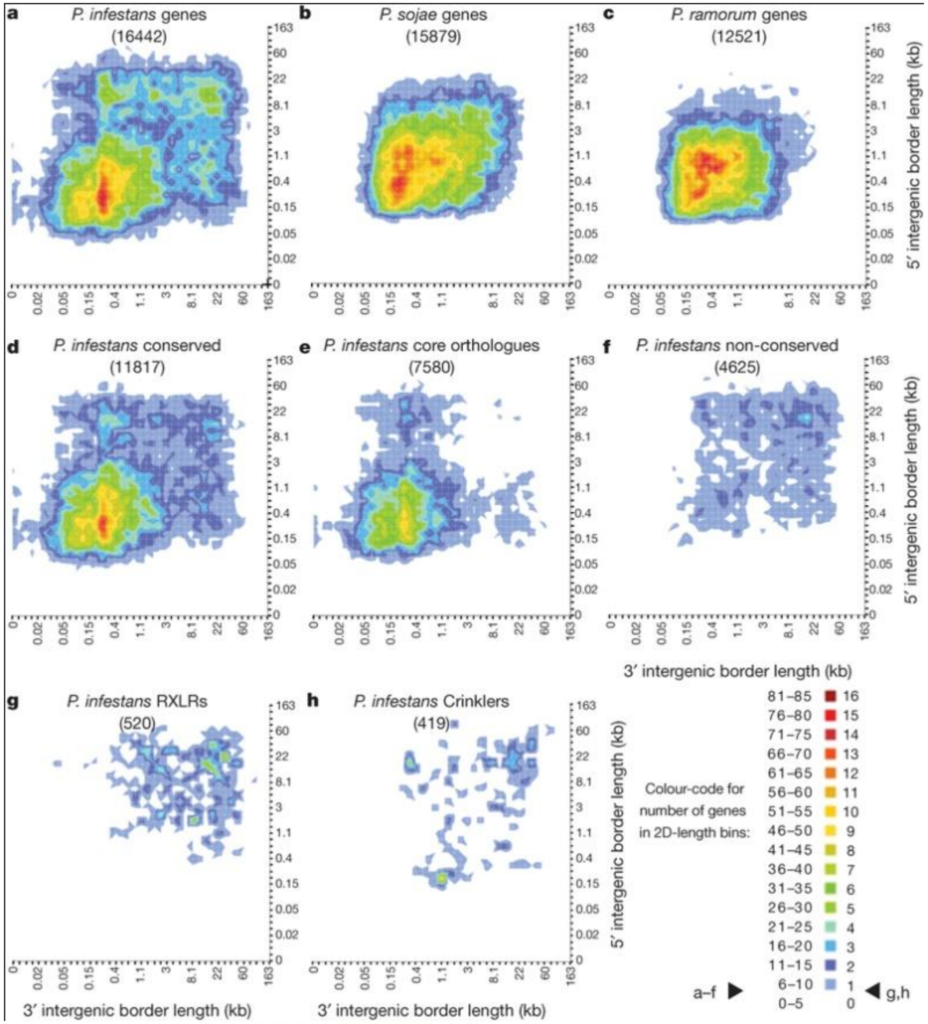




Host resistance for effective disease control

E.g. Potato: Commonwealth Potato Collection and Phureja ‘core collection’
- rich source of disease resistance

(new knowledge from potato genome sequence will aid identification and location R genes)



Virulence and effector diversity

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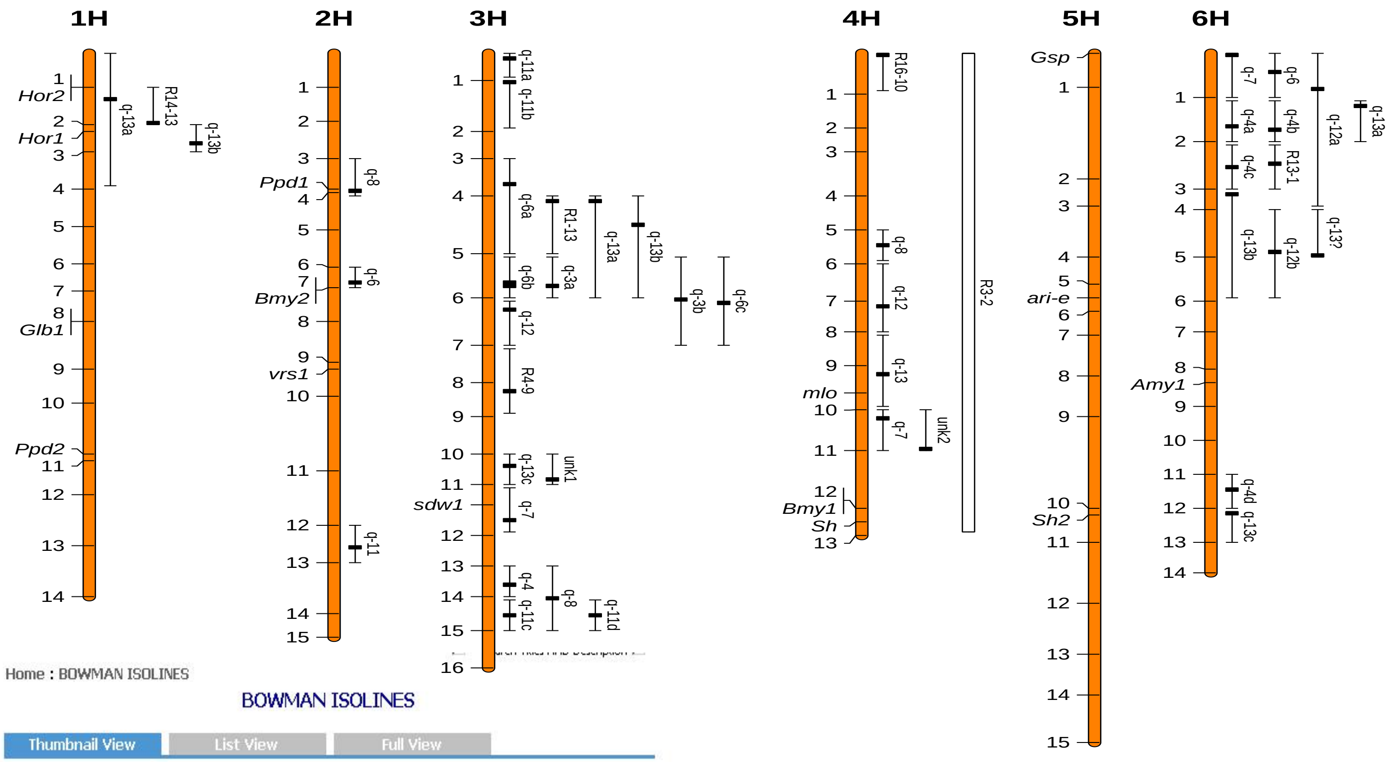
P. infestans SSR genotype	R3a virulence	avr3a allele	R2 virulence	avr2 wt allele	avr2 var. allele
13_A2	+	EM	+	absent	MI/TV
13_A2	+	EM	+	absent	MI/TV
13_A2	+	EM	+	absent	MI/TV
13_A2	+	EM	+	absent	MI/TV
3_A2	+	EM	+	absent	MI/TV
3b_A2	+	EM	+	absent	MI/TV
3b_A2	+	EM	+	absent	MI/TV
17_A2	+	EM	+	K/N	MI
6_A1	+	EM	-	K/N	absent
6_A1	+	EM	-	K/N	absent
10_A2	+	EM	-	K	absent
4_A1	+	EM	-	K	absent
1_A1	+	EM	-	K/N	TV
1_A1	+	EM	-	K/N	TV
2_A1	+	EM	-	K	MI
2_A1	+	EM	-	K	MI
22_A2	+	EM	-	K	MI/TV
22_A2	+	EM	-	K	MI/TV
7_A1	-	KI/EM	+	K	MI
7_A1	-	KI/EM	+	K	MI
8_2a_A1	-	KI/EM	-	K	MI
8a_A1	-	KI/EM	-	K	MI
8a_A1	-	KI/EM	-	K	MI
15_A2	-	KI	-	K/N	absent

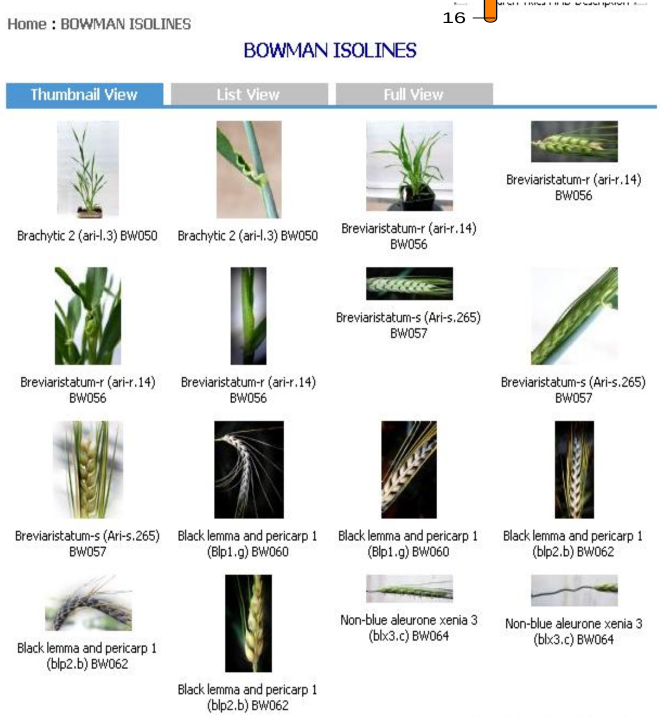
Pathogen has genome architecture that generates effector gene diversity

Haas et al., Nature, 2009

Phytophthora – using knowledge from pathogen genomes to adopt smart effector-based screening strategies to identify resistances that will be durable across different races

Birch, Hein, Whisson, Cooke, Bryan





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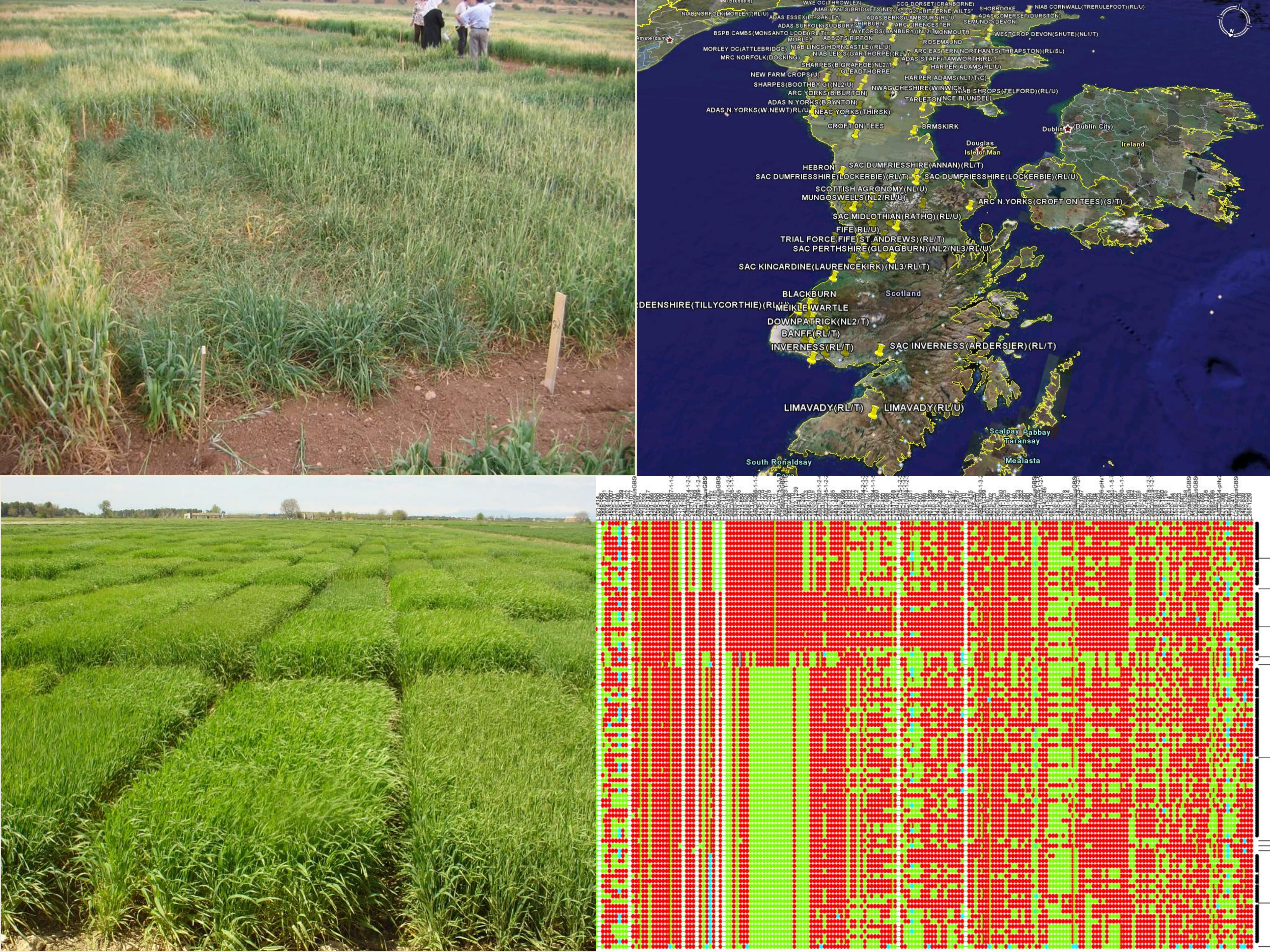
Cereals: Sequence and association genetics resources of hosts (e.g. Barley) and pathogens (e.g. *Rhynchosporium secalis*)



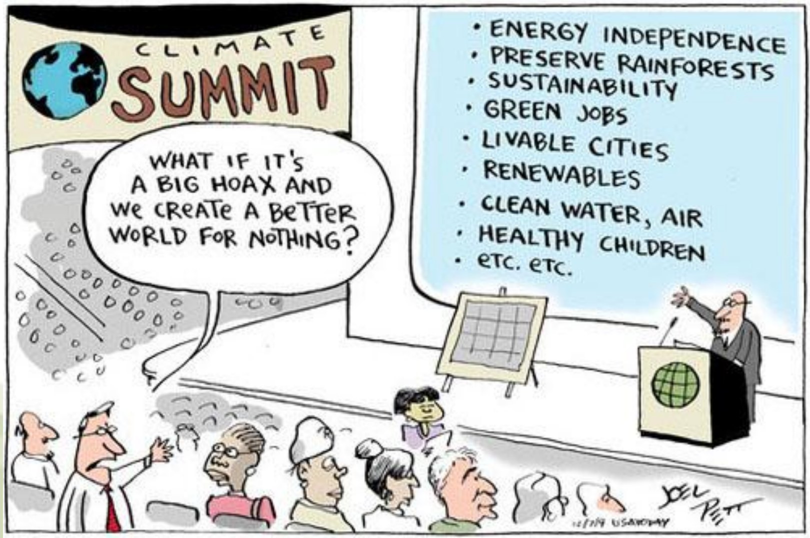
WYE OC(THROWLEY)
CCG DORSET(CRANBORNE)
NIAB CORNWALL(TRERULEFOOT)(RL/U)
SHOBROOKE
ADAS SOMERSET(DURSTON)
SEMUNDO(DEVON)
WESTCROP DEVON(SHUTE)(NL1/T)
ROSEMAUND
ARC EASTERN NORTHANTS(THRAPSTON)(RL/SL)
ADAS STAFF.TAMWORTH(RL/T
HARPER ADAMS(RL/U)
HARPER ADAMS(NL1/T/C)
NWAG CHESHIRE(WINWICK)
NIAB SHROPS(TELFORD)(RL/U)
TARLETON
NCE BLUNDELL
ADAS ESSEX(L.OAKLEY)
ADAS SUFFOLK(SUDBURY)
BSPB CAMBS(MONSANTO LODE)(RL/T)
MORLEY OC(ATTLEBRIDGE)
MRC NORFOLK(DOCKING)
NEW FARM CROPS(U)
SHARPES(BOOTHBY G)(NL2/U)
ARC YORKS(B.BURTON)
ADAS N.YORKS(BOYNTON)
ADAS N.YORKS(W.NEWT)(RL/U)
NEAC YORKS(THIRSK)
GLEADTHORPE
CROFT ON TEES
ORMSKIRK
Douglas
Isle of Man
Dublin
(Dublin City)
Ireland
Amsterdam
HEBRON
SAC DUMFRIESSHIRE(ANNAN)(RL/T)
SAC DUMFRIESSHIRE(LOCKERBIE)(RL/T)
SAC DUMFRIESSHIRE(LOCKERBIE)(RL/U)
SCOTTISH AGRONOMY(NL1/U)
MUNGOSWELLS(NL2/RL/U)
ARC N.YORKS(CROFT ON TEES)(S/T)
SAC MIDLOTHIAN(RATHO)(RL/U)
FIFE(RL/U)
TRIAL FORCE FIFE(ST.ANDREWS)(RL/T)
SAC PERTHSHIRE(GLOAGBURN)(NL2/NL3/RL/U)
SAC KINCARDINE(LAURENCEKIRK)(NL3/RL/T)
BLACKBURN
Scotland
MEIKLE WARTLE
DOWNPATRICK(NL2/T)
BANFF(RL/T)
INVERNESS(RL/T)
SAC INVERNESS(ARDERSIER)(RL/T)
LIMAVADY(RL/T)
LIMAVADY(RL/U)
Scalpay
Pabbay
Taransay
South Ronaldsay
Mealasta

Summary:

- Climate changes are regionally variable
- Increased pest and disease threats to Scottish crops

- Pests and pathogens highly adaptable
- Resistance needs to be environmentally –robust
- Plant microbe interactions are complex and some are beneficial

- Understanding of microbe and crop ecology needed
- Germplasm and tools to respond to climate change are available



Robust resistance, crop agronomy and crop protection based on:

understanding of pest and pathogen epidemiology and crop ecology

Thanks

The James Hutton Institute

Science connecting land and people