Tougher crops for a warming world

THE UNIVERSITY OF ADELAIDE AUSTRALIA

Research Tuesday Lecture Series

8 May 2007

By Mark Tester
Australian Centre for Plant Functional Genomics
School of Agriculture, Food & Wine

Life Impact The University of Adelaide

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http://plantscience.acpfg.com.au

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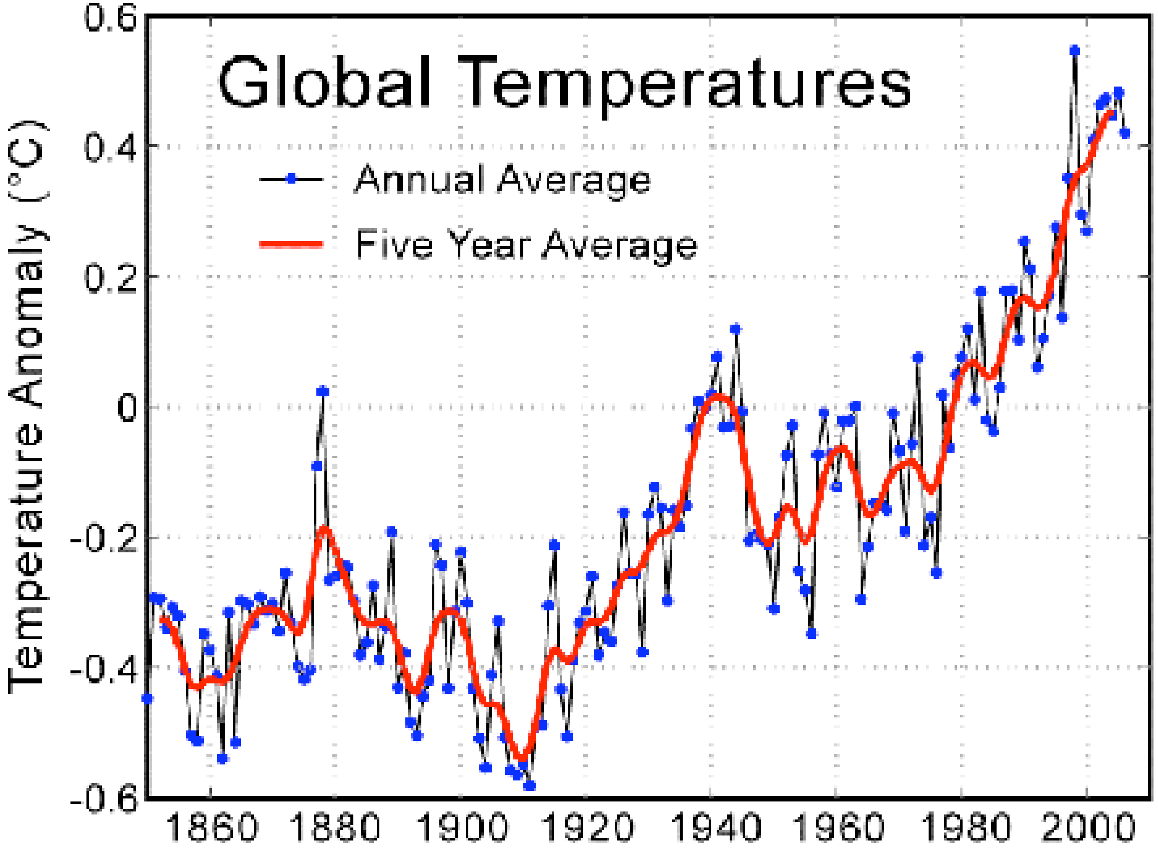
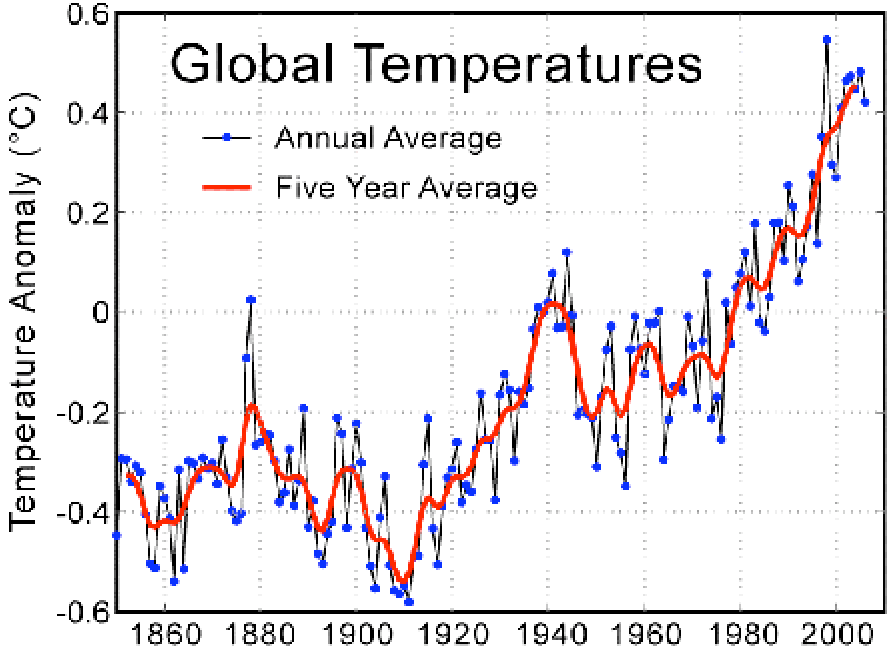
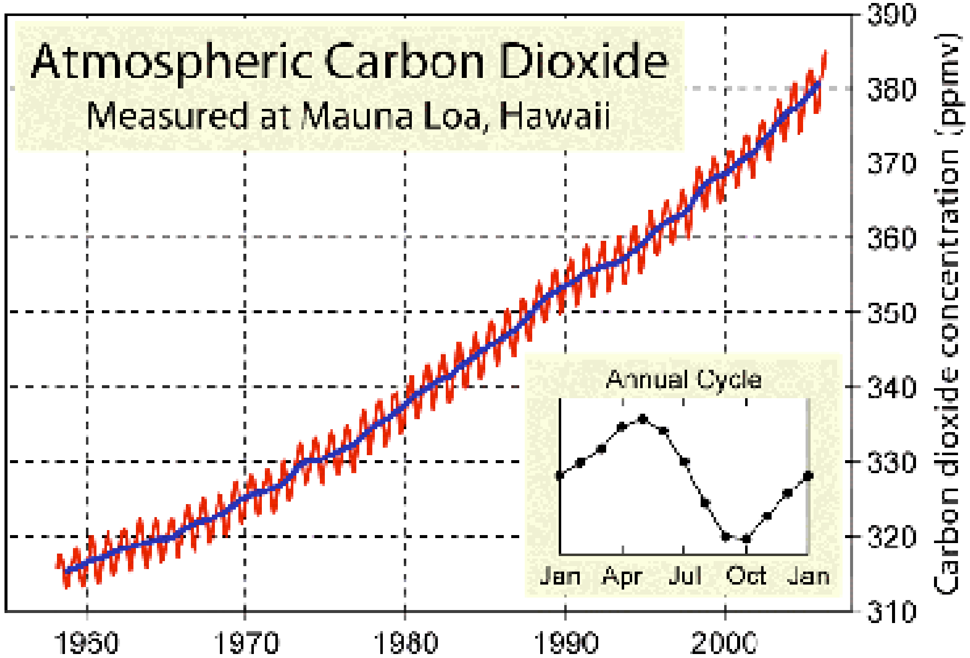
The warming world

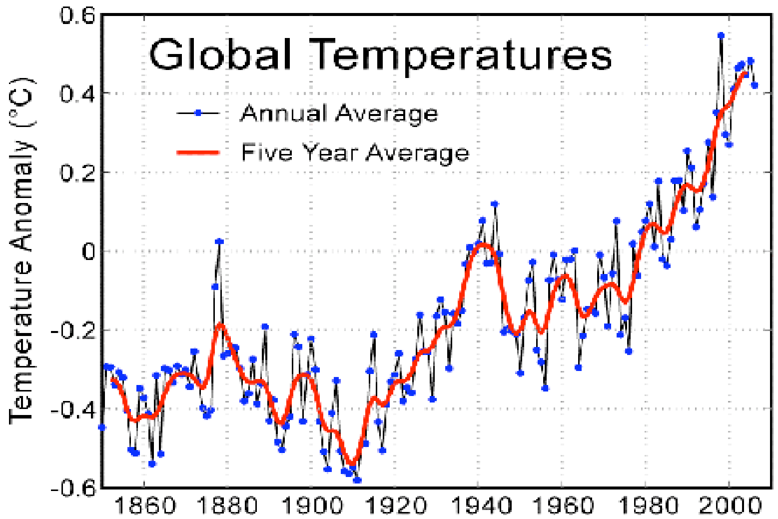


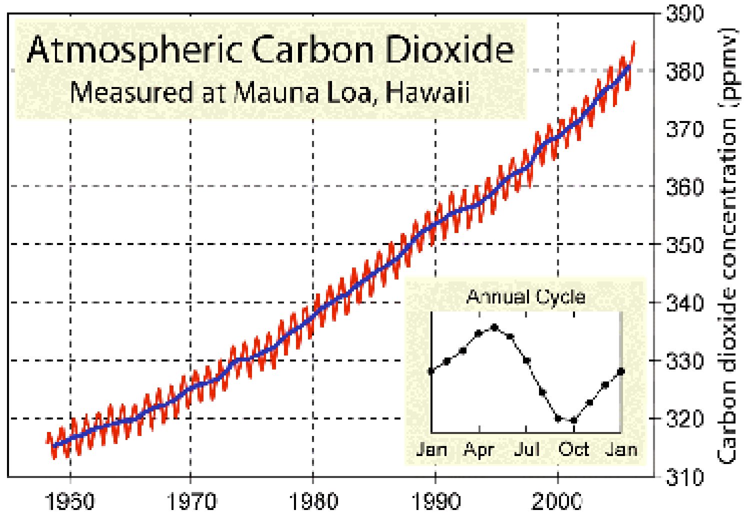
Rising CO_2 is correlated with this rise in temperature

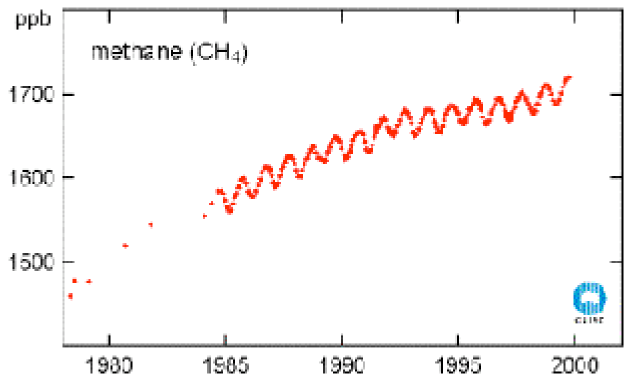


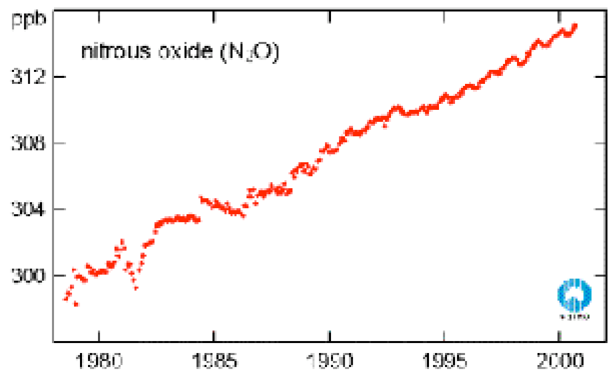


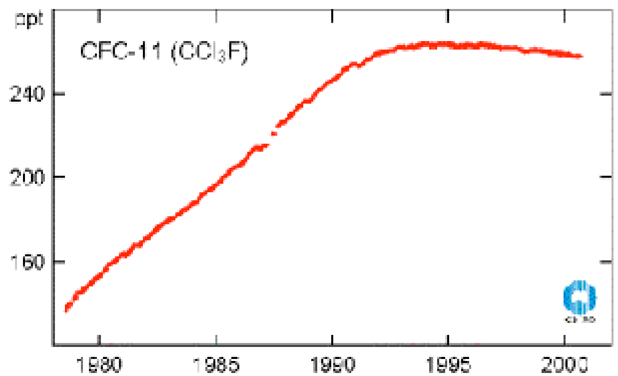
Many pollutants are correlated with this rise in temperature











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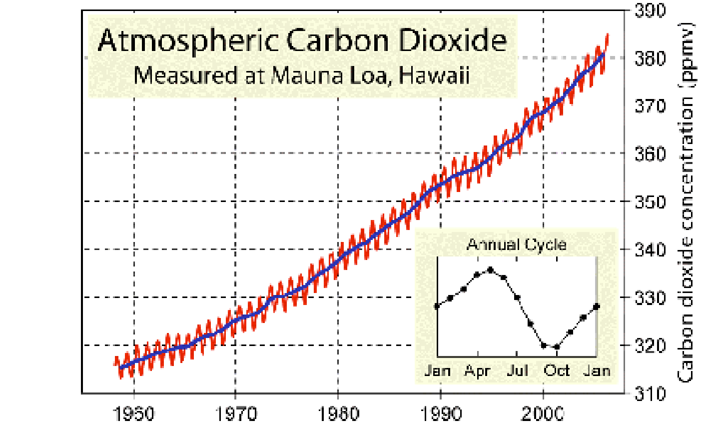
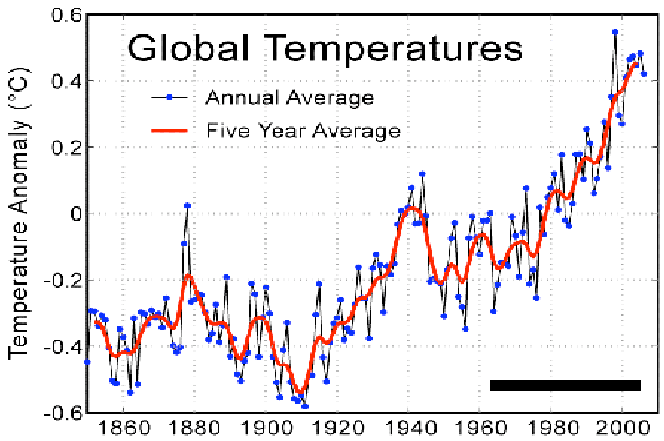
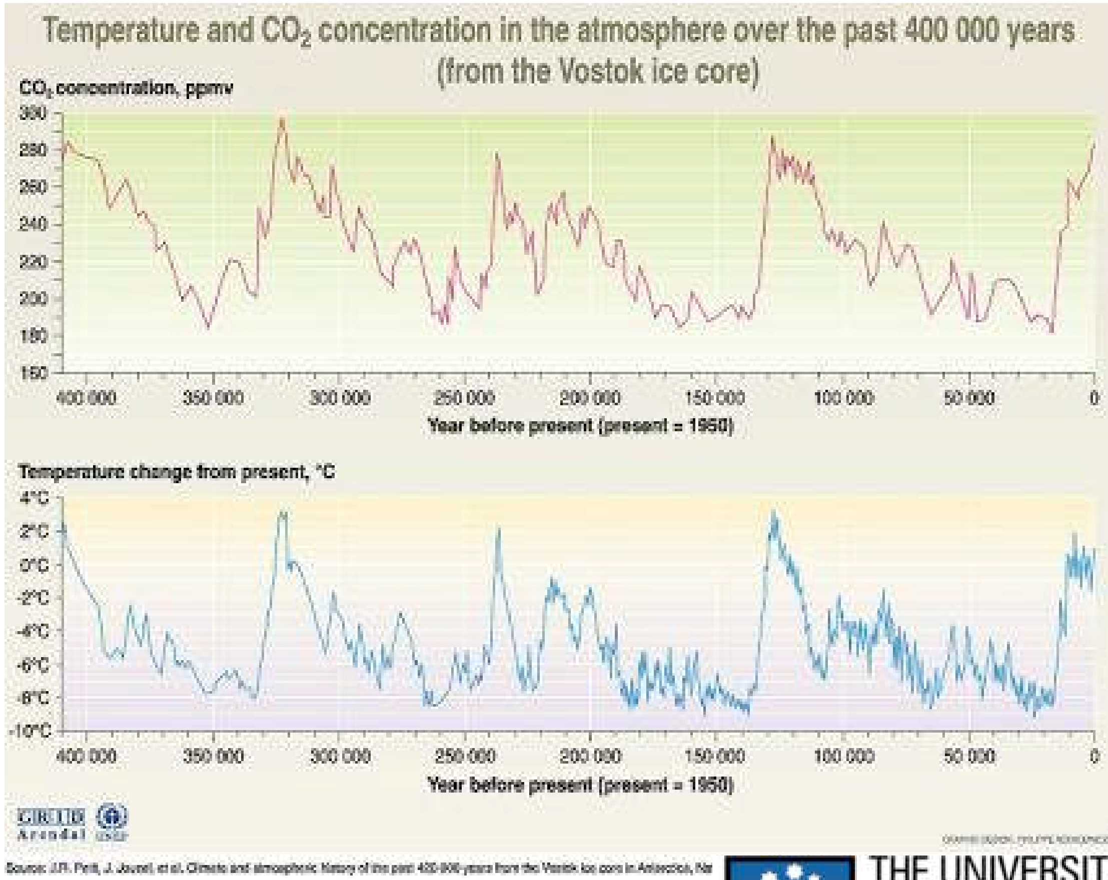
Rising CO_2 correlated with this rise in temperature for 400,000 years







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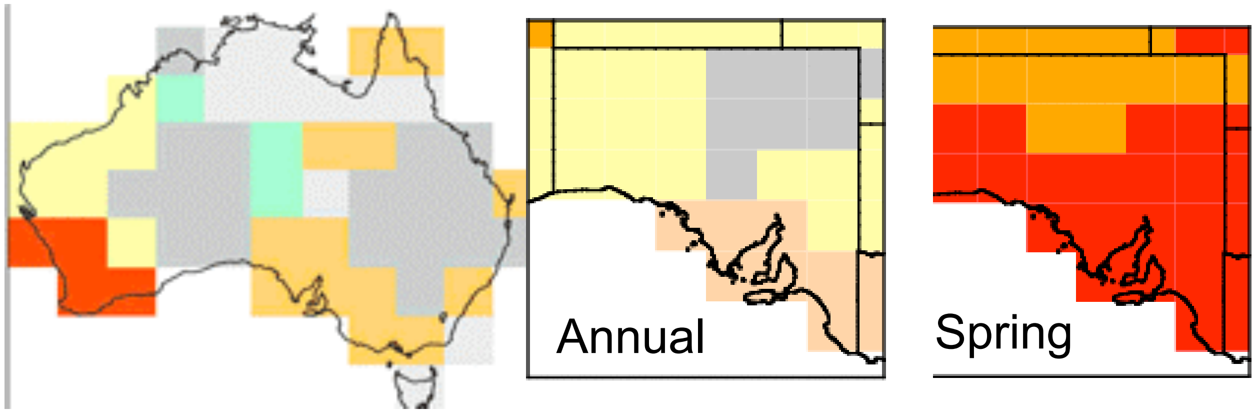
Impacts of climate change on Australia

Australia will be hotter and drier

Over most of the continent, annual average temperatures will be 0.4 to 2°C greater than 1990 by 2030

Evaporation will increase over most of the country, adding to moisture stress on plants, and to drought

http://www.cmar.csiro.au/e-print/open/holper_2001b.html



Impacts of climate change on Australian agriculture

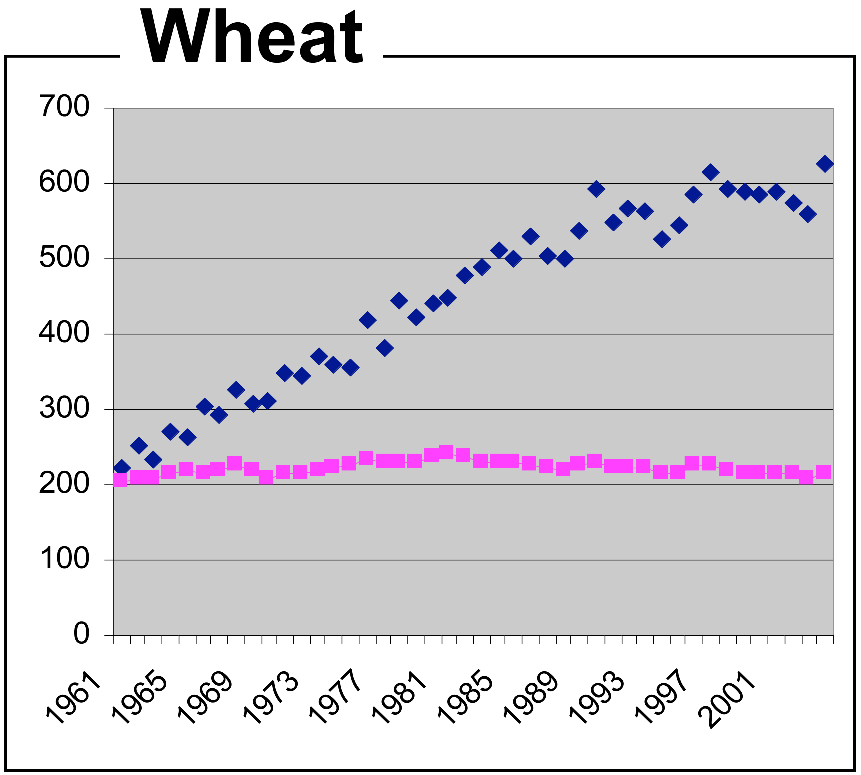
Ross Garnaut, International Food Policy Institute, CGIAR

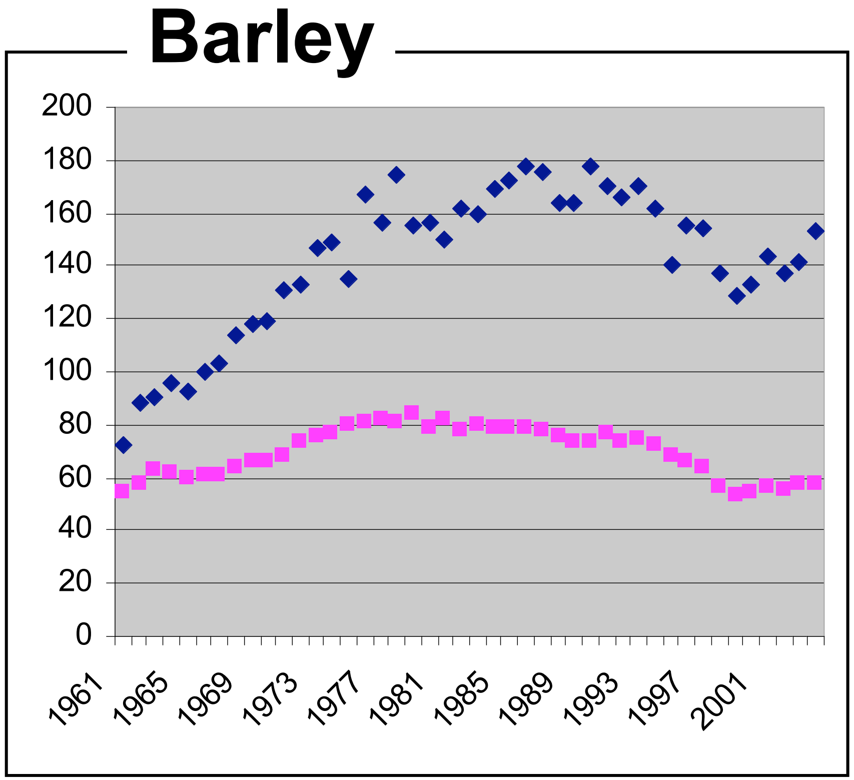
ABC Radio National, ‘PM’ - Monday, 30 April, 2007

‘it's a more serious problem in Australia than in any other developed country.’

http://www.abc.net.au/pm/content/2007/s1910460.htm

We already have a problem

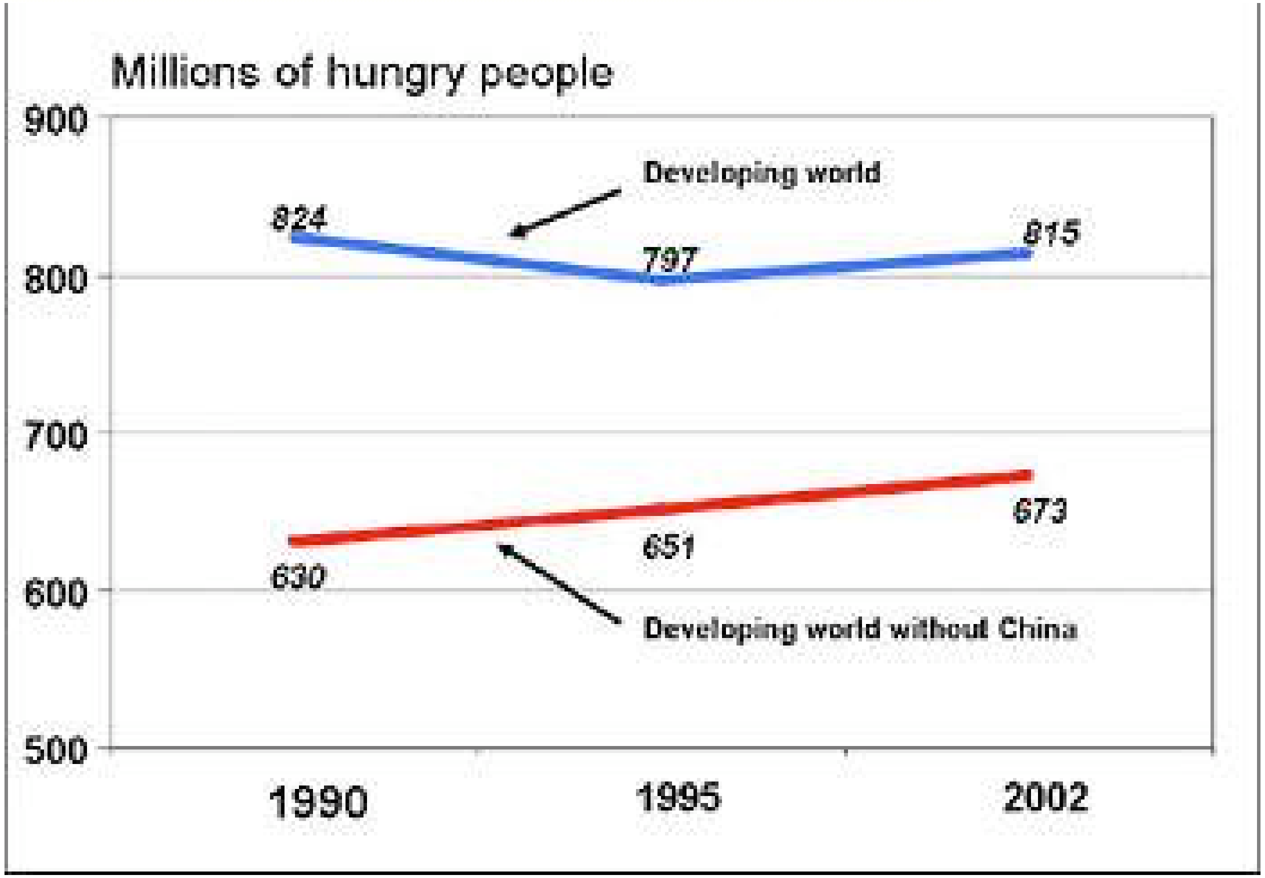




Grain production growing modestly, population growth still >1% p.a

Source: FAO (2005)

We already have a big problem



7% rise

Source: International Food Policy Institute. Dec, 2005

Global food production must increase

….even without global climate change, biofuels, international politics, other environmental degradation

Global environmental change

One-third of world food produced under irrigation

– water supplies critically threatened in much of the world
– amount and quality

So, we need to increase food supply

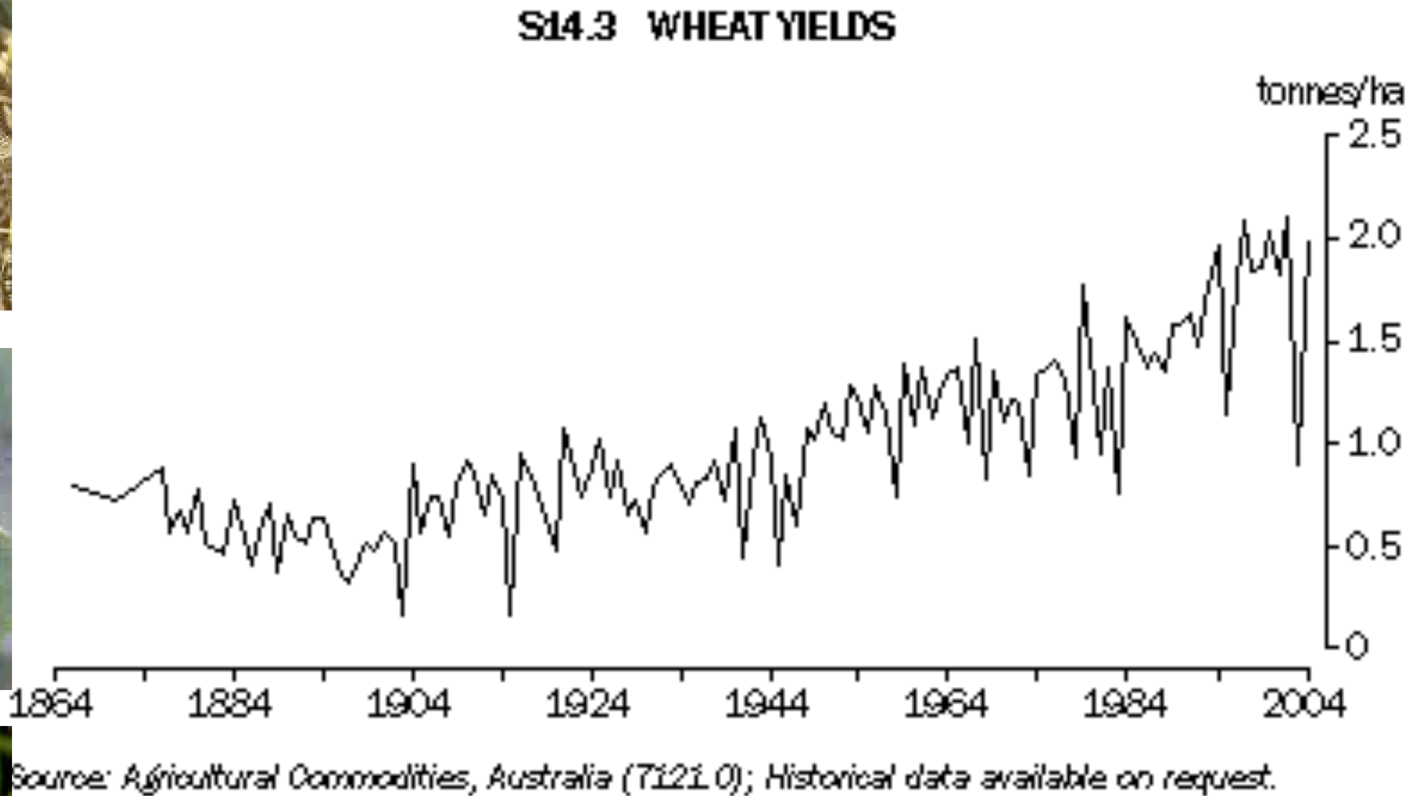
- few opportunities to increase area under cultivation
- little theoretical chance to increase ‘yield potential’
- need to increase ‘yield stability’

Many factors limit wheat yields

Rusts and other pathogens and pests
- a perpetual challenge
- breeders keep pace

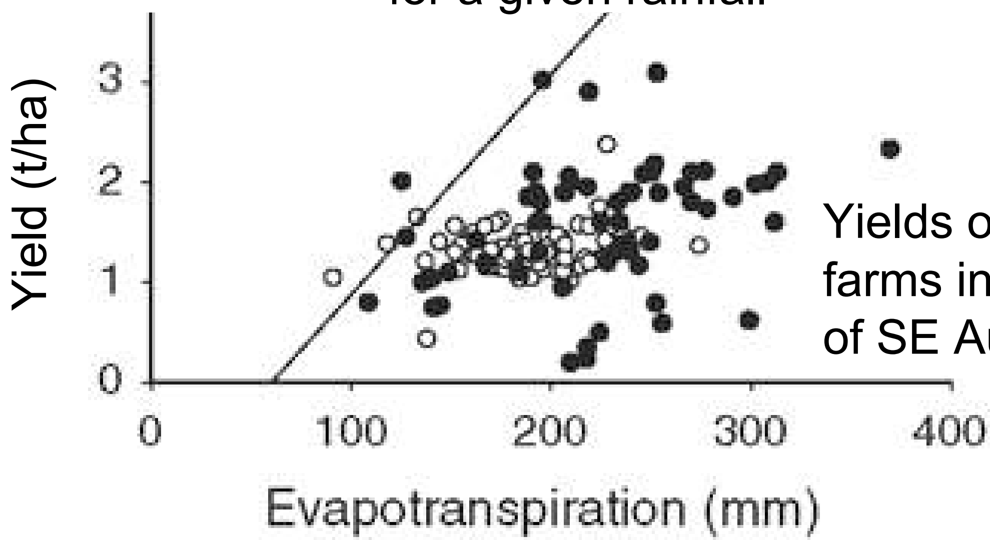
Abiotic stresses
- drought
- salinity
- frost

Wheat yields affected by rainfall



Source: Australian Bureau of Statistics, 2006

Drought is not the only abiotic stress limiting wheat yields



From Sadras & Angus (2006)
Aust J Agric. Res. **57,** 847-856

Potential Transient Salinity and Subsoil Constraints

(GRDC Project UA463, Supervisor Dr. P Rengasamy)

Pichu Rengasamy

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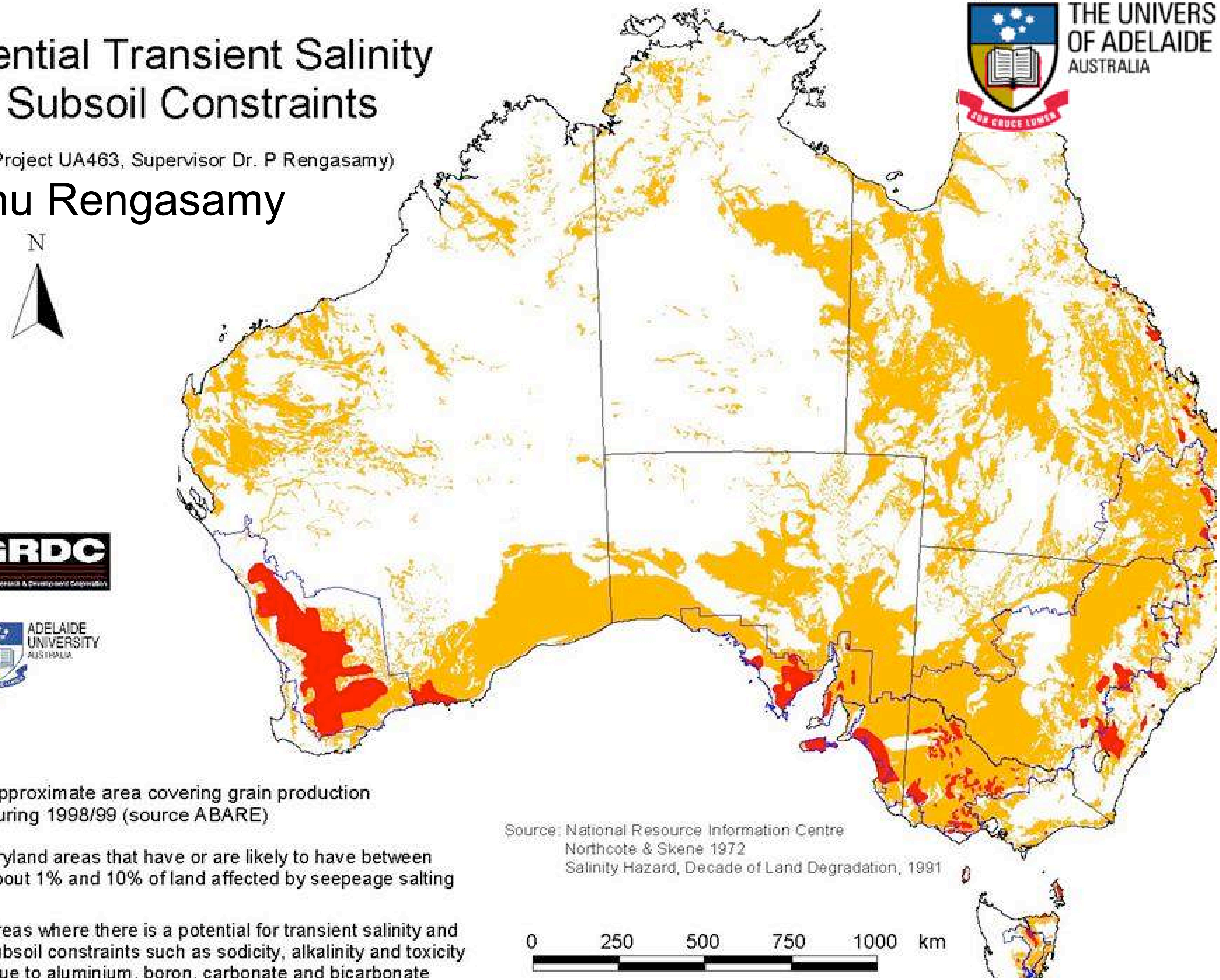


Approximate area covering grain production during 1998/99 (source ABARE)

Dryland areas that have or are likely to have between about 1% and 10% of land affected by seepage salting

Areas where there is a potential for transient salinity and subsoil constraints such as sodicity, alkalinity and toxicity due to aluminium, boron, carbonate and bicarbonate

Salinity is an important problem

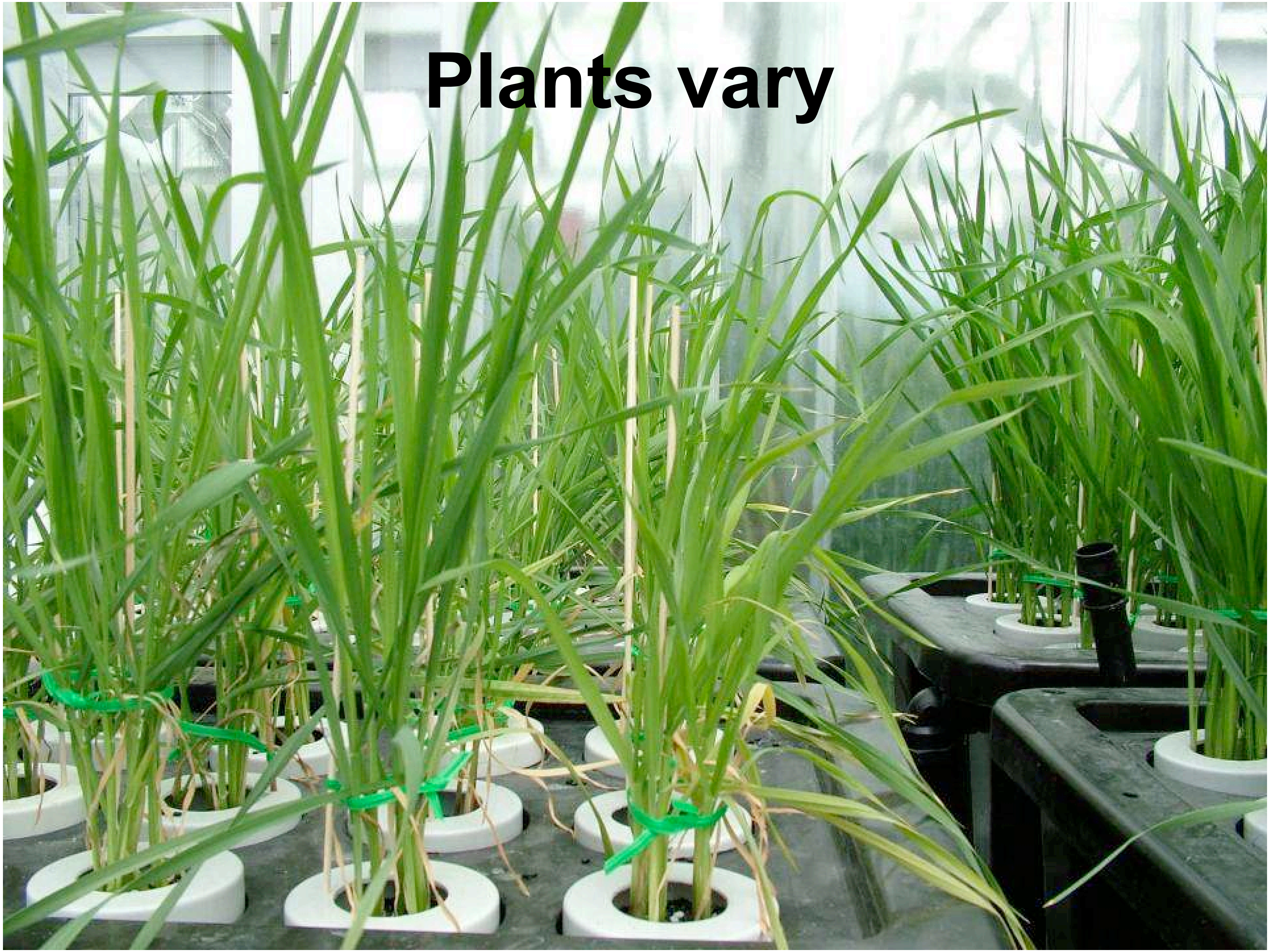
Salinity toxicity a major limitation of crop production
– 5.7m ha affected

A growing problem
– estimate 17m ha by 2050

Wheat – 69% of crop affected by primary salinity
(ACPFG) 69% of 10% of $3bn exports = $200 million p.a.
[total grains industry production > 40m tonnes, value >$8bn]

Plant based solutions main viable option

Plants vary




Primary salinity – ‘subsoil’ salinity
Some wheat can cope better than others
David Cooper

Salinity tolerance

Main toxic ion in saline soils is Na^+

Main site of Na^+ toxicity is the leaf

Two main strategies to maintain growth in high Na^+

- Exclude Na^+ from the leaves

- Tolerate Na^+ that cannot be kept out of leaves

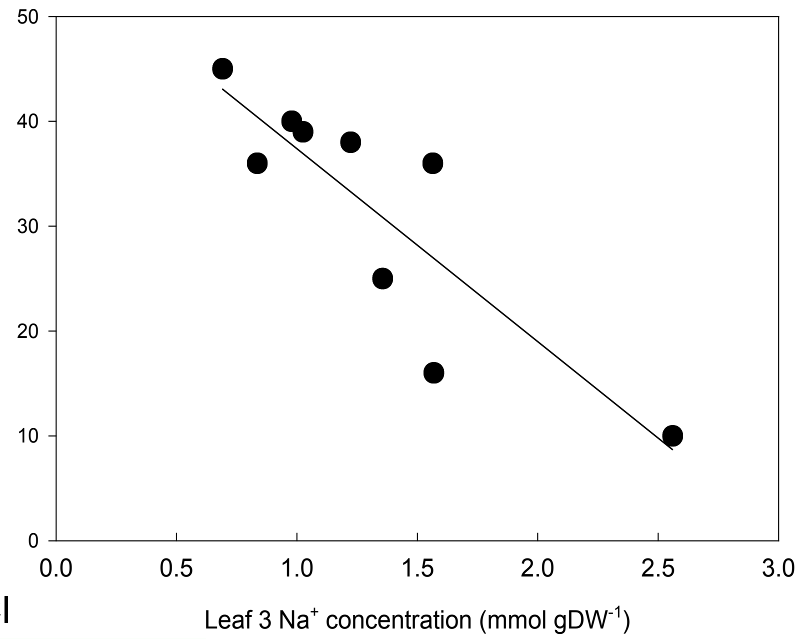
Salinity tolerance research

The primary research driver

A major component of salinity tolerance is Na^+ exclusion

A salt tolerant plant is one that excludes more Na^+ than a salt sensitive plant

- especially in wheat, barley, rice



Relationship between 10d old leaf 3 [Na^+] and shoot dry wt at 24 d in various durum wheat lines grown in 150 mM NaCl

Munns & James (2003) *Plant Soil* **253,** 201-18

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Forward genetics
Discover novel variation

Screen near-origin landraces for altered shoot [Na^+]

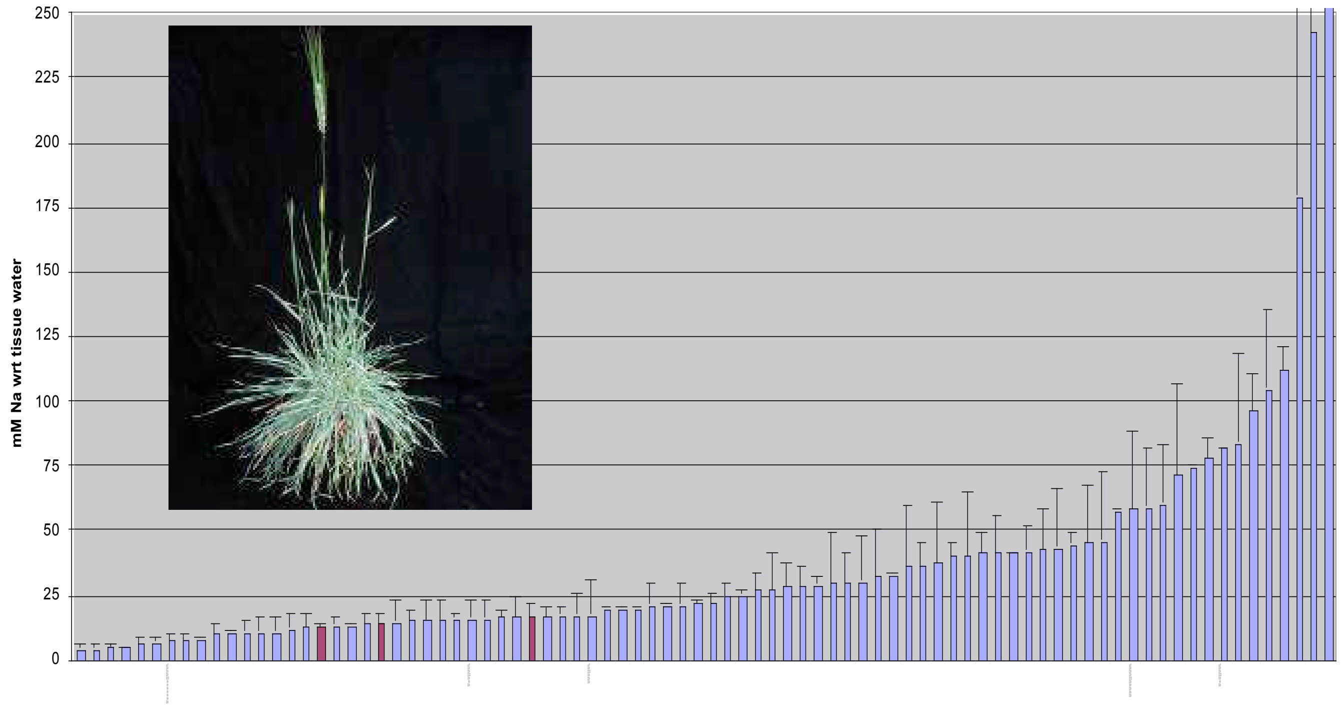
Supported hydroponics
100 mM NaCl
10-d-old leaf 3, leaf 4

190 *T. aestivum*
179 *T. durum*
92 *T. monococcum*
22 *T. urartu*
17 *T. tauschii*
68 *H. vulgare*
50 *H. spontaneum*
(n = 4 per accession)

Yuri Shavrukov, Nenah Mackenzie, Robin Hosking, Jairus Bowne, Pat Warner

Forward genetics
Huge variation in some cereals

>50-fold variation in leaf 3 Na^+ concentration in 84 *monococcum* varieties



Now: introgress traits into commercial lines; test effects on yield; elucidate molecular basis for Na^+ exclusion

Bowne, Shavrukov & Tester, unpubl.

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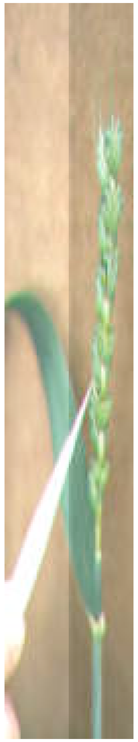
Conventional plant breeding

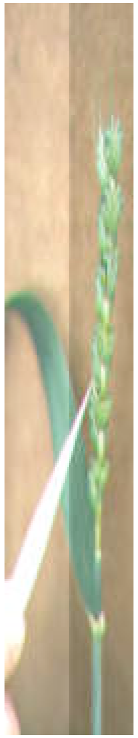
PARENT 1



High yield
Salt sensitive

X

PARENT 2



Low yield
Salt tolerant

=

Which ones are salt tolerant?

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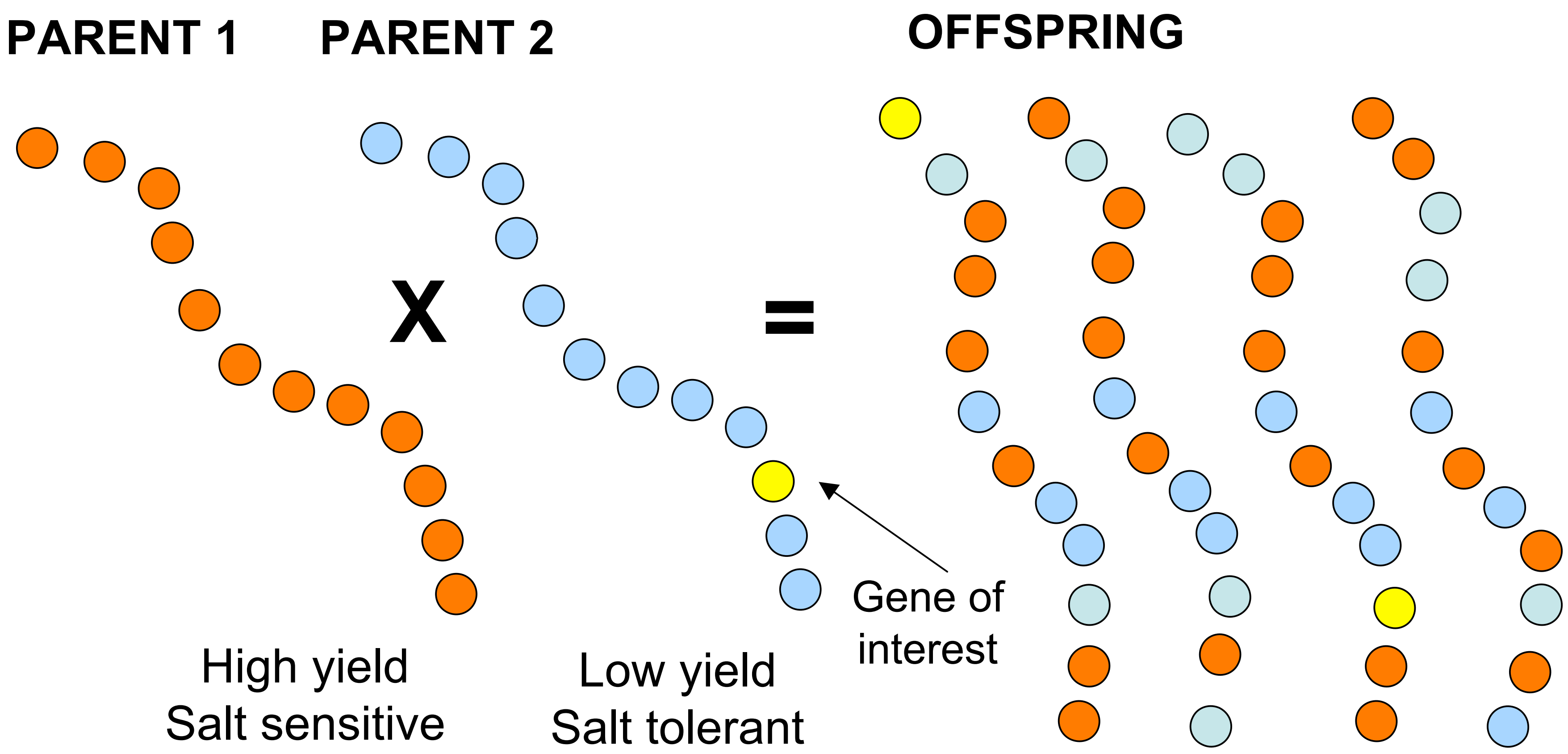
Marker assisted selection



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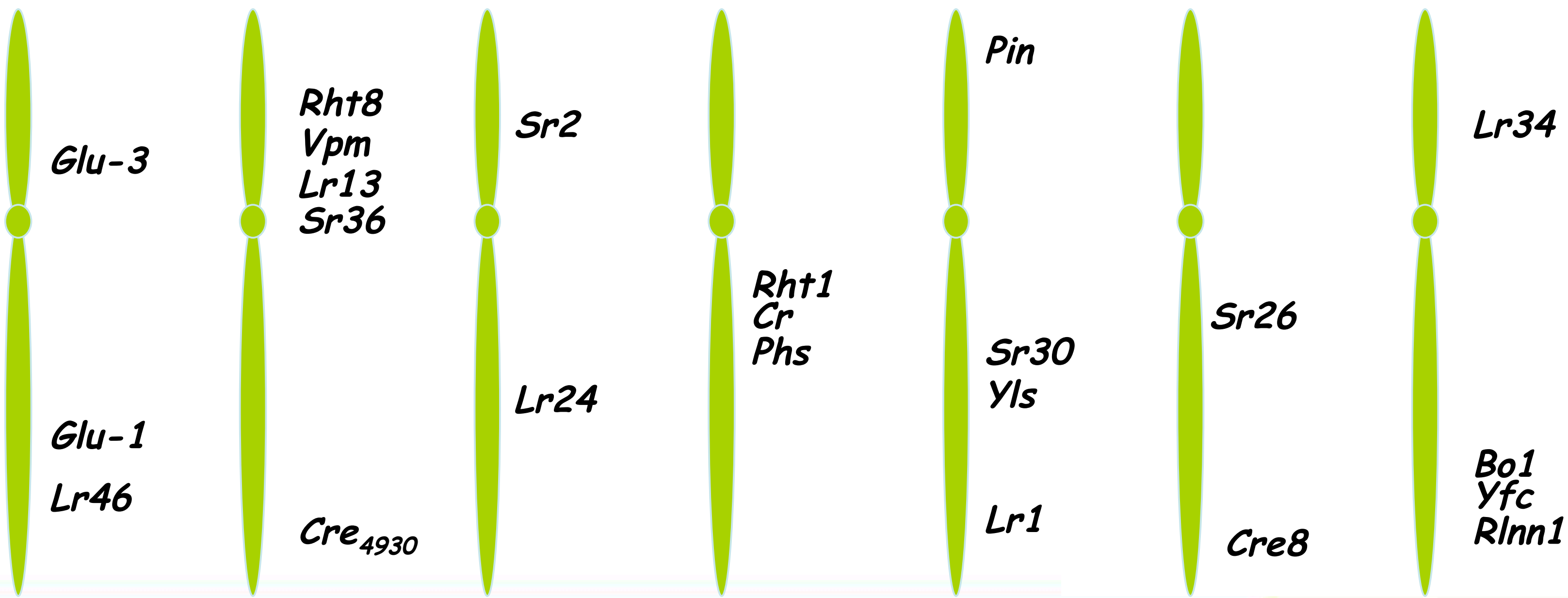
Marker assisted selection accelerates breeding

- Use ‘genetic markers’ to track segments of DNA
- Speeds introgression of desirable traits
- Over 30,000 genes in barley and 100,000 in wheat



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The ACPFG employs over 100 research scientists and associated staff…

Forward genetics helped identify the basis for Na^+ tolerance in pasta wheat

Byrt *et al*. (2007) *Plant Physiology* **143:**1918-1928

HKT1;5-like cation transporters linked to Na^+ exclusion loci in wheat, Nax2 and Kna1

Rana Munns   CSIRO Plant Industry
Caitlin Byrt   Joint PhD student

CSIRO

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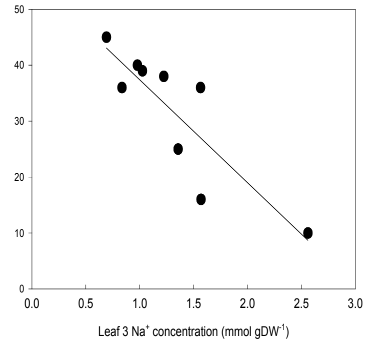
Forward genetics is not the only approach to identify and manipulate Na^+ tolerance

Forward genetics and conventional breeding use natural or induced variation in a gene pool limited by sexual reproduction

Genetic engineering can use variation from all possible sources

Salinity tolerance research

Three main approaches



Aim: To identify and manipulate the mechanisms that limit Na^+ accumulation to the leaves

Forward genetics

Discover, exploit naturally occurring variation (landraces, synthetics, wide crosses)

Positionally clone responsible alleles; introgress into commercial lines

Reverse genetics

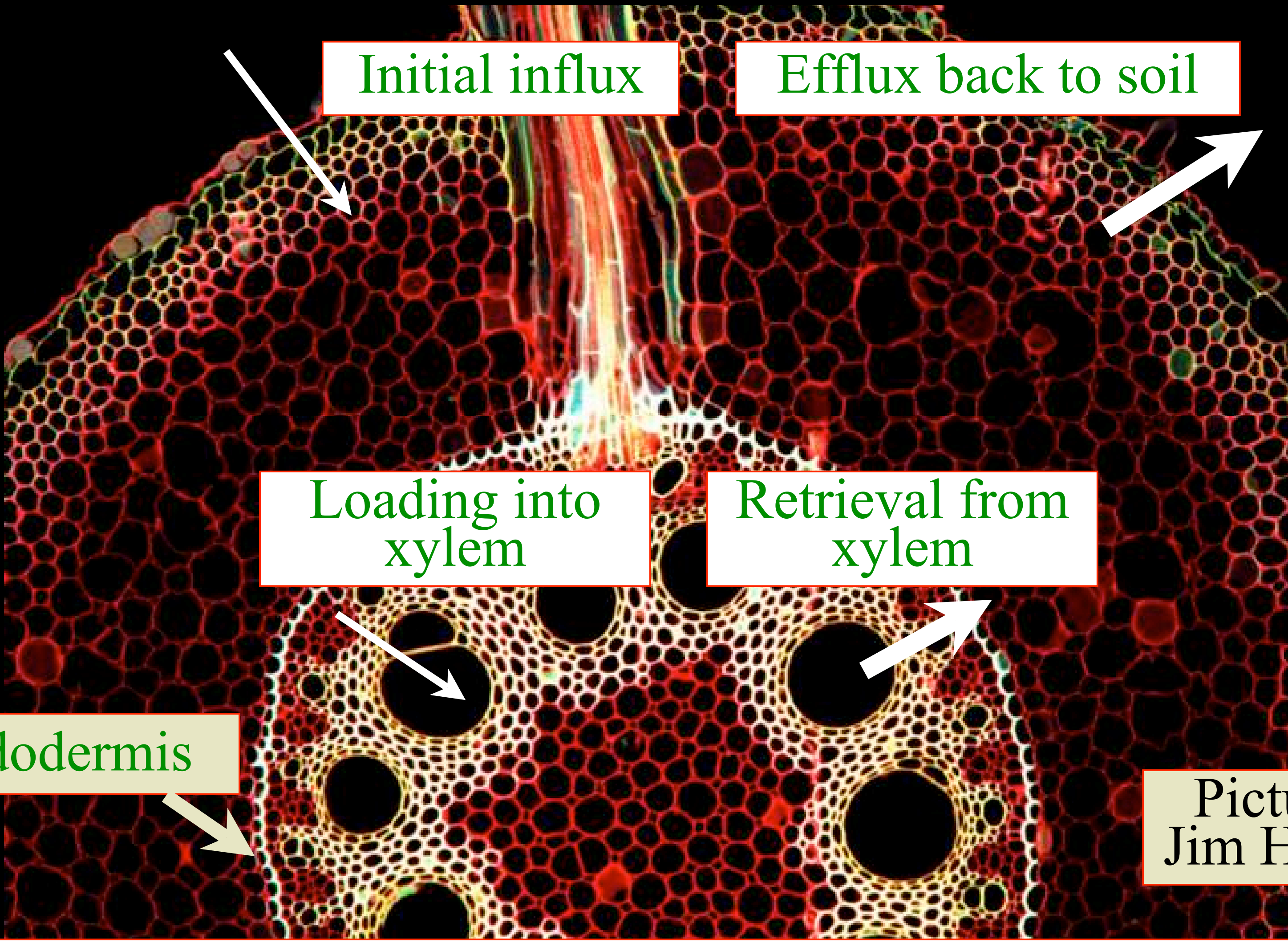
Nominate candidate genes from -omics approaches, bioinformatics

Measure effects of altering levels and patterns of expression

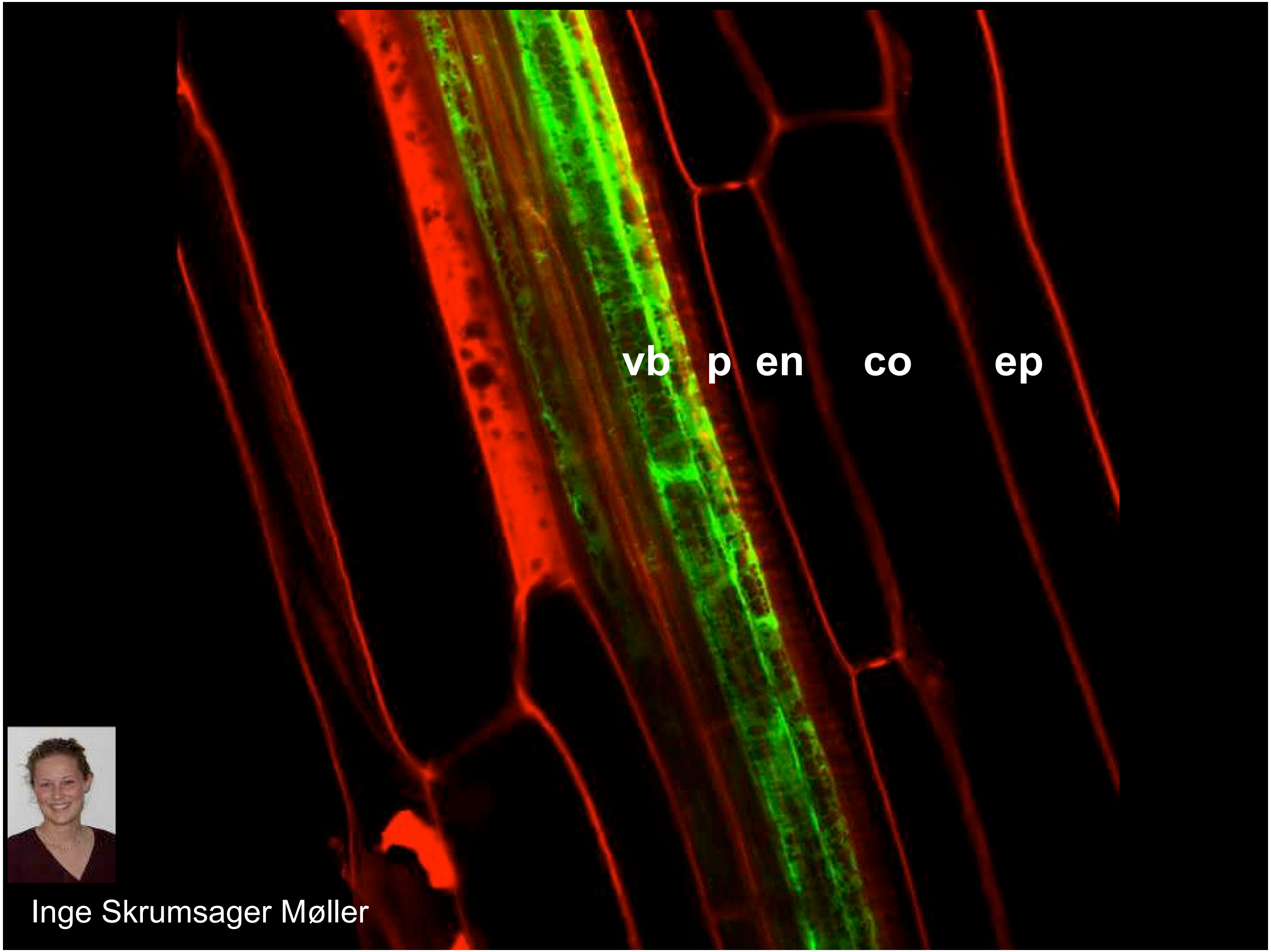
Molecular genetics

Generate novel variation in leaf Na^+ accumulation by manipulating gene expression in specific cell types hypothesised to be important in controlling leaf Na^+ accumulation

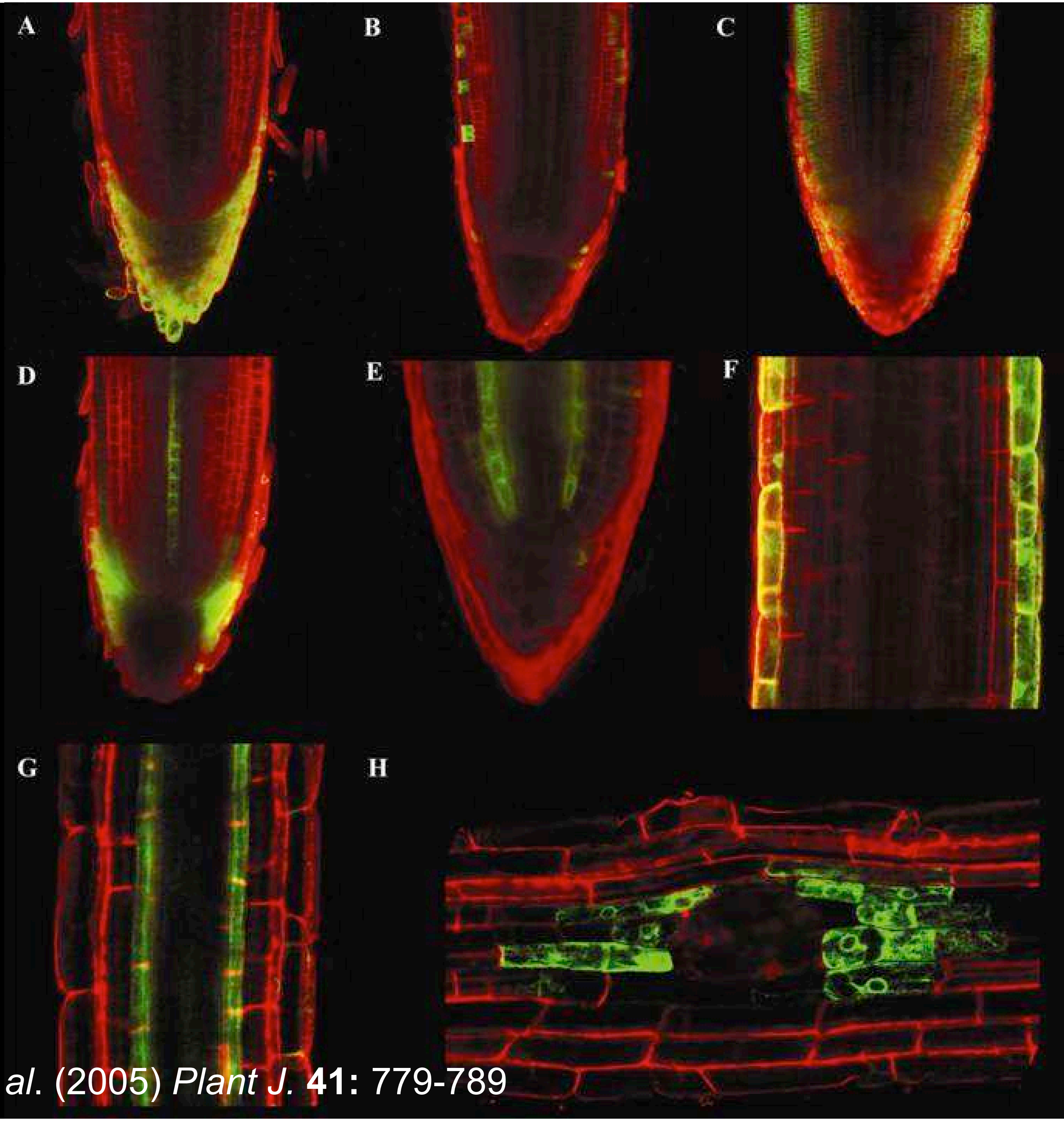
Tolerance partly determined by accumulation
Accumulation determined by root-shoot transfer?



SO, need to move from whole organ to **single** cell types



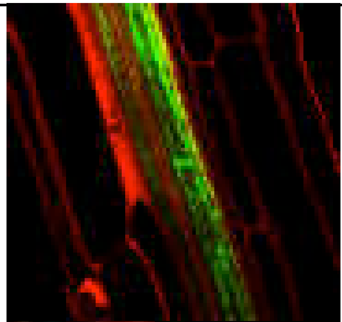
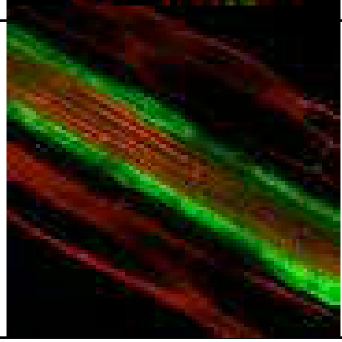
Inge Skrumsager Møller



Johnson *et al*. (2005) *Plant J.* **41:** 779-789

Molecular genetics:

Cell-type specific expression of *AtHKT1* in Arabidopsis lowers shoot Na^+

Plant material			Na^+ ($mg.kg^{-1}$ FW)
Columbia E2586 (stelar-specific expression)		Parent	198 ± 12 (n = 65)
		Null segregants	211± 11 (n = 39)
		UAS-AtHKT1;1	123 ± 4 (n = 217)
C24 J2731* (pericycle-specific expression)		Parent	605 ± 17 (n = 93)
		Null segregants	605 ± 22 (n = 71)
		UAS-AtHKT1;1	217 ± 6 (n = 285)

Inge Møller

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Constitutive expression of *AtHKT1;1* in Arabidopsis

Expression of *AtKT1;1* throughout the plant has the opposite effect on shoot Na^+

Plant material		Na^+ ($mg.kg^{-1}$ FW)
Columbia (constitutive expression)	**Parent**	**122 ± 6 (n = 53)**
	35S-AtHKT1;1	**438 ± 43 (n = 25)**

Deepa Jha

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Types of genetic modification

'Close transfer'

- inter- & intra-plant

e.g. herbicide resistance crossed into related varieties

e.g. activation of Na^{+} transport genes to increase salinity tolerance

'Wide transfer'

- inter-Kingdom

unique to new GM

e.g. bacterial toxin into corn

Tester (1999) *Nature* **402,** 575

Types of genetic modification

- There are many types of GM
- There are many applications for new GM
- Generalizations about new GM not possible
- New and old GM mostly similar
  (but, crucially, NOT always!)
- Objections must address unique features of new GM
  (e.g. wide transfer of insecticidal proteins)

http://plantscience.acpfg.com.au/gmcrops.html

Tester (2001) *New Phytologist* **149,** 9-12

Why does genetic modification matter?

- The bottom line – world food production must increase
- Conventional approaches making decreasing proportional impact
- Need more tools – GM is one of them
- GM is not ‘the answer’, but it may provide another contribution
- GM with potential to help increase food quantity and quality, and environmental sustainability

Phenotyping - the new bottleneck in plant science

- Genomics is accelerating gene discovery and novel plant development
  - Developing genetically powerful populations
  - Generating transgenic lines of interest
  - Discovering candidate genes for tolerance to Na^+, B, drought
- High throughput growth and analysis capacity now the factor limiting discovery of new traits and varieties
  - Need more technology
    - to elucidate function
    - to support forward genetics
- Need to measure effects of gene manipulations on plant function - ‘phenotyping’

The vision

- With robotics, image analysis and computing power, there is now an opportunity to relieve the plant phenotyping bottleneck

- World leading quantitative high throughput screening facility

- Help deliver genomics advances to plant science

- Accelerate transfer of genes, markers and information to breeding of innovative new varieties

The Waite Campus of the University of Adelaide

National Plant Phenomics Facility
THE PLANT ACCELERATOR

Australian Plant Phenomics Facility

The Plant Accelerator
Adelaide, SA

National Plant Phenomics Facility
THE PLANT ACCELERATOR

The Plant Accelerator

- 4,000 m^2 of greenhouses, 40 x 12 m^2 growth chambers
- Grow 160,000 plants per year (440/day)
- All supports 4 x 200 m^2 fully automated ‘Phenotyping Greenhouses’
  - high capacity image analysis equipment
  - regular, non-destructive measurements of growth, development, physiology
- First public sector facility of this type and scale in the world

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Modern plant science

Genomics

High throughput analysis of genes and their immediate products, to study the structure and function of genes and genomes

Phenomics

High throughput analysis of plant growth and physiology, to reveal the role of each plant gene in the function of the whole plant

Genomics + Phenomics = Functional Genomics

Tougher crops for a warming world

Combining genomics and phenomics will

- significantly increase understanding of plant function
- permit research on previously intractable problems
- speed crop improvement

Imperative, especially in the face of global climate change

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Tougher crops for a warming world

Forward Genetics
Yuri Shavrukov
Alireza Rivandi
Widodo
Ali Izanloo
Caitlin Byrt
Karthika Rajendran
Courtney Ramsey
Robin Hosking
Sunita Gupta
Nilmini Dharmathilake

Molecular Genetics – nutriomics
Stuart Roy
Gehan El-Hussieny ('Gigi')
Inge Skrumsager-Møller
Emily Grace
Deepa Jha
Marilyn Henderson
Irandokht Fathi
Shakid Khan

Reverse Genetics
Andrew Jacobs
Julie Hayes
Juan Juttner
Scott Carter
Damian Drew
Mahima Krishnan
Michael Dow
Jessie Parker
Jodie Kretschmer
Nadim Shadiac

Molecular Genetics - rice
Alex Johnson
Olivier Cotsaftis
Darren Plett
Lorraine Carruthers
Narendra Gupta
Joanna Sundstrom

Australian Government
Australian Research Council

GRDC
Grains Research & Development Corporation

Government of South Australia

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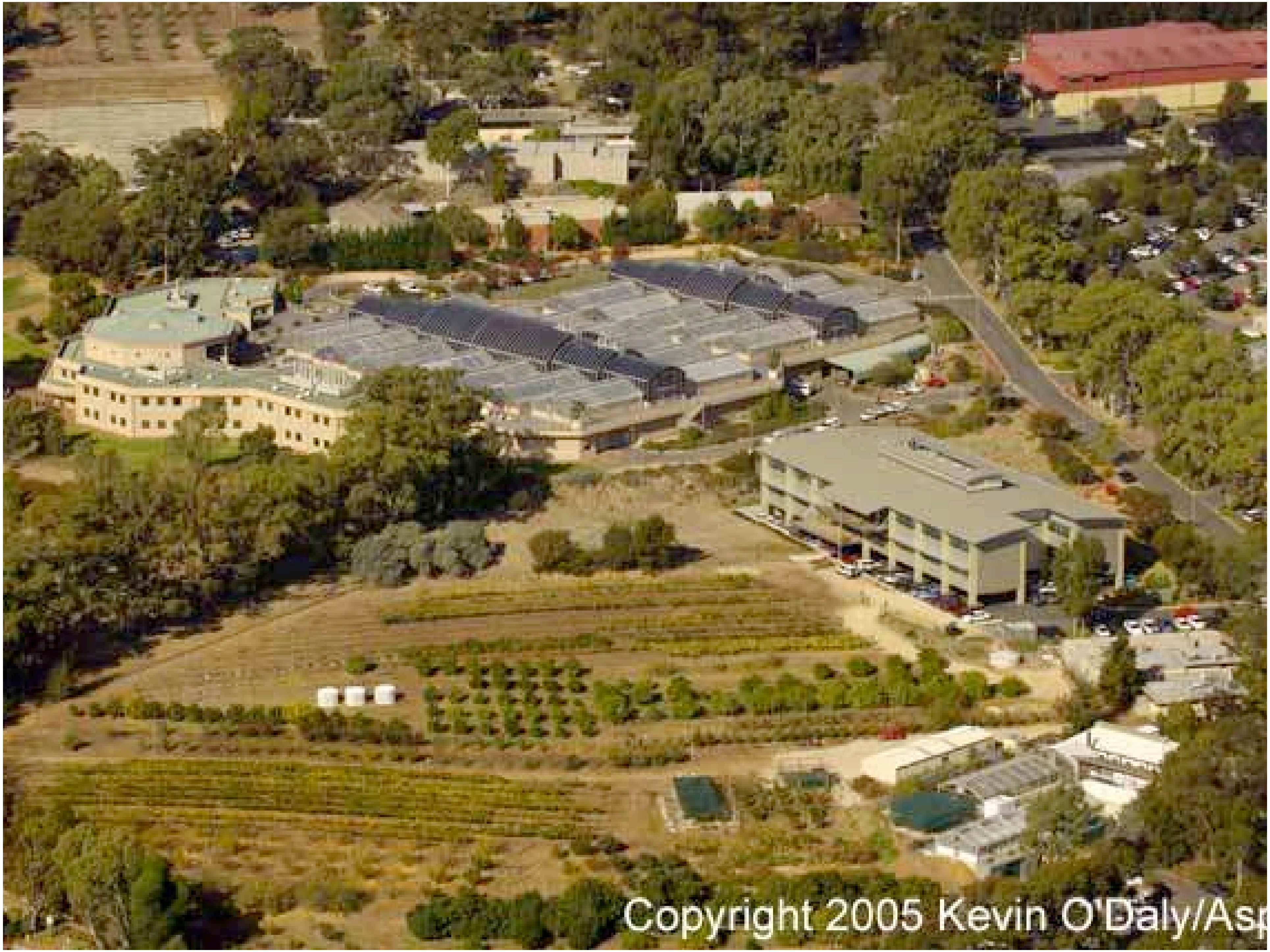
http://plantscience.acpfg.com.au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