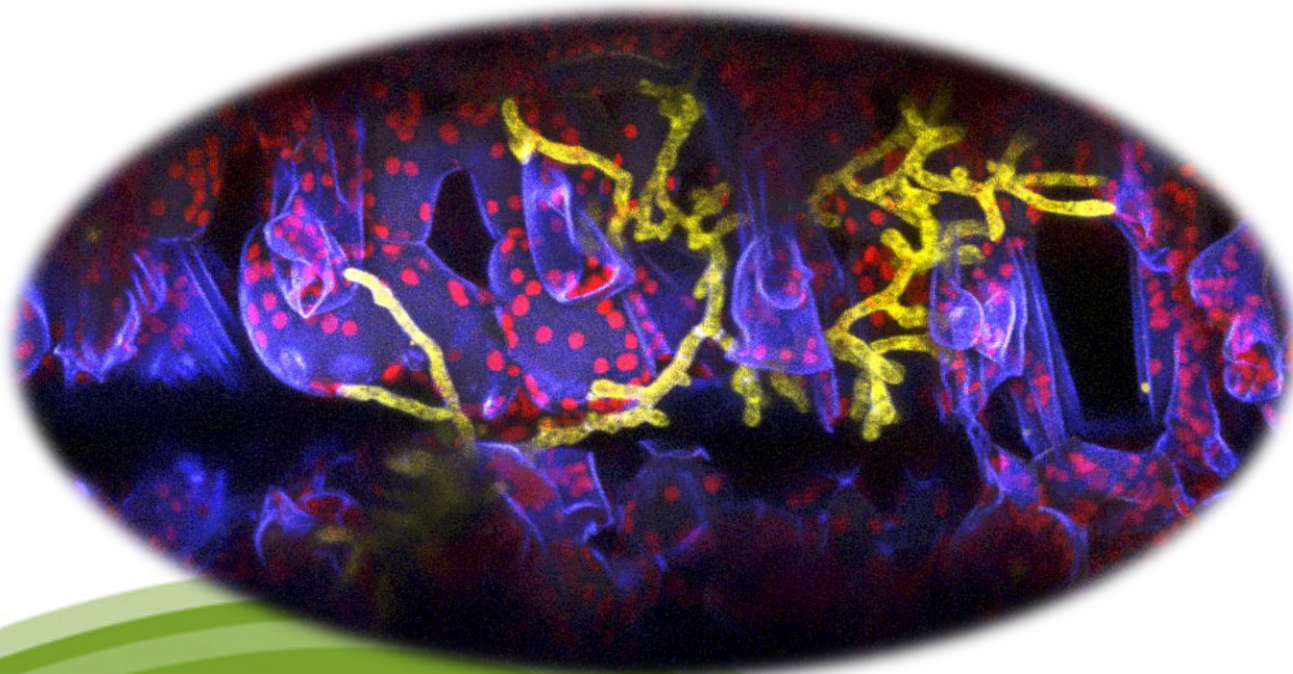


Climate change, plant disease and food security: an overview

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Climate change, plant disease and food security: an overview

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REVIEW

Climate change, plant diseases and food security: an overview

S. Chakraborty¹ and A. C. Newton²

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Global food production must increase by 50% to meet the projected demand of the world's population by 2050. Meeting this difficult challenge will be made even harder if climate change melts portions of the Himalayan glaciers to affect 2.5% of world cereal production in Asia by influencing water availability. Pest and disease management has played its role in doubling food production in the last 40 years, but pathogens still claim 10–16% of the global harvest. We consider the effect of climate change on the many complex biological interactions affecting pests and pathogen impacts and how they might be manipulated to mitigate these effects. Integrated solutions and international co-ordination in their implementation are considered essential. Providing a background on key constraints to food security, this overview uses fusarium head blight as a case study to illustrate key influences of climate change on production and quality of wheat, outlines key links between plant diseases, climate change and food security, and highlights key disease management issues to be addressed in improving food security in a changing climate.

Keywords: climate change, food safety, fusarium head blight, global food security, mycotoxin, plant disease

Introduction

The earth's climate has always changed in response to changes in the cryosphere, hydrosphere, biosphere and other atmospheric and interacting factors. It is widely accepted that human activities are now increasingly influencing changes in global climate (Paclautz & Reisinger, 2007). Since 1750, global emissions of radiatively active gases, including CO₂, have increased rapidly, a trend that is likely to accelerate if increase in global emissions cannot be curbed effectively. Man-made increases in CO₂ emissions have come from industry, particularly as a result of the use of carbon-based fuels. Over the last 100 years, the global mean temperature has increased by 0.74°C and atmospheric CO₂ concentration has increased from 280 p.p.m. in 1750 to 368 p.p.m. in 2000 (Watson, 2001). Temperature is projected to increase by 3–4°C and CO₂ concentration to increase to 1250 p.p.m. by ~2095 under the A2 scenario, accompanied by much greater variability in climate and more extreme weather-related events (Pachauri & Reisinger, 2007). Underlying these trends is much spatial and temporal heterogeneity, with projections of climate change impacts differing among various regions on the globe. Some of this is clear in the outputs from models that take into account geo-

graphic criteria such as land mass distribution, topography, ocean currents and water masses, and known meteorological features such as air streams. Nevertheless, historic data show seasonal and regional variation not accounted for in model processes (e.g. Barnett *et al.*, 2006) that have major implications for practical processes such as crop sowing, harvest or pest and pathogen infection and therefore all the activities that derive from these effects.

Defining uncertainty is important in all areas of climate change research, not only in assumptions for stochastic or deterministic models, but also in biological processes where knowledge or understanding is lacking. However, uncertainties are arguably greater when the implications of climate change on food security are considered. Food security can be defined as 'when all people, at all times, have physical and economic access to sufficient, safe, and nutritious food to meet their dietary needs and food preferences for an active and healthy life' (FAO, 2003) or 'fair prices, choice, access through open and competitive markets, continuous improvements in food safety, transition to healthier diets, and a more environmentally sustainable food chain' (Anonimus, 2008a), although a simpler definition could be 'the risk of a adequate food not being available'. It is a combination of multiple food availability, food access and food utilization issues. Each of these is influenced by many factors, such as economic recession, currency fluctuations, water pollution, politi-

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REVIEW

Implications of climate change for diseases, crop yields and food security

Adrian C. Newton¹, Scott N. Johnson²,
Peter J. Gregory¹

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Abstract

Accelerated climate change directly, as well as indirectly through its effects on pest and pathogen interactions, is expected to have a profound impact on food security. This review examines the complex interactions between climate change, crop production and food security, and discusses the implications for food security in a changing climate.

Keywords: Real-time quality

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REVIEW PAPER

Integrating pests and pathogens into the climate change/food security debate

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Abstract

While many studies have demonstrated the sensitivities of plants and of crop yield to a changing climate, a major challenge for the agricultural research community is to relate those findings to the broader societal concern with food security. This paper reviews the direct effects of climate on both crop growth and yield and on plant pests and pathogens and the interactions that may occur between crops, pests, and pathogens under changed climate. Finally, we consider the contribution that better understanding of the roles of pests and pathogens in crop production systems might make to enhanced food security. Evidence for the measured climate change on crops and their associated pests and pathogens is starting to be documented. Globally atmospheric CO₂ has increased, and in northern latitudes mean temperatures at many locations has increased by about 1.0–1.4 °C with accompanying changes in pest and pathogen incidence and to farming practices. Many pests and pathogens exhibit considerable capacity for generalist recombining, and selecting its combinations of variants in key pathogenicity, fitness, and aggressiveness traits that there is little doubt that any new opportunities resulting from climate change will be exploited by them. However, the interactions between crops and pests and pathogens are complex and poorly understood in the context of climate change. More mechanistic inclusion of pests and pathogens effects in crop models would lead to more realistic predictions of crop production on a regional scale and thereby assist in the development of more robust regional food security policies.

Key words: Crop-pathogen interactions, crop-pest interactions, crop productivity, yield

Introduction

The last 40–50 years have seen major changes to agricultural systems worldwide that have contributed to, and interacted with, new food systems. Von Braun (2007) highlighted the transforming role of the interacting driving forces of population increase, income growth, urbanization, and globalization on food production, markets, and consumption. To these forces can be added the twin elements of climate variability and climate change which have direct effects on both food production and food security (Parry *et al.*, 2004). It is well known that the sensitivity of agricultural systems to climate change depends on whether they are operating near their optimum or not. Fisher (2006) concluded that there was ample evidence to demonstrate the sensitivity of agricultural systems to climate change, and that the range of effects on potential productivity was from extremely negative in areas that were already water-limited to positive in areas that were temperature-limited. Similarly, the effects of climate variability and change on food security are also location-specific and, more importantly, socially-specific with countries and groups with low income and limited adaptive capacity facing significant threats to food security (von Braun, 2007). In particular, food insecurity in sub-Saharan Africa will be affected more by socio-economic factors than by climate change per se (Rötter *et al.*, 2007).

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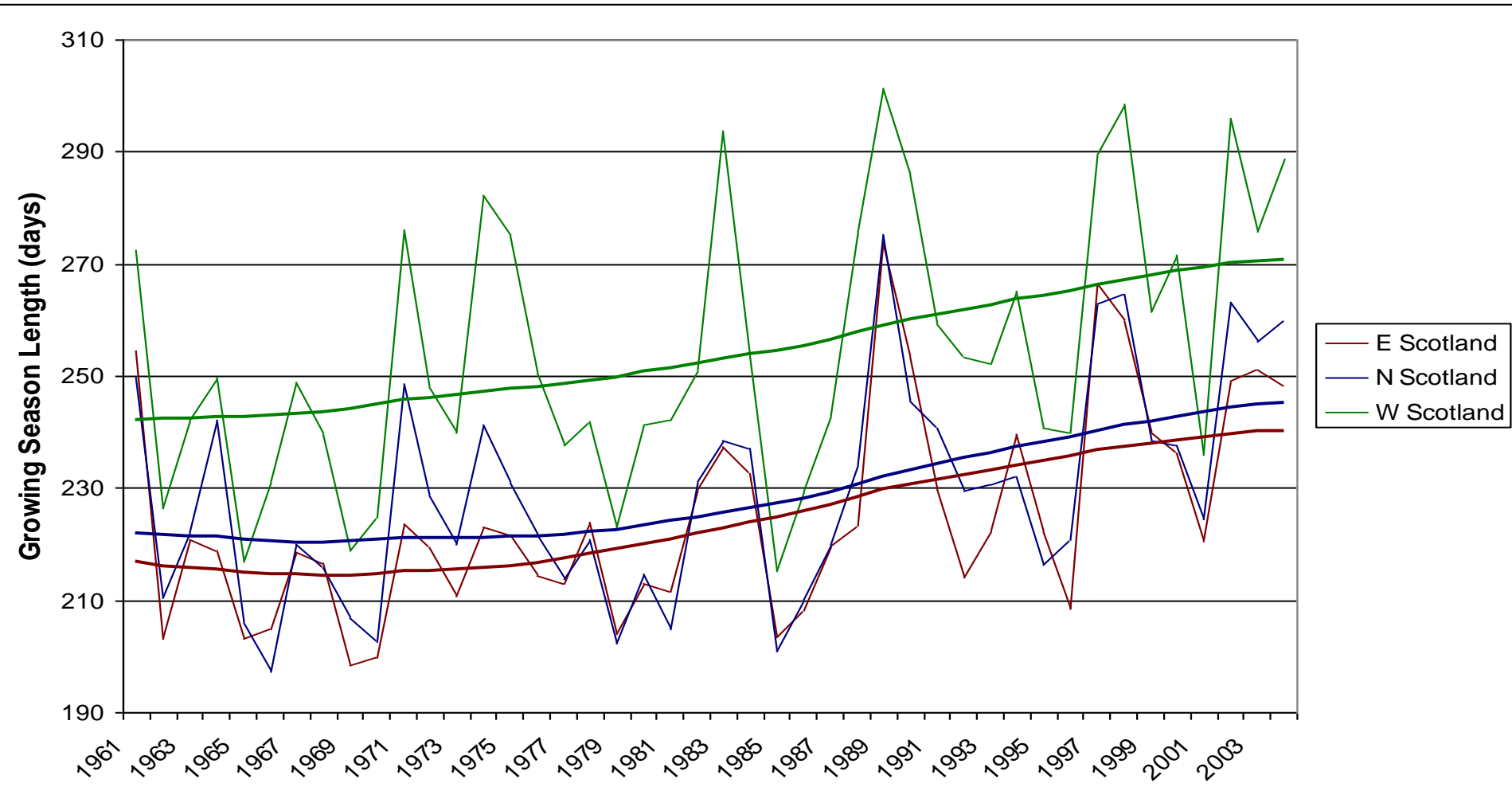


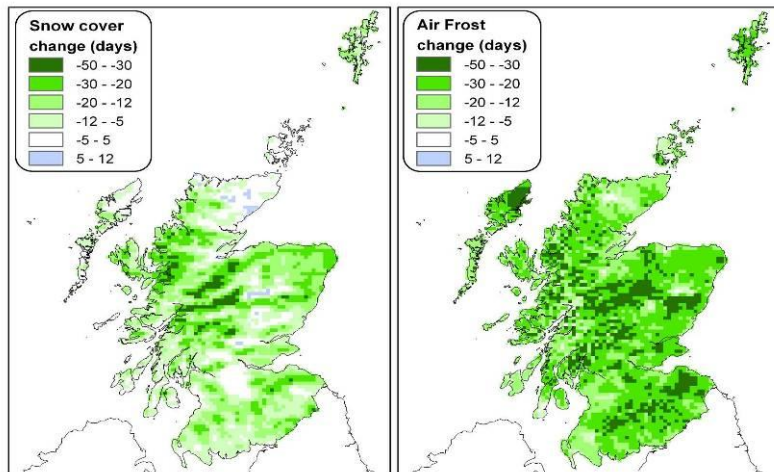
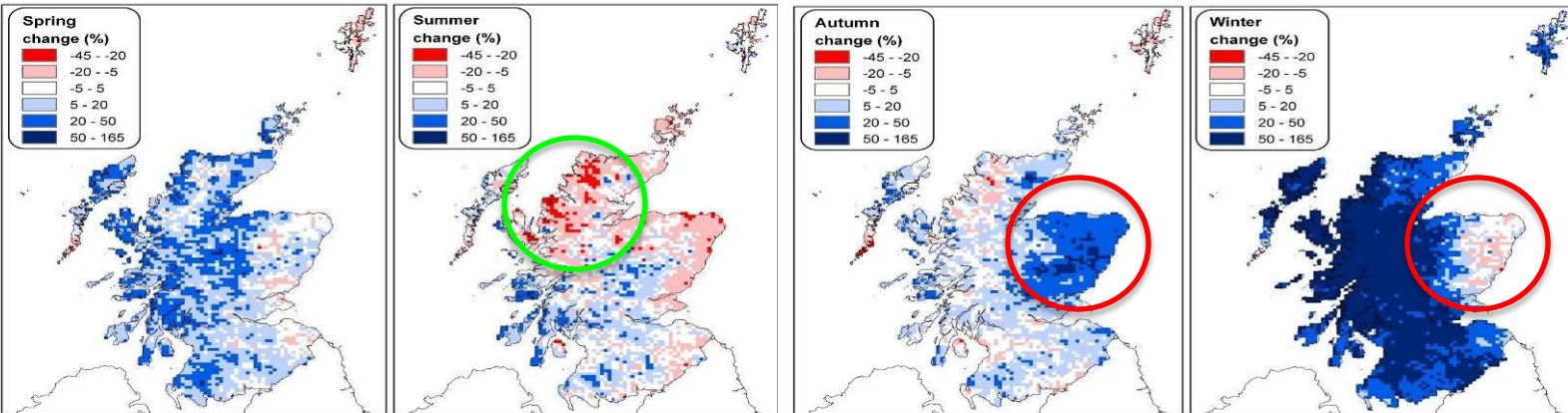
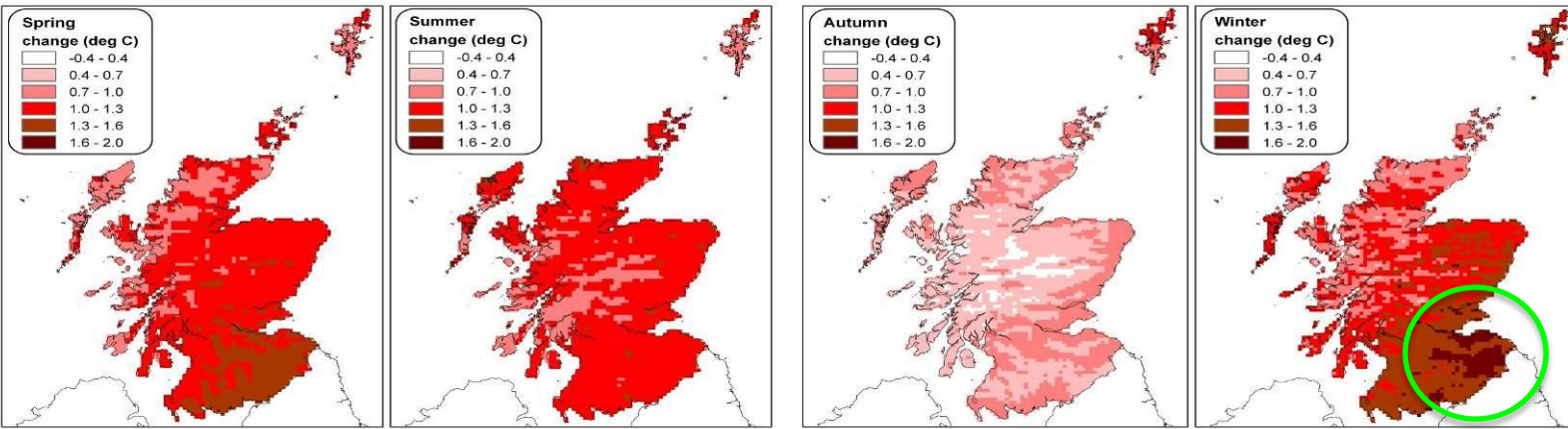
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Ian Toth, Nicola Holden, Lesley Torrance

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





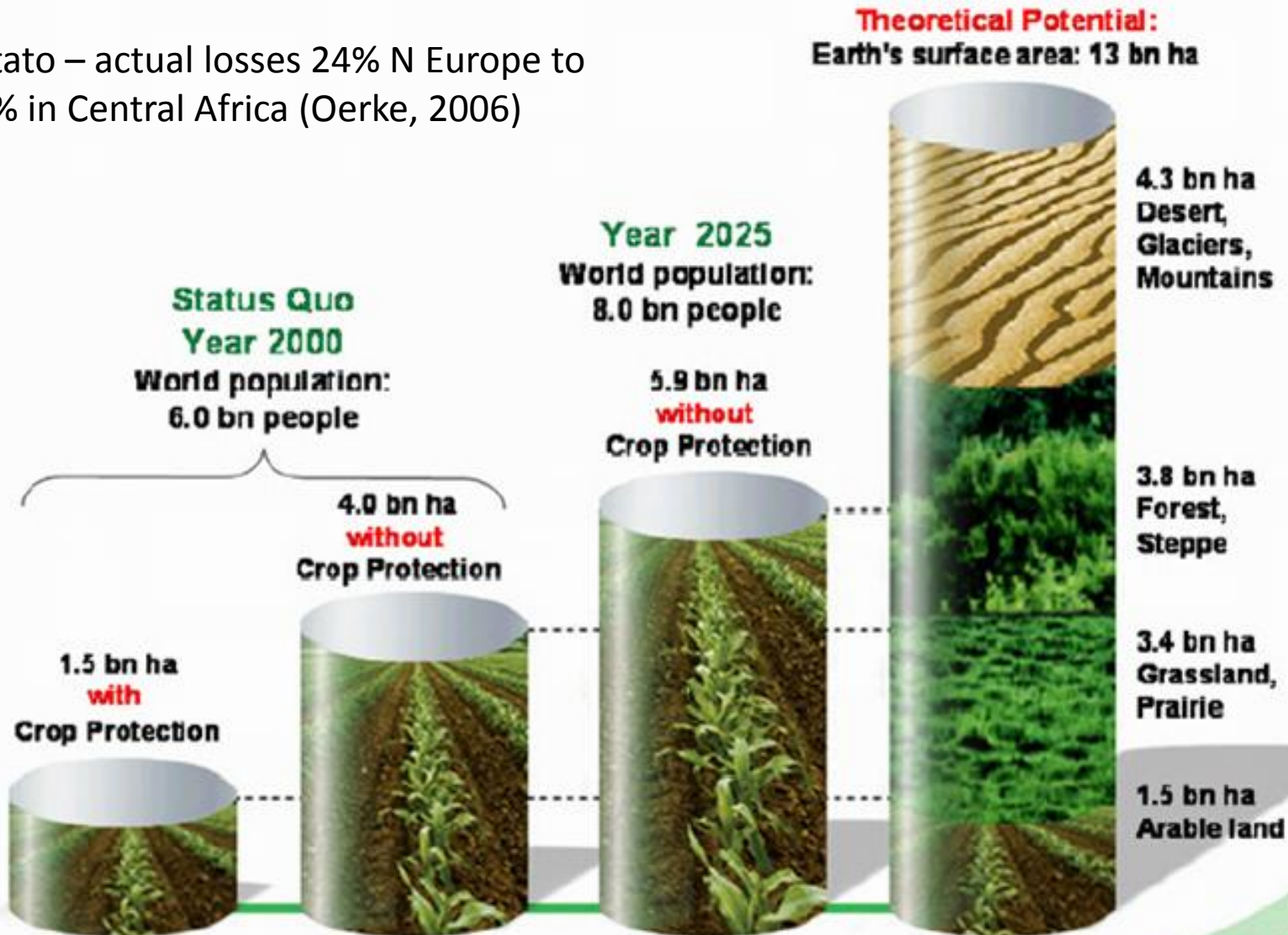
Changes in: temperature rainfall, frost and snow cover in Scotland 1961-2004

(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)



Source: D.T. Avery, US-Hudson Institute - FAO

1 Hectare (ha) = 10 000 m²

Soft fruit pest and pathogens

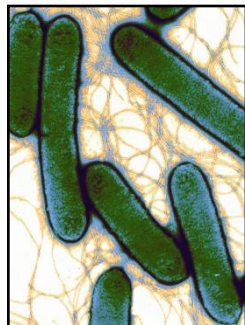


Soft fruit

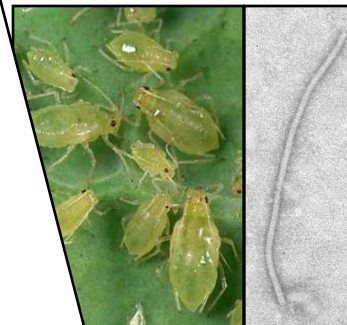
Potato pest, pathogen and diseases



Pests and pathogens



Impact of Climate Change on Pests and Diseases of Potatoes in Scotland: Risks and Recommendations (2008)
RERAD Work Package 1.5 (Potato Pathology)



Understand climate change parameters

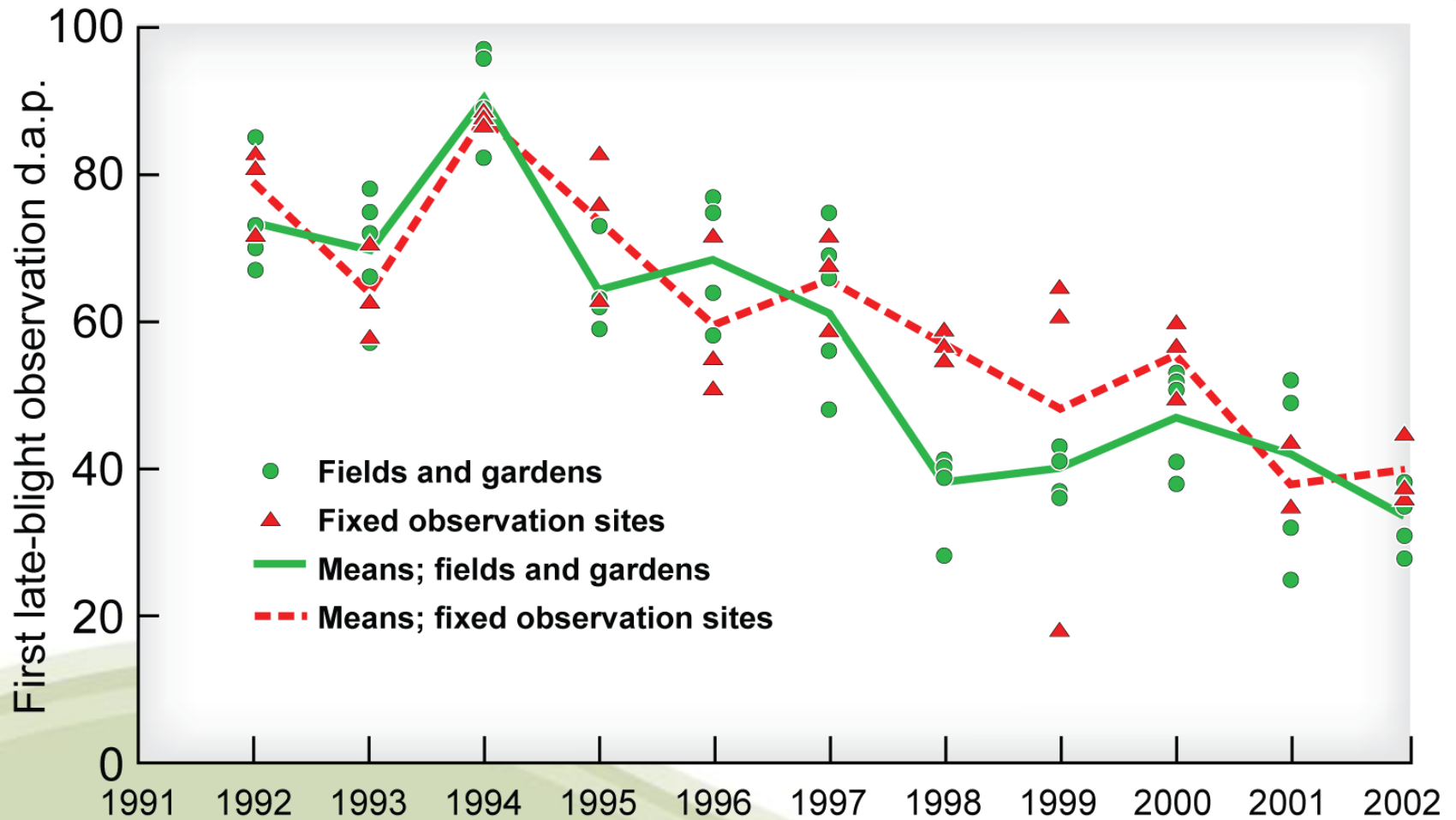


respond to key

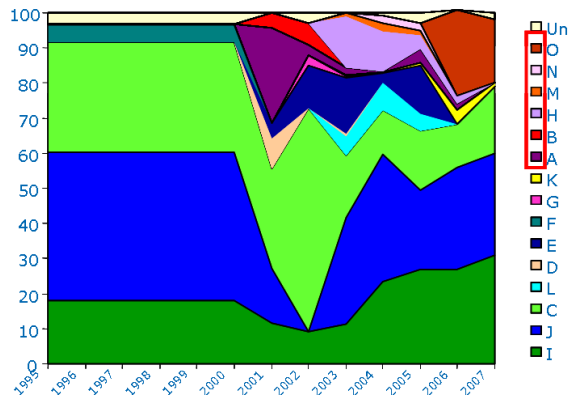
Potato

Earlier outbreaks of late blight in Finland

(Hannukkala et al., 2007)



Pathogen population change

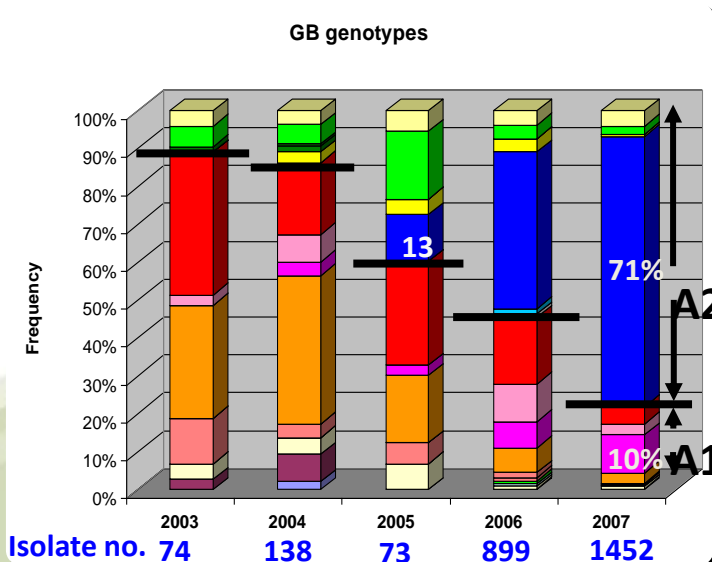


Peach-potato aphid

Driven by:

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

GB genotypes



Potato late blight

Site	Isolate name	Seedling virulence	Cultivar	Marker														Genotype
				1	2	3	4	5	6	7	8	9	10	11	12	13	14	
1	L2A	3,2,3	Sumo	100	229	126	237	138	228	193	177	167	172	246	203	196	318	A
2	L43A	1,2,3,4,8	Saffron	118	229	126	232	134	232	193	200	147	141	199	220	216	314	B
2	L43B	1,3	Saffron	118	229	126	232	134	230	193	200	147	141	199	220	216	314	B2
2	L43C	1,3	Saffron	118	229	126	232	134	232	193	200	147	141	199	220	216	314	B
2	L43D	1,3	Saffron	118	229	126	232	134	232	193	200	147	141	199	220	216	314	B
3	L47A	1,3,4	Sumo	103	229	126	217	141	226	232	177	167	166	228	201	196		C
3	L47B	1,3,4	Sumo	140	231	129	246	138	209	226	177	147	166	262	214	160	316	D
3	L47C	1,3	Sumo	140	231	129	246	138	209	226	177	147	166	262	214	160	316	D
4	L73A	1,	Flagon	103	229	126		140	226	216	165	176	169	268	195	198	318	E
4	L74B	1,3	Flagon	103	229	126	217	140	226	216	165	176	165	268	195	198		E2
4	L99B	3,2,3	Sumo	193	229	126	217	140	213	232	180	147	166	268				F
4	L99C	3,3,4	Sumo	103	229	126		138	226	232	200							G
4	L101B	3,3,4	Sumo	103	229	126	217	141	229									H
4	L102B	3,3,4	Saffron	100	229	126	217											I
4	L104B	1,2,3,4	Saffron	100	229	126	217											I
6	L1A	3,4,7,8	Sumo	103	229	126	217	141	226	232	177	167	166	228	201	196		J
6	L1B	3,4,8	Sumo	103	229	126	217	141	226	232	177	167	166	228	201	196		K
6	L1C	3,4,8	Sumo	103	229	126	217	141	226	232	177	167	166	228	201	196		L
6	L1D	3,4,8	Sumo	103	229	126	217	141	226	232	177	167	166	228	201	196		M
6	L1E	3,4,8	Sumo	103	229	126	217	141	226	232	177	167	166	228	201	196		N
6	L1F	3,4,8	Sumo	103	229	126	217	141	226	232	177	167	166	228	201	196		O
6	L1G	3,4,8	Sumo	118	228	129		134	209	232	200	147	141	220	220	200	312	P
7	L32C	3,4,7,8	Saffron	118	231	129	238	135	209	238	211	157	172	210	218	160	354	Q
7	L32C	3,4,7,8	Saffron	118	231	129	238	136	208		211	157	172	210	220	160	354	Q2
7	L38A	3,4,8	Sumo	103	229	117	217	140	213	238	188	147	141	206	201	196	316	R
7	L38B	3,4	Sumo	103	229	117	217	140	215		188	147	141		222			R3
3	L46	3,4	Sumo	103	229	126	217	140	226	216	165	176	169	268	201	196	318	S
4	L60A	3,4,7,8	Saffron	103	229	126	217	140	226	232	177	167	166	245	201	196	320	T
4	L60B	3,4,7,8	Saffron	118	231	129	239	134	200	240	211	157	172	210	220	160	354	U
4	L77	3,4,7,8	Manitou	103	229	126	217	142	213	232	165	171	166	228	199	195	316	V

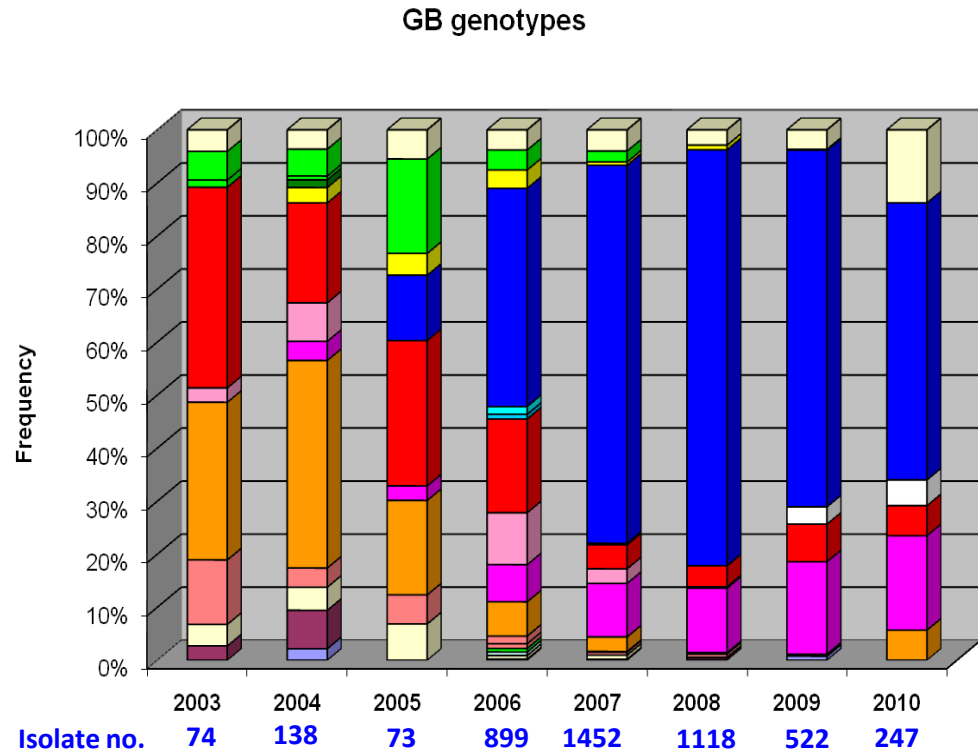
Rhynchosporium on barley

A changing population

SSR markers used to genotype 24,000 isolates across Europe



A new dominant A2 strain 13_A2 (blue)



More aggressive, faster generation time, phenylamide R

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

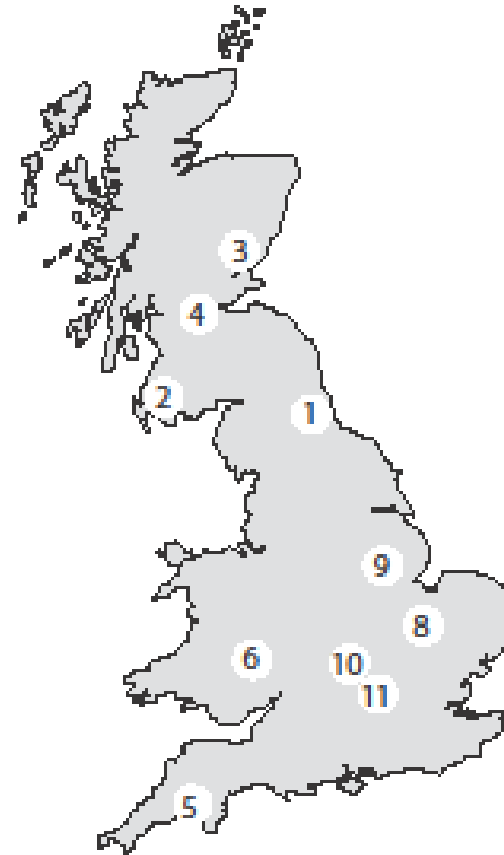
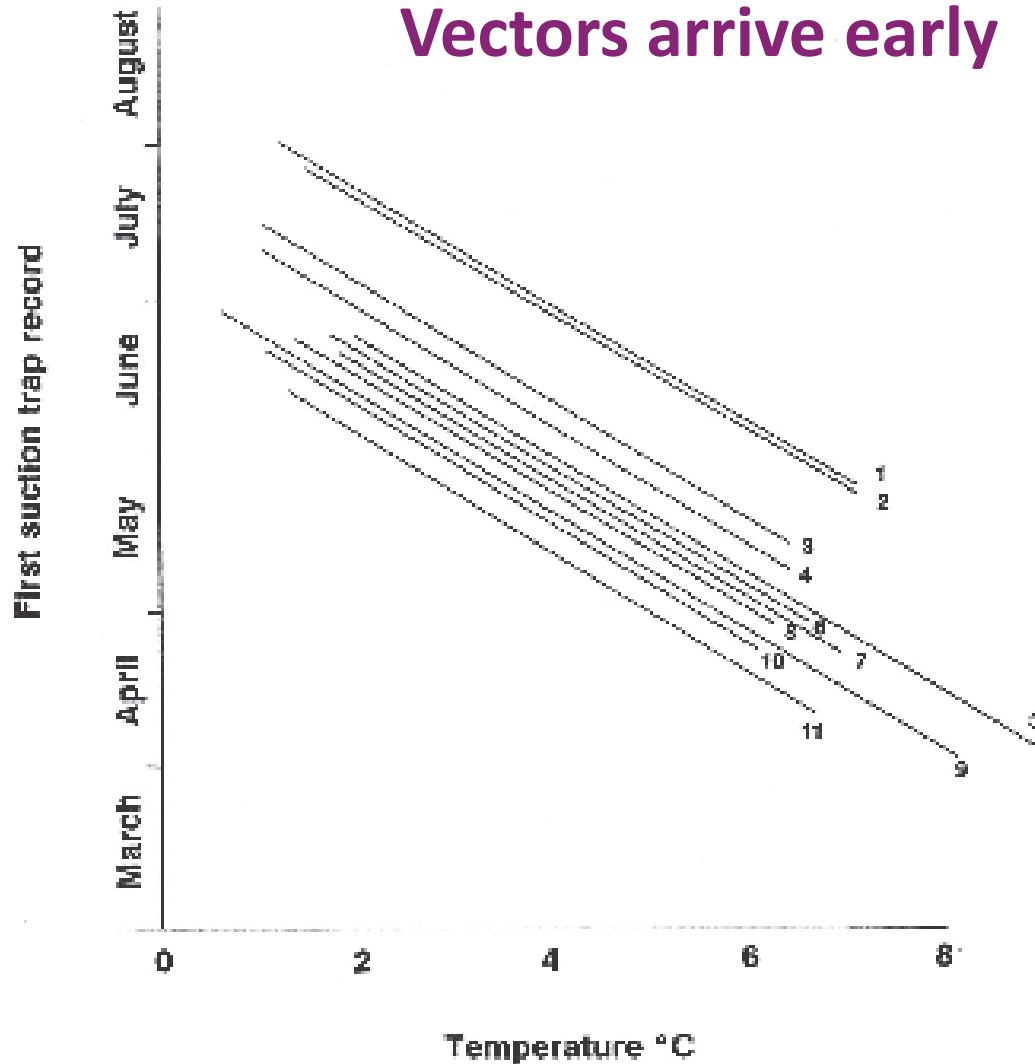
	Atem <i>mlo11</i>	Apex <i>mlo9</i>
Non-stressed	0	0
Stress-relieved: water	23%	10%
Stress-relieved: nutrients	62%	19%

Host resistance is compromised by temperature

- Abiotic stresses (heat, drought) can increase or decrease susceptibility.
- Virus resistance complex - mediated by different mechanisms:
 - lower temperatures ($<20^{\circ}\text{C}$) RNA silencing less effective
 - whereas high temp ($>28^{\circ}\text{C}$) 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



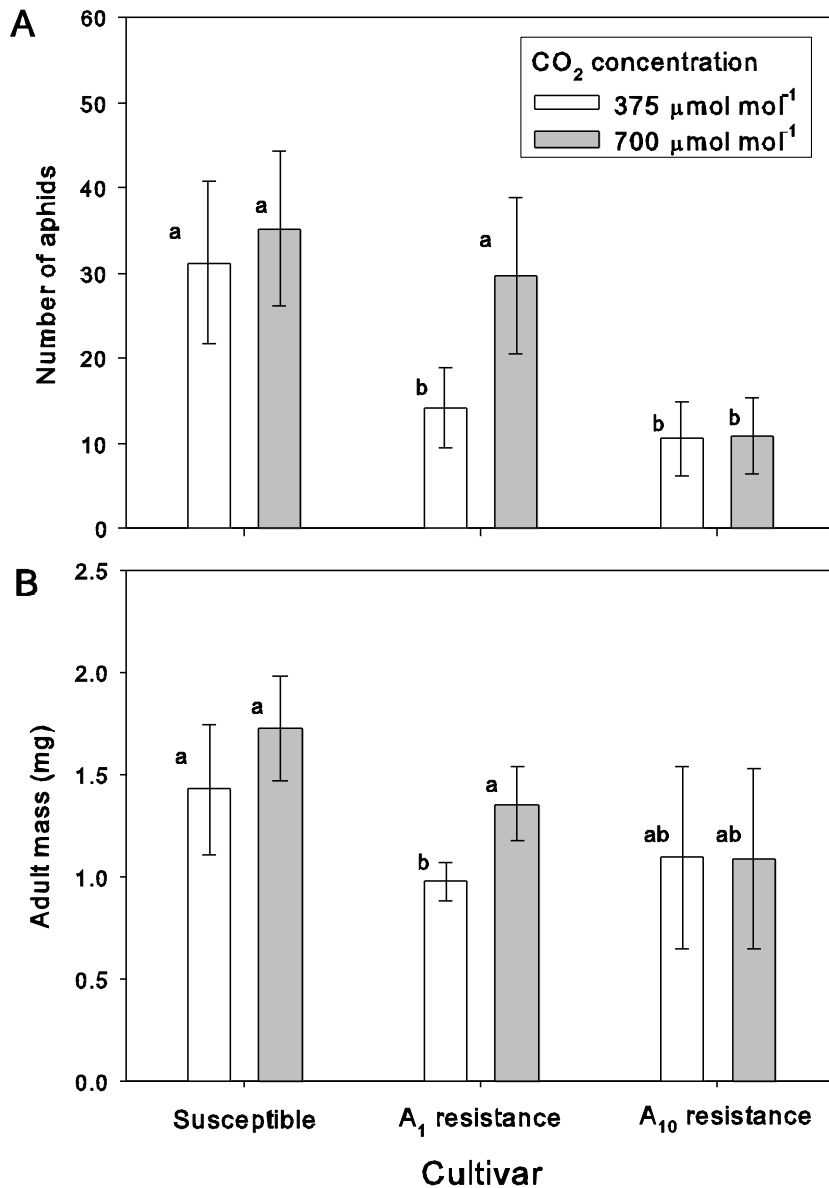
Raspberry Leaf
Spot Virus



Two resistance genes partially overcome:

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

Resistance breakdown CO₂ effect



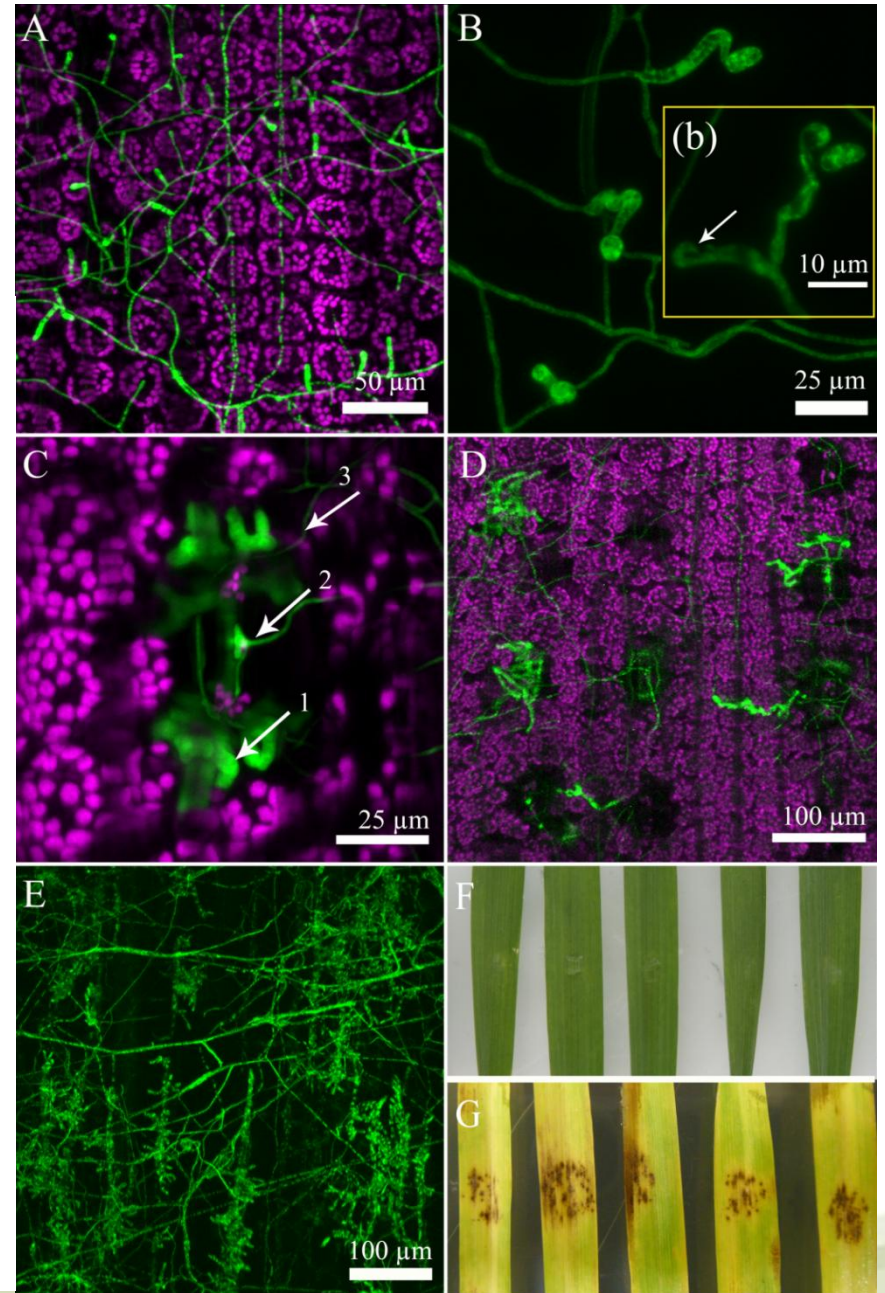
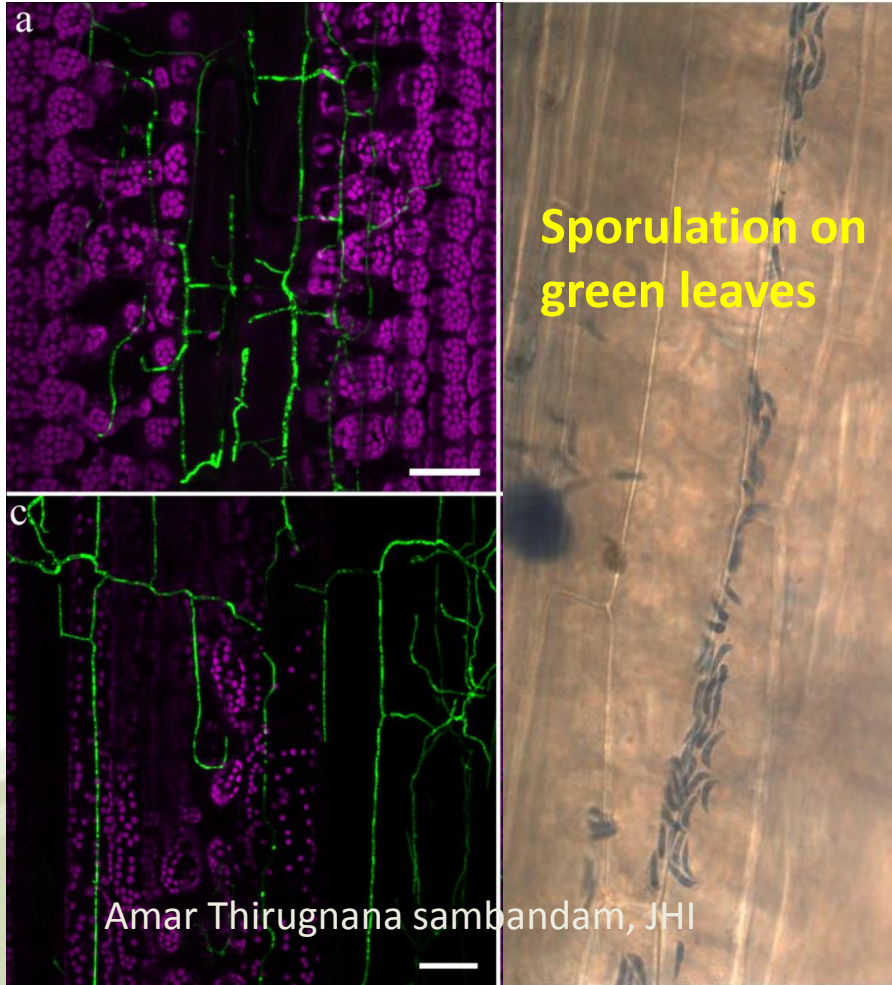
European large raspberry aphid
(*Amporophora idaei*) on:

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

at ambient and elevated CO₂

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*)

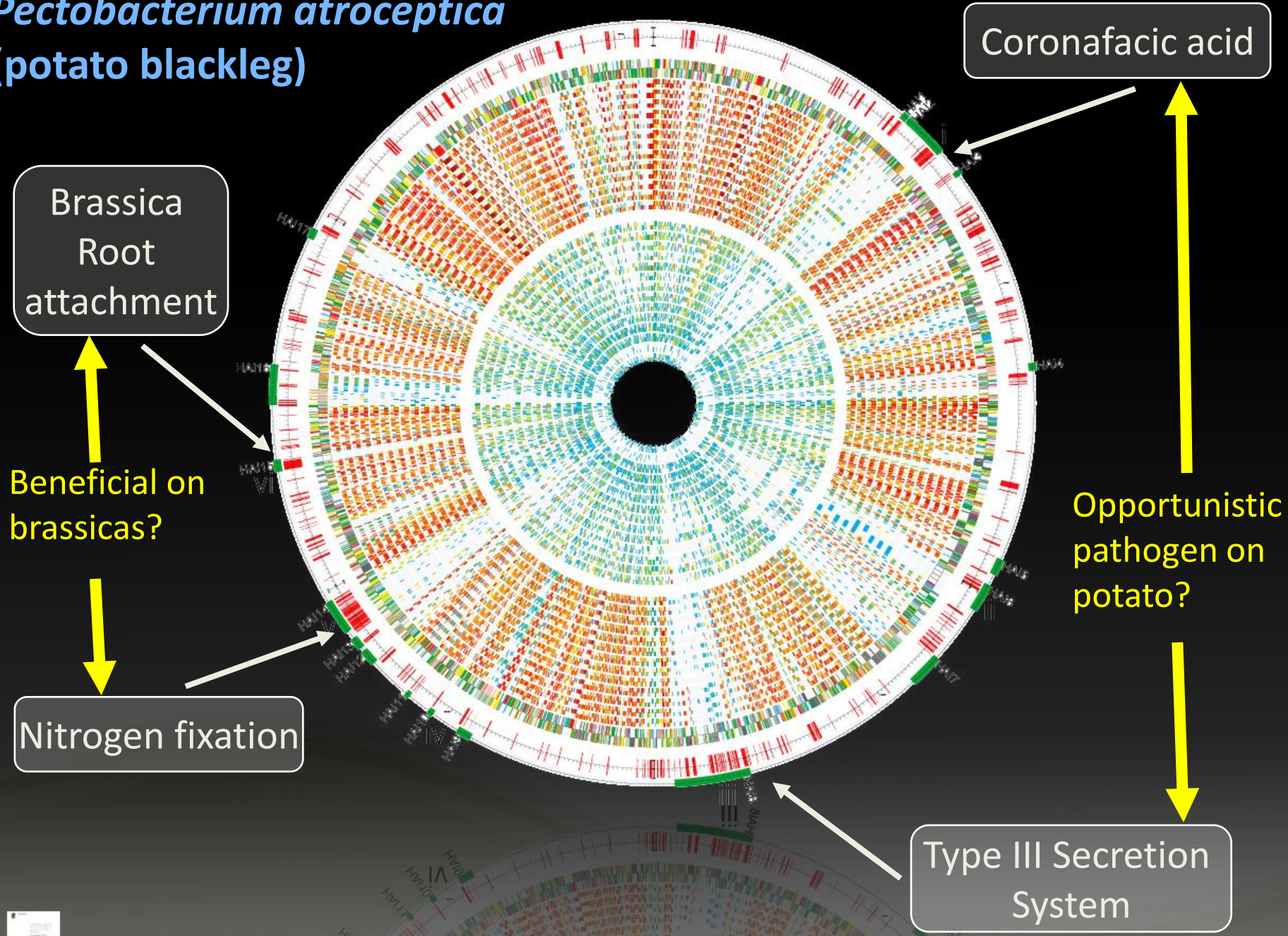


***Dickeya* species spread from Mainland Europe to UK in 1990s**

- 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



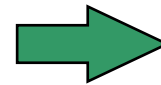
Pectobacterium atroceptica
(potato blackleg)



Pectobacterium colonises wild plant species



All plants tested are colonised, although to different extents



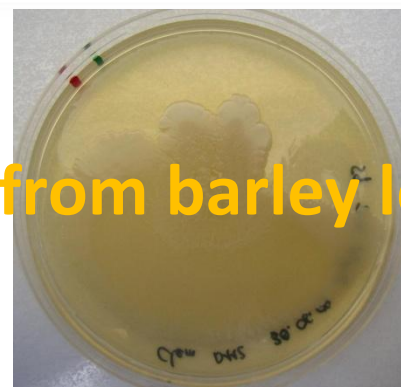
Culturable bacteria from barley leaf surfaces



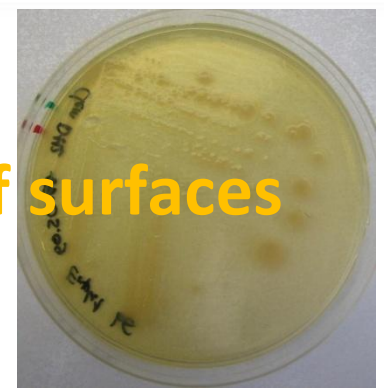
B3: *Pseudomonas poae*



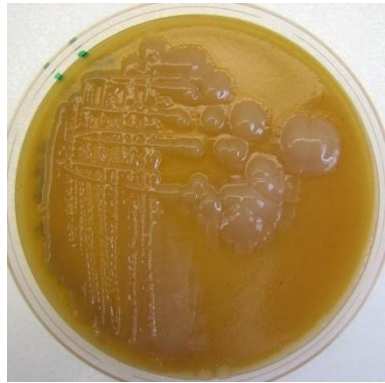
B4: *Duganella zoogloeoides* or
Zoogloea ramigera



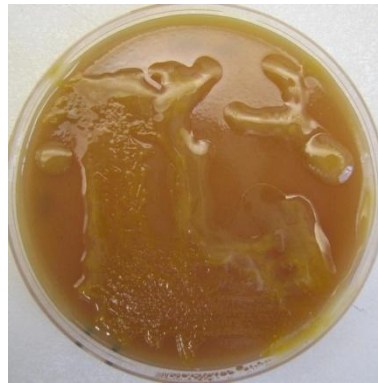
B5: *Pseudomonas poae*



B6: *Pseudomonas veronii*



B7: *Pseudomonas poae*



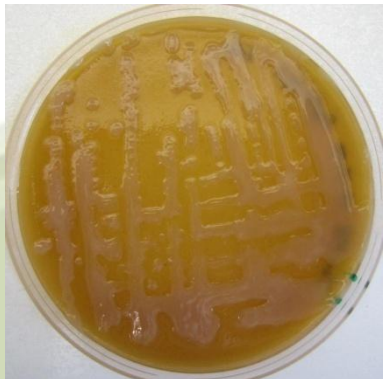
B8: *Pantoea agglomerans*



B11: *Duganella zoogloeoides* or
Zoogloea ramigera



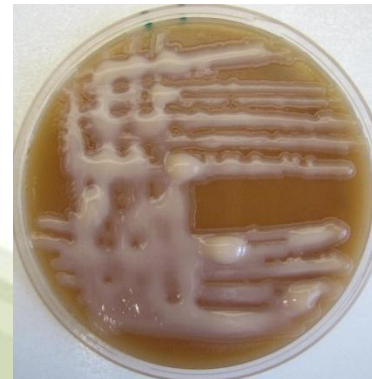
B12: *Pseudomonas veronii*



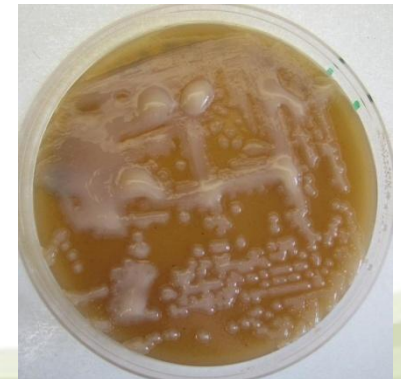
B13: *Pantoea agglomerans*



B14: *Pseudomonas syringae*



B16: *Pseudomonas syringae*



B17: *Pseudomonas syringae*

Culturable fungi from barley leaf surfaces



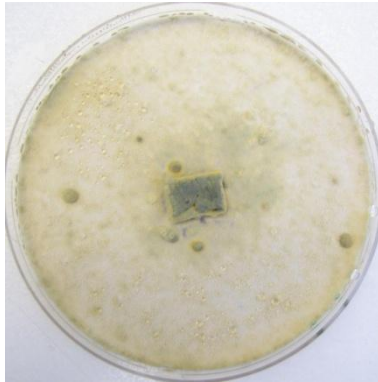
F1 *Apiospora montagnei* / *Arthrinium mairii* /
Arthrinium mediterranei / *Arthrinium hispanicum*



F2 *Botryotinia fuckeliana*



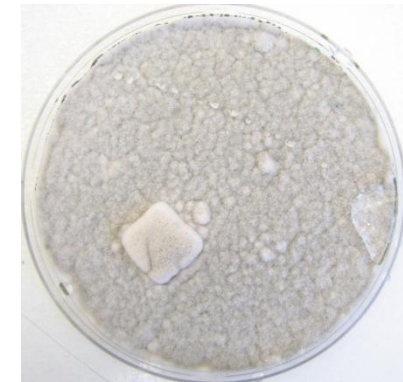
F3 *Humicola fuscoatra* var.
fuscoatra



F4 *Penicillium piceum*



F5 *Davidiella tassiana*



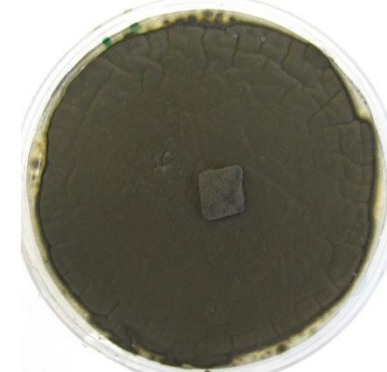
F6 *Davidiella tassiana*



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

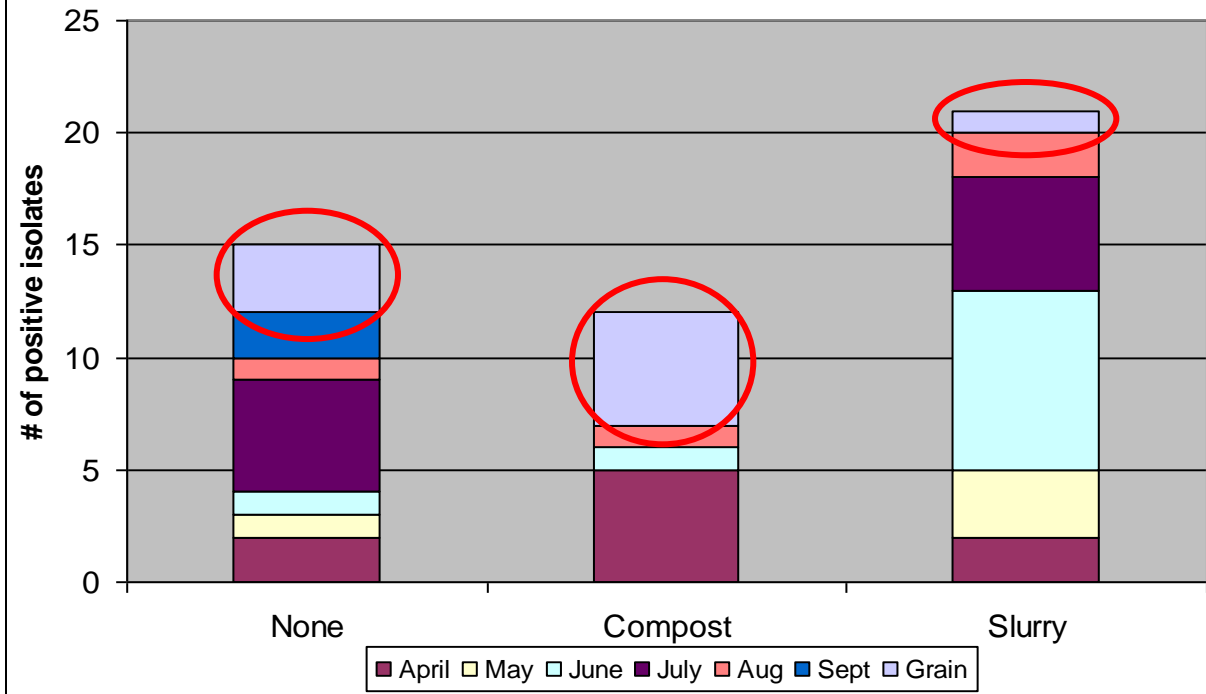


F9 *Phoma* sp. / *Phyllosticta phaseolina* /
Phaeosphaeriaceae sp. / *Ascochyta* sp. /
Didymella bryoniae / dothideomycete sp.



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

Escherichia coli - like, by treatment type

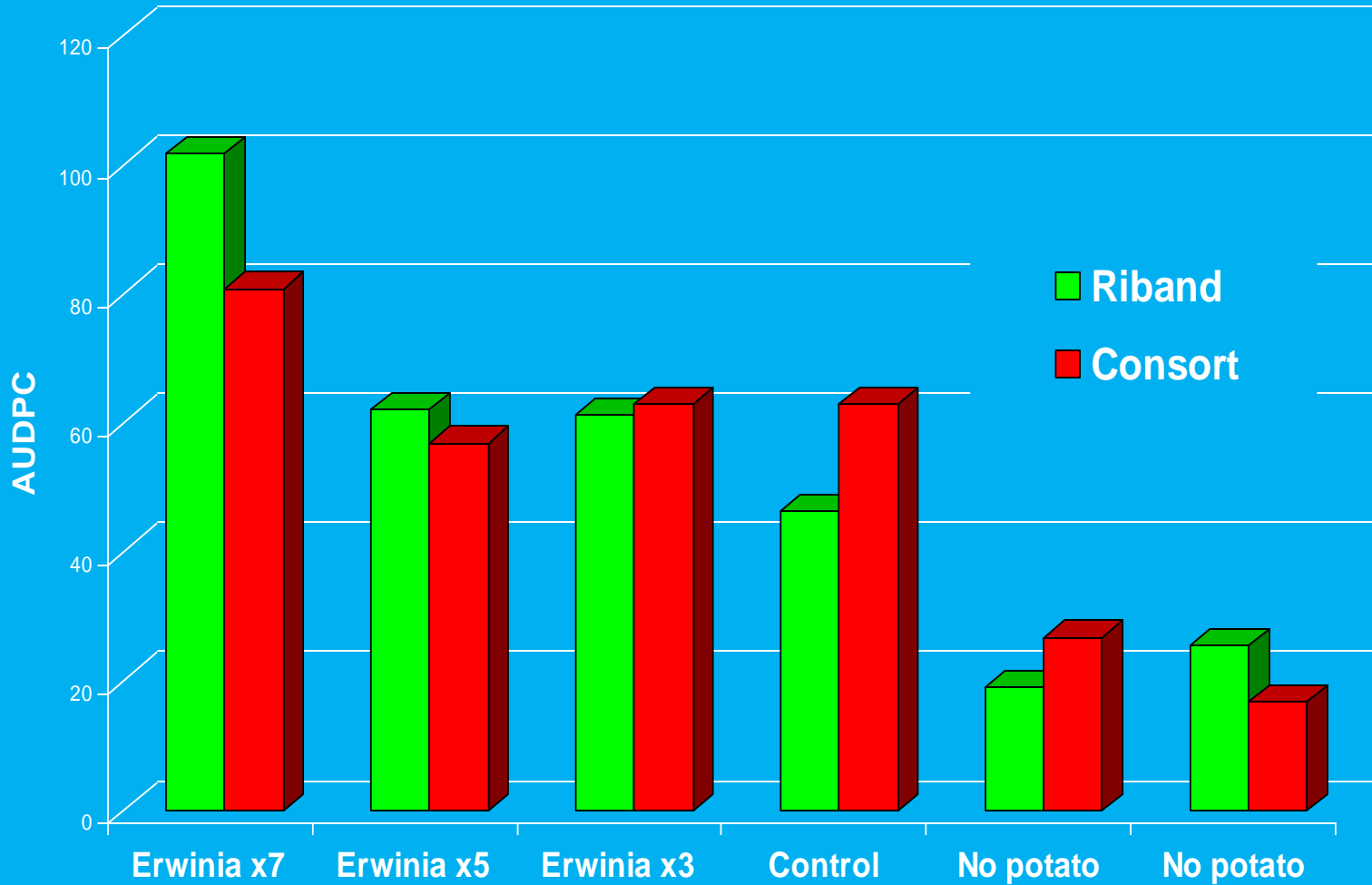


Presence of
E. coli-like
bacteria on
barley (cv. Troon)

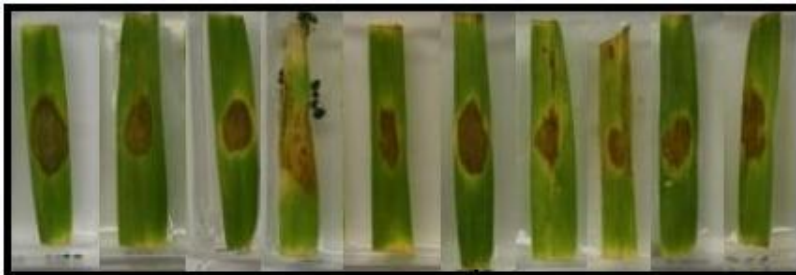
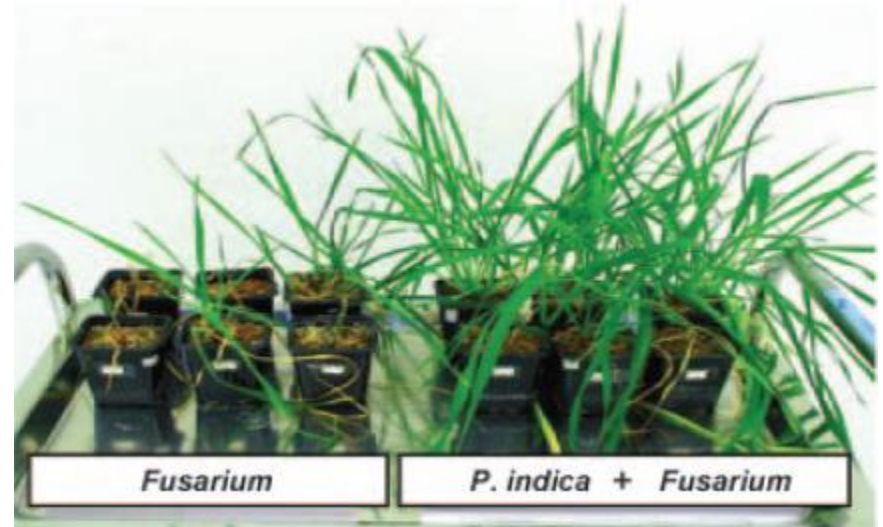
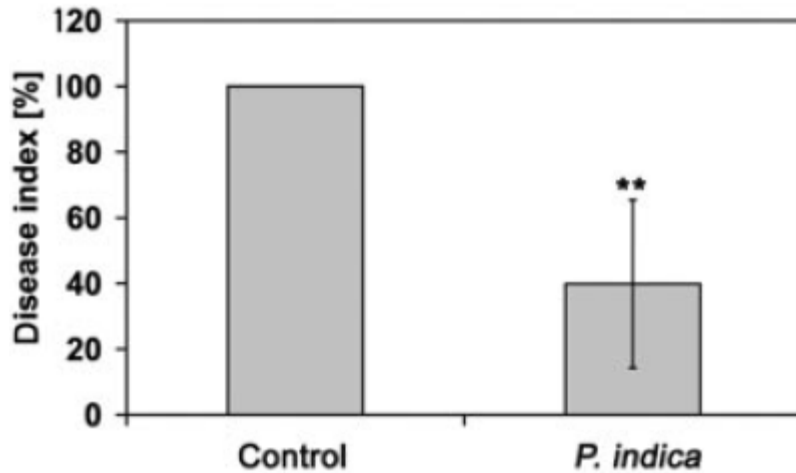
- Zoonotic bacteria can be transmitted into GROWING plants from animal sources.

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.

Effect of Blackleg on wheat mildew



Piriformospora indica (Basidiomycetes)



Control

- Increased biomass
- Salt tolerance
- Mildew resistance

Pi-infected



Mutualist/symbiont viruses and complex symbioses

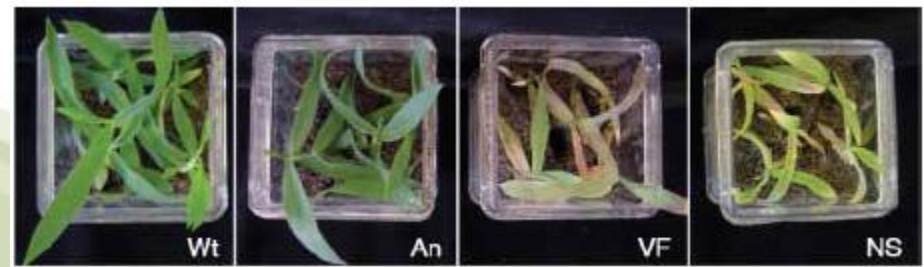


Viruses, normally obligate intercellular parasites, can be beneficial to hosts

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

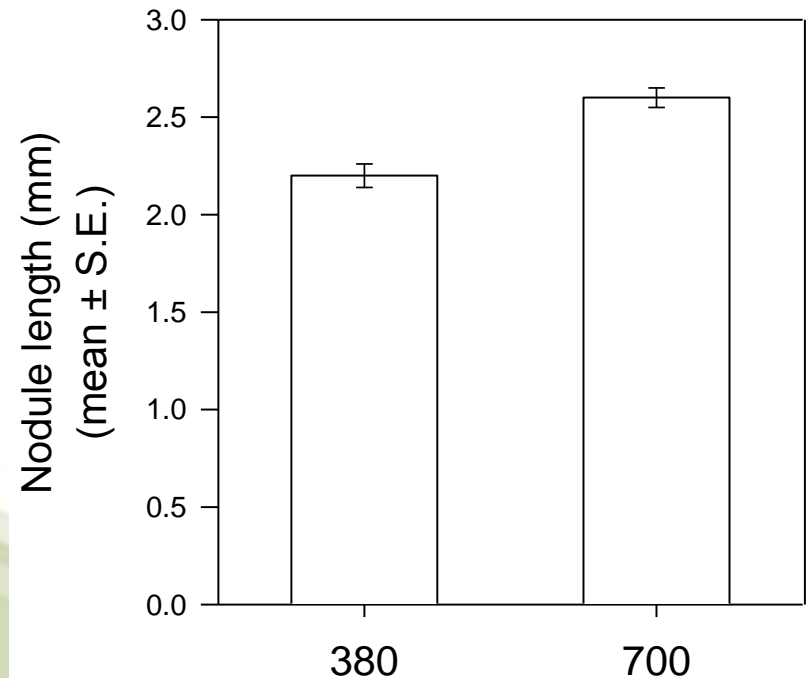
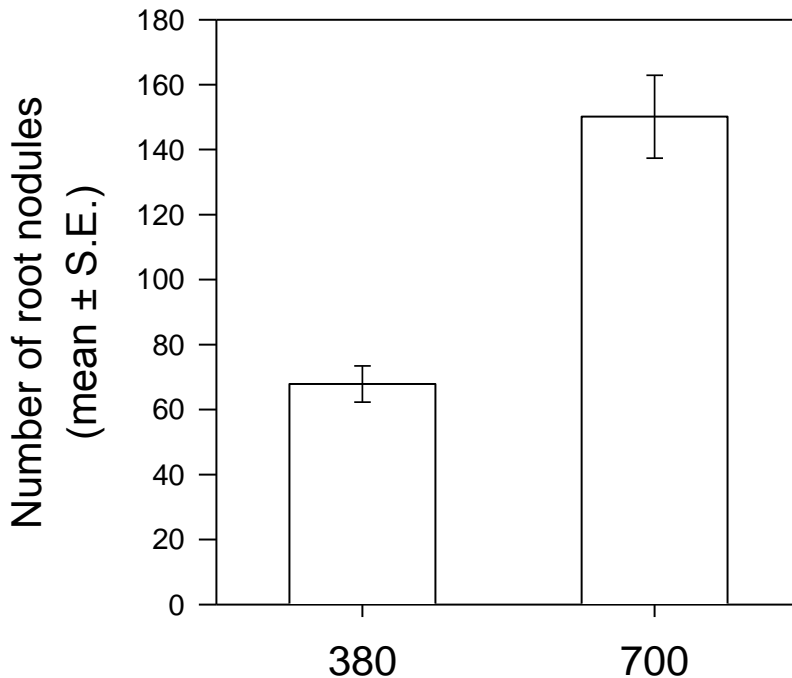
A Virus in a Fungus in a Plant: Three-Way Symbiosis Required for Thermal Tolerance. Márquez et al. 2007. Science 315, 513

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



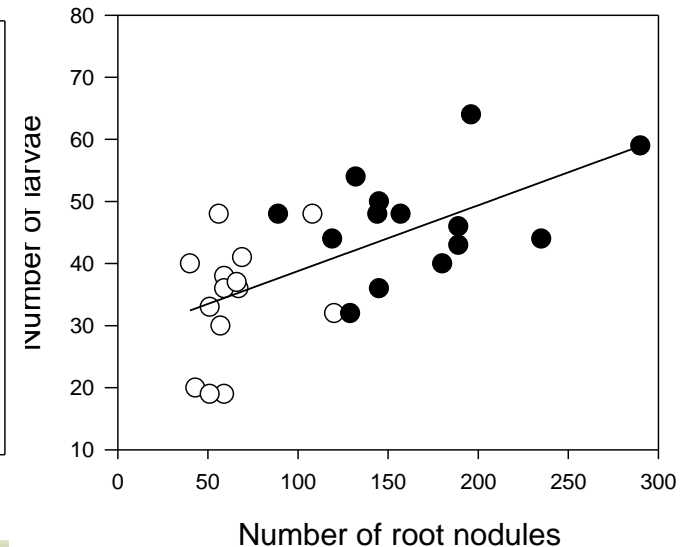
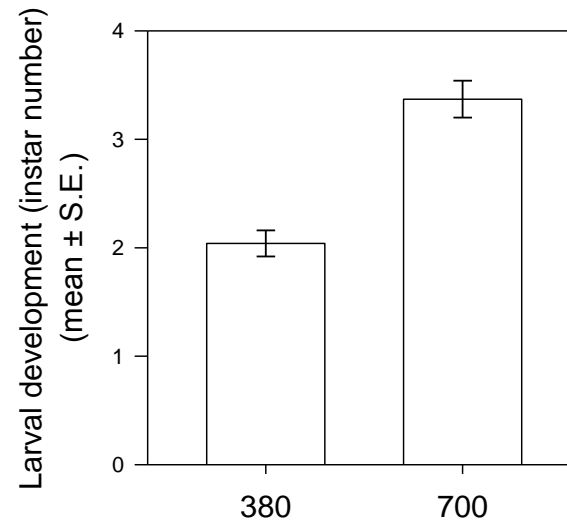
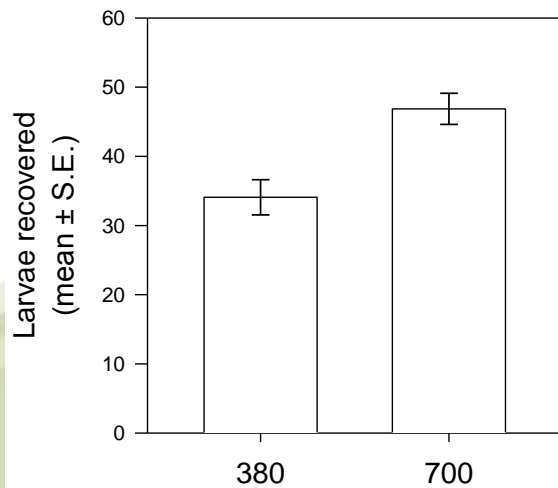
Complex interactions... Clover growth

- In general elevated CO₂ 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 CO₂ results in more weevils which develop faster



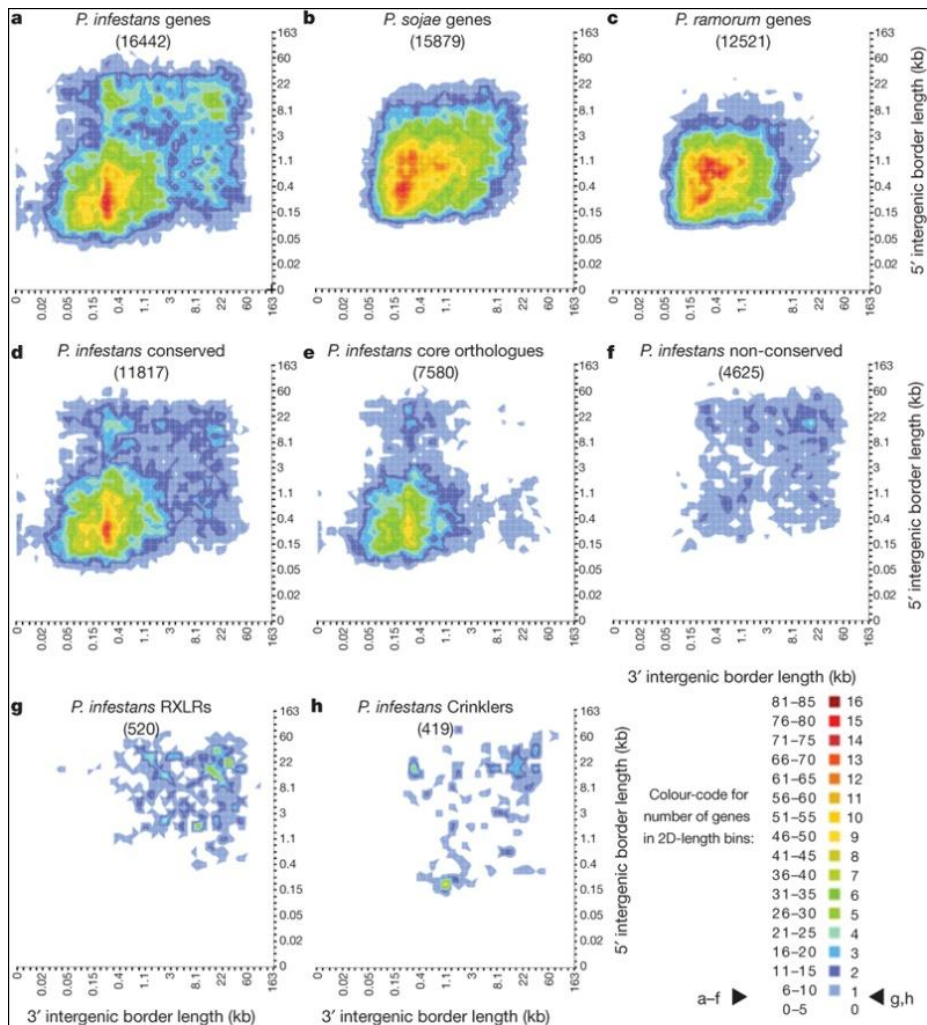
Host resistance for effective disease control

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



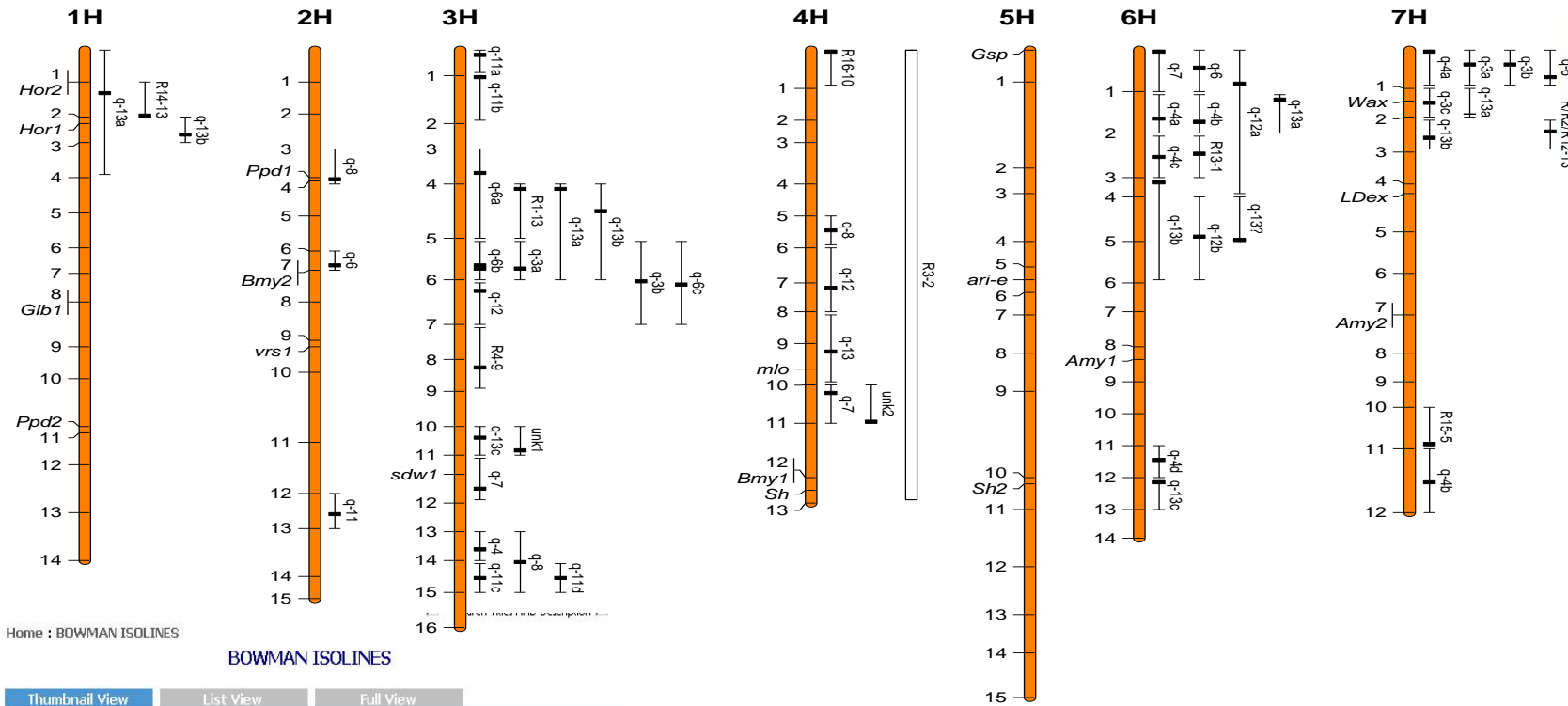
Pathogen has genome architecture that generates effector gene diversity

Haas et al., Nature, 2009

<i>P. infestans</i> 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












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

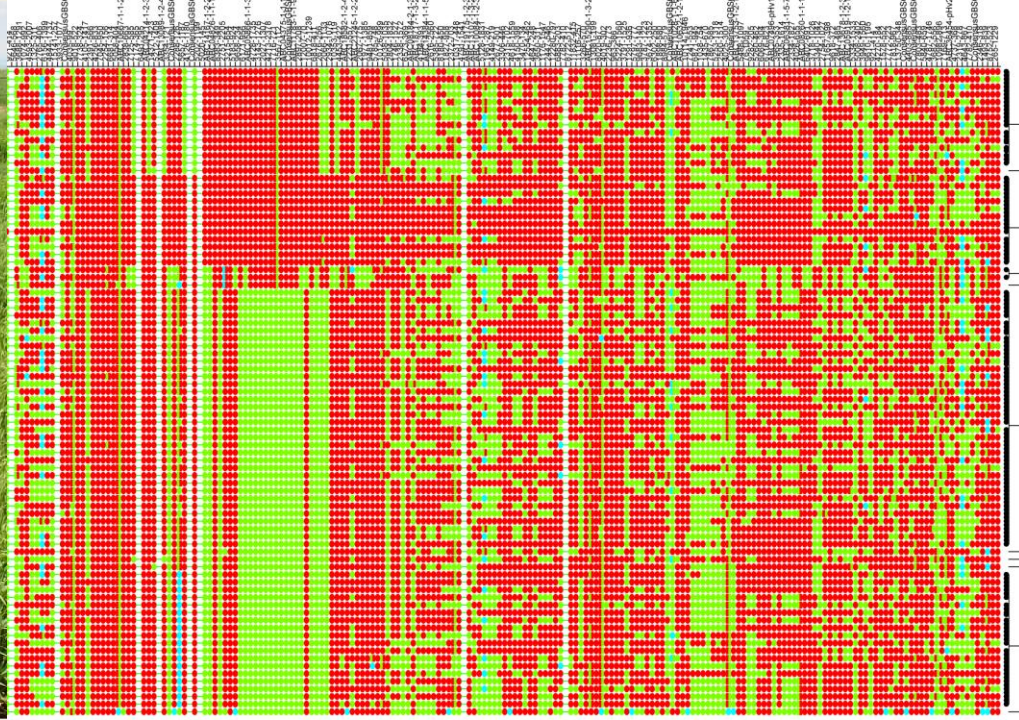


Home : BOWMAN ISOLINES

BOWMAN ISOLINES

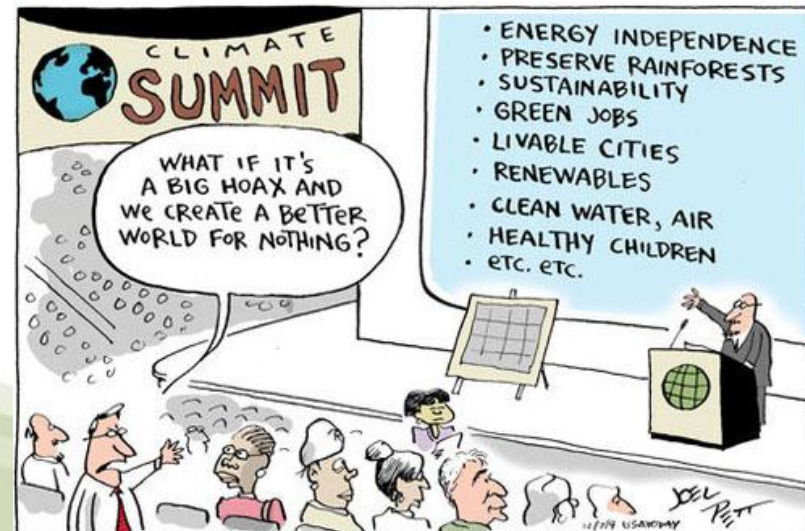
Thumbnail View	List View	Full View
		
Brachytic 2 (ari-l.3) BW050	Brachytic 2 (ari-l.3) BW050	Breviaristatum-r (ari-r.14) BW056
		
Breviaristatum-r (ari-r.14) BW056	Breviaristatum-r (ari-r.14) BW056	Breviaristatum-s (Ari-s.265) BW057
		
Breviaristatum-s (Ari-s.265) BW057	Black lemma and pericarp 1 (Blp1.g) BW060	Black lemma and pericarp 1 (Blp1.g) BW060
		
Black lemma and pericarp 1 (blp2.b) BW062	Black lemma and pericarp 1 (blp2.b) BW062	Non-blue aleurone xenia 3 (blx3.c) BW064

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



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**



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