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Rust-proofing wheat for changing climate

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Climate change and plant diseases

Only three empirical studies on field crop diseases under realistic Free to Air CO₂ Enrichment (FACE) – all since 2006!

1. **RiceFACE:** At high CO₂ rice was more susceptible to *Magnaporthe* leaf blast, but not to panicle blast (Kobayashi *et al.*, 2006)
2. **SoyFACE:** High CO₂ reduced *Peronospora* downy mildew but increased *Septoria* brown spot (Eastburn *et al.*, 2009)
3. **AGFACE:** High CO₂ increased *Fusarium* biomass but this effect was modified by wheat variety and soil water (Melloy *et al.*, 2010)

Other FACE studies of diseases are on forest and native tree species

The limited and variable findings do not allow generalisations

Very limited research on crop diseases under realistic field conditions

Outline of presentation

- Aspects of climate change relevant to this talk
- Climate change influence on wheat-Puccinia interaction
 - effects mediated via changing host plant
 - effects mediated via changing pathogen / host-pathogen interaction
 - effects on pathogen evolution
- Climate change and geographical distribution of wheat
 - effect on management options
- Future research needs to rust-proof wheat

No empirical research on wheat rusts: projections are best guesses

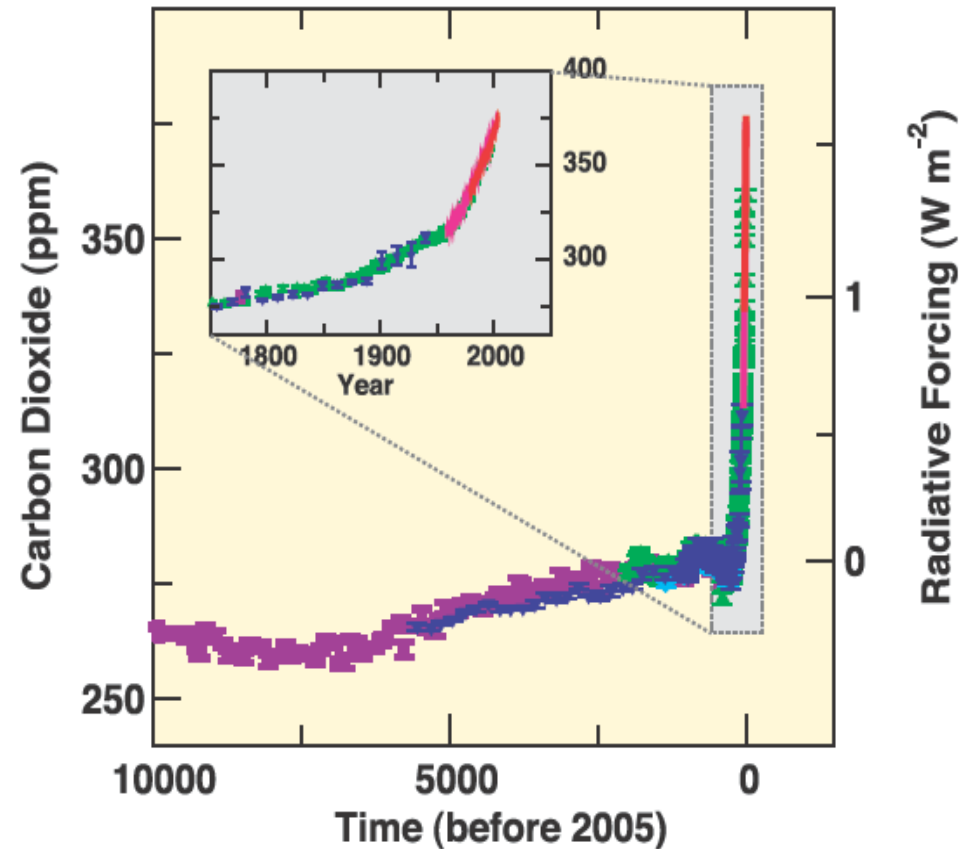
Rising CO₂ and its consequence

Past 420,000 yr - 180 & 280ppm, but 2004 - 377ppm; >31% rise since 1750

The atmosphere traps radiatively active gases (eg. CO₂, CH₃, H₂O)

Radiative forcing is the influence in the balance of incoming & outgoing energy in the Earth-atmosphere system.

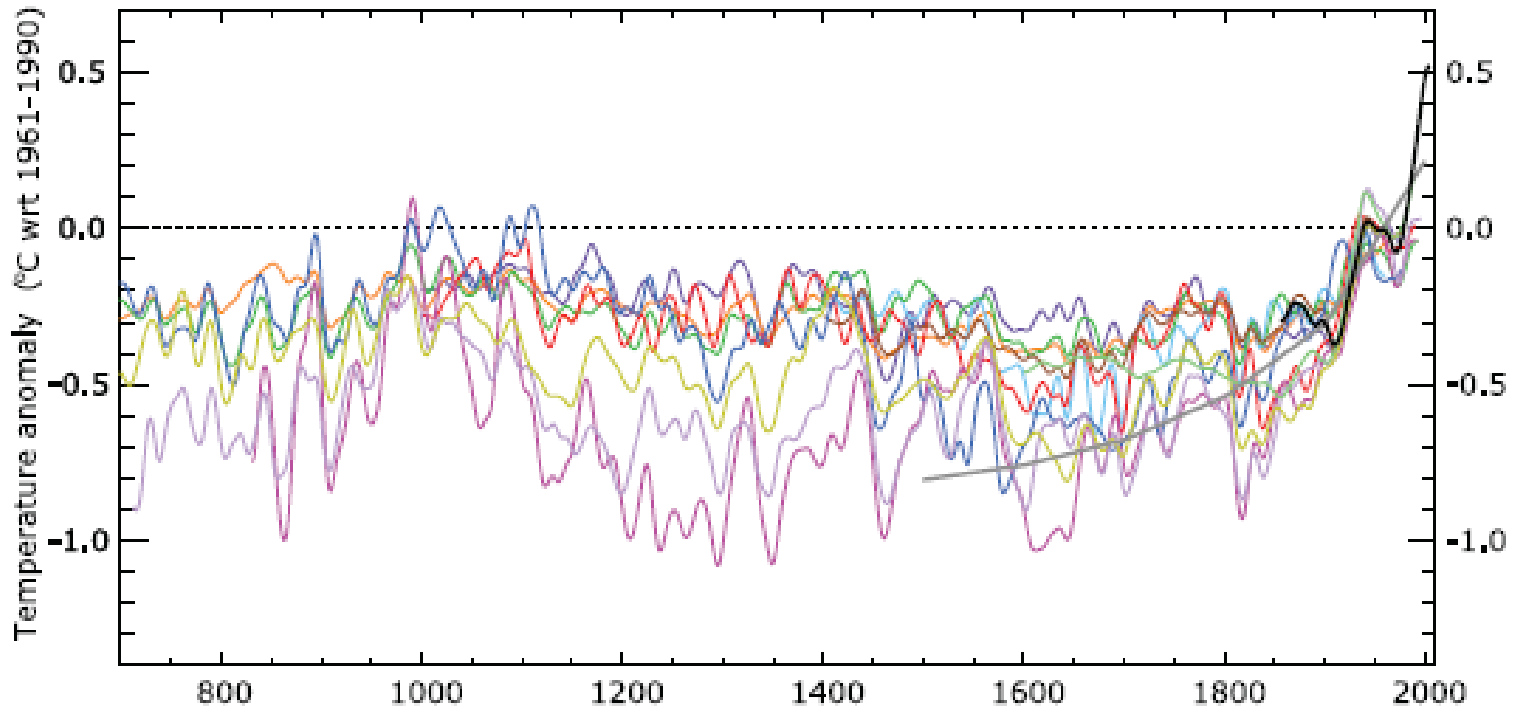
Positive forcing warms the surface and negative forcing cools it.



This is the 'greenhouse effect' without which the Earth will be a frigid -18C

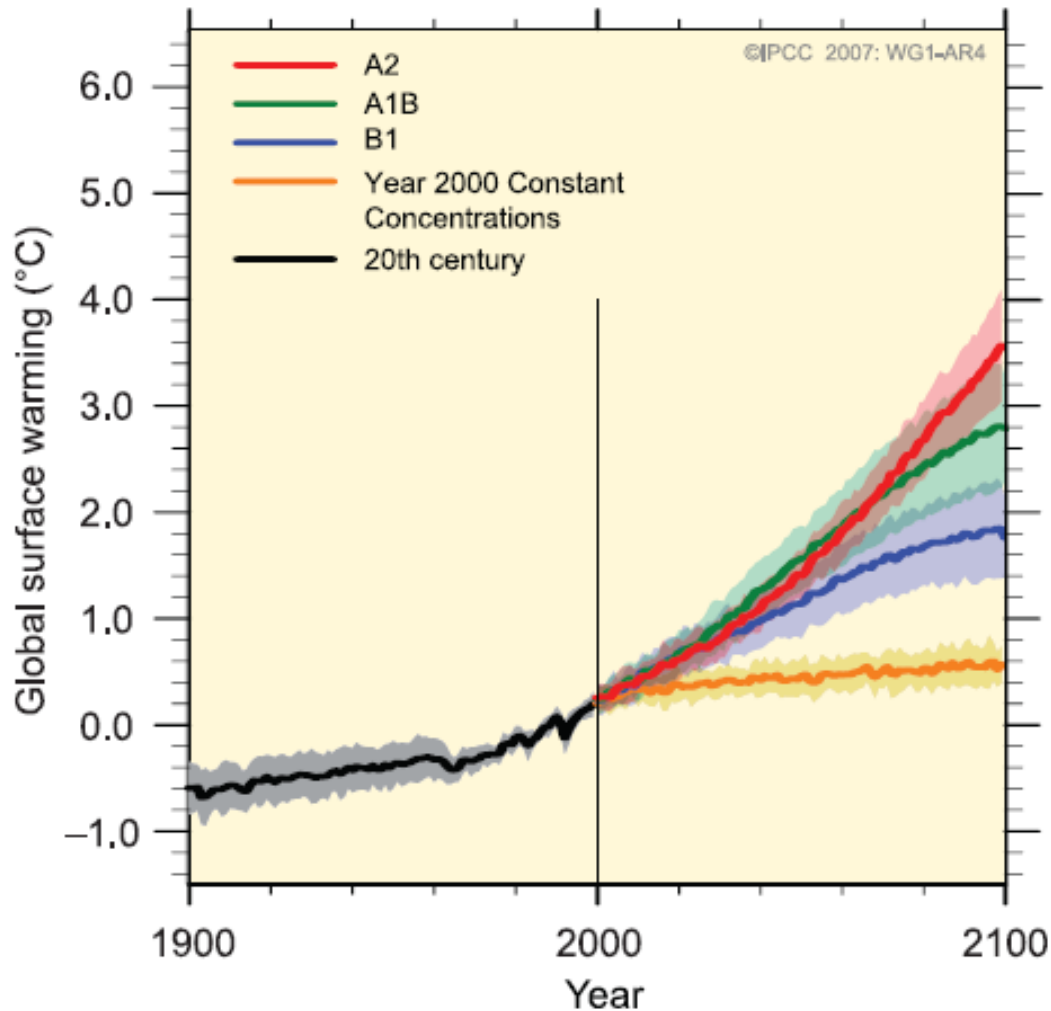
The IPCC (2007) concluded:

NORTHERN HEMISPHERE TEMPERATURE RECONSTRUCTIONS



Climate models agree that it is now warmer than it has ever been over the past 1250 years

Emission scenarios & Global temperature



- **Red [A2]: business as usual: up to 4C warming in next 100 yr**
- **Yellow: emission held at 2000 level, 10 yr ago**
- **More realistic scenarios project rising emissions**

Rising CO₂, temperature and wheat

- Morphology, anatomy, physiology and chemical composition change
- CO₂ fertilization effect increases biomass, yield, canopy size by up to 30%
- There are more susceptible tissue in enlarged canopy
- Microclimate is modified in a dense canopy
- Some rust resistance genes become less-effective at higher temperature [*Sr15*], and some are more effective [*Yr18*]; in the UK, 50% of leaf rust resistant varieties were effective at 10°C but not at 25°C & vice versa

There is extensive literature on elevated CO₂, temperature and wheat

Plants function differently at high CO₂

Anatomy, morphology & physiology

Waxes, leaf cuticle, silicone

Lignin, non-structural carbohydrates, phenolics

Leaf longevity, leaf area, mesophyll cells

Number of branches, nodes, leaves

Stomatal physiology, density & conductance

Photosynthetic carbon uptake

Nitrogen concentration, C:N ratio

Water use efficiency

Changed gene expression profiles

Many of these changes will influence Rusts

Rising temperature and wheat rusts

- *Puccinia striiformis* populations from Eastern USA before and after 2000 has different temperature and virulence profiles
- At 18°C the new population has shorter latent period and higher germination, but no difference at 12°C (Milus *et al.*, 2009)
- Strains with increased aggressiveness at higher temperature have caused recent epidemics
- Milder winter will allow over-wintering and/or early start in Canada; together with increased rainfall, over-summering of rusts will increase in parts of Australia

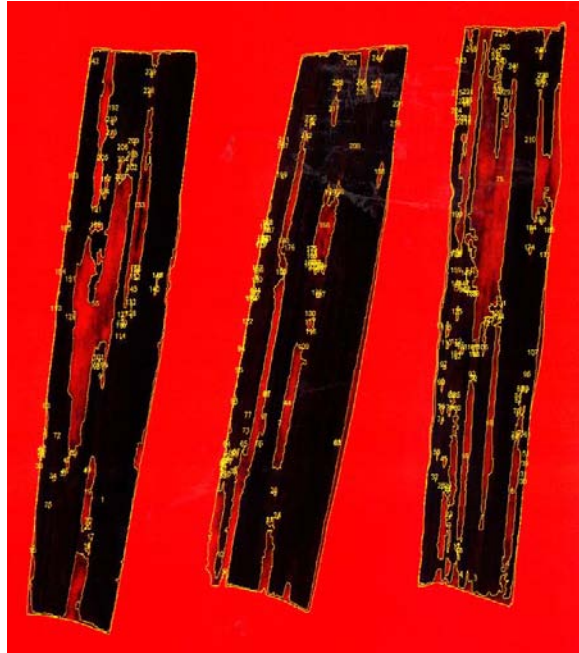
Rusts will adapt to become severe in previously unfavourable environments

Rising CO₂ and wheat rusts



- One unpublished field study from a FACE facility in Australia:
 - Susceptible and partially resistant variety, 380 and 700ppm CO₂ with/without irrigation
 - *P. striiformis* fecundity and stripe rust progress 2007 and 2008

P. striiformis Fecundity



Fecundity= Urediniospores
produced per unit pustule
area

Image Tools: The University of Texas Health Science Centre

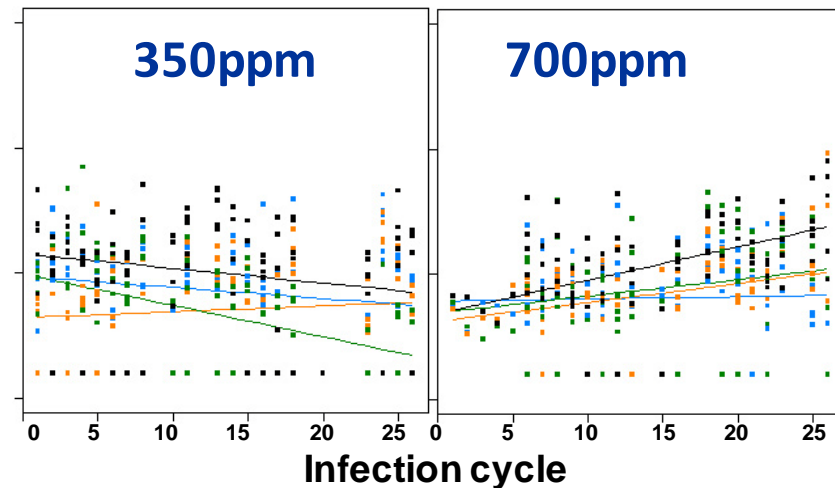
Preliminary results:

No significant CO₂ effect on stripe rust progress

**No change in urediniospore production per unit
lesion area at high CO₂**

Increased rust inoculum at high CO₂

- Even with unchanged fecundity rust inoculum will increase within enlarged wheat canopy
- An expanded growing season due to rising temperature will add to this
- Rusts may become more damaging at local and regional level
- New virulent strains evolving in one location will quickly spread



Fecundity of rubbervine rust, barley mildew, *Colletotrichum* and *Fusarium* increase at high CO₂

Fecundity keeps rising at high CO₂ in some host-*Colletotrichum* combination

Rising CO₂ and temperature will increase rust inoculum

Accelerated evolution of rust races?

- Mutation is the dominant evolutionary force despite sexual stage now known for all three wheat rusts
- In the absence of recombination rust populations maintain high levels of heterozygosity by sequential mutation
- Mutation frequency (avirulence to virulence) 8.3×10^{-6} for heterozygous locus; 6.9×10^{-11} for homozygous locus
- Large population size and increased uredinial generations will increase probability of mutation (new races sooner?)
- Speculative in the absence of empirical/modelling studies

Increased population size and uredinial generation can accelerate evolution

Geographical distribution of wheat will change

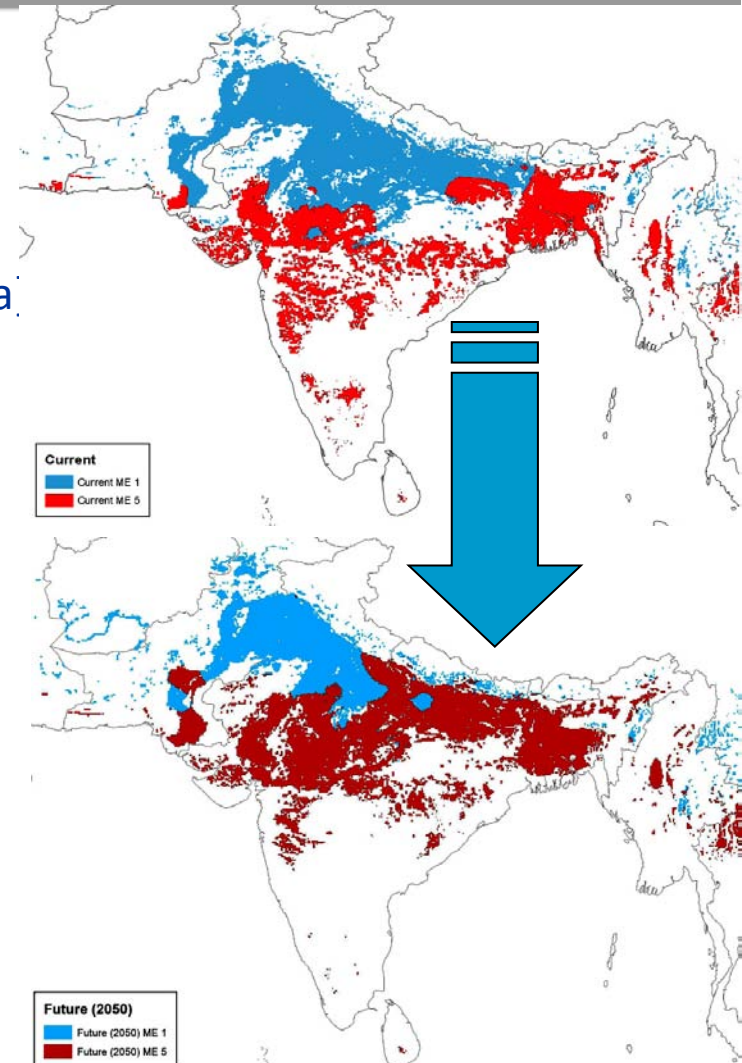
Wheat growing regions: 12 Mega-environments

ME1:

Indo-Gangetic plain, Nile Valley & NW Mexico [32Mha]
currently high yield potential

By 2050 >50% area may become heat-stressed short-season ME5 (Ortiz *et al.*, 2008)

- If wheat suffers from chronic stress, necrotrophs will become more important than rusts
- Breeding targets will need to reflect changing importance of diseases
- Rusts distribution speculative – no published study



Economic importance of rusts will change

Rust management options

- Efficacy of fungicides may change
 - more frequent application if rising rainfall wash residue
 - changed wheat physiology and metabolic rate will influence uptake, translocation and efficacy
 - large population increase the risk of fungicide resistance
- Some rust resistance genes will be less-effective with rising temperature
- Management to reduce production and dissemination of rust inoculum will become more important
 - destroying green bridge (volunteer wheat, triticale)

Efficacy of management options will change

Summary: potential effects

1. Risk of increased loss from wheat rusts

- increased over-wintering, extended growing season
- reduced fungicide efficacy and/or increased application
- larger 'green bridge' as inoculum reservoir

2. Risk of new rust race evolving faster

- increased uredinial generations with extended wheat season
- enlarged canopy with microclimate conducive to rusts

3. Risk of reduced effectiveness of rust resistance

- temperature-sensitivity of some rust resistance genes; changing physiology at high CO₂ altering effectiveness of rust resistance
- better-adapted and more damaging rust strains with rising temperature

Economic significance of wheat rusts will change

The future: what can we do?

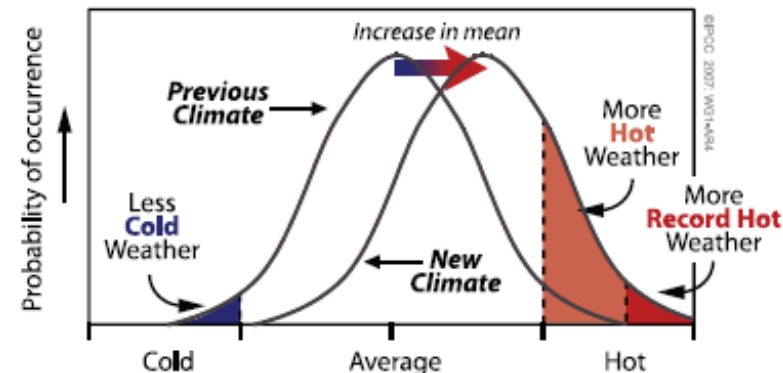
We [wheat researchers] can not control climate

- Shifting of temperature frequency curve to warmer end
- More extreme warm and less frequent cold weather
- Increased frequency of drought, flood, hurricane, tornado, heat waves, etc.

OR

Change the biology of wheat rusts

- Naturally adapting to a changing climate
- Overcoming rust resistance, perhaps with increasing frequency



ALL we can do is to rust-proof wheat for future climate

- By increasing the adaptive capacity of wheat and its farming system

Research needs: rust-proof wheat

A: impact assessment and evaluation

1. Impact of changing climate on wheat rusts
 - Climate matching and process-based models
2. Efficacy of current rust management strategies
 - Efficacy of *mfg* and *mff* under rising CO₂- temperature
3. Influence of range shift on farming systems
 - Changing farming system and epidemiology

Both empirical and modelling research

Research needs: rust-proof wheat

B: Increased adaptation

1. Biology of wheat-rust interaction in FACE
 - Identify and exploit weakness in the pathogen
2. Rust evolution under rising CO₂ and temperature
 - Changing pathogen fitness under sequential infection cycles
3. Factor in climate change in breeding for rust resistance
 - All current varieties will be grown in a changed climate
4. Rust epidemiology under changing farming systems
 - Inoculum: production, dispersal, survival etc.

Mainly empirical research

Thank you

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