Breeding grain sorghum hybrids:
successes, opportunities and challenges

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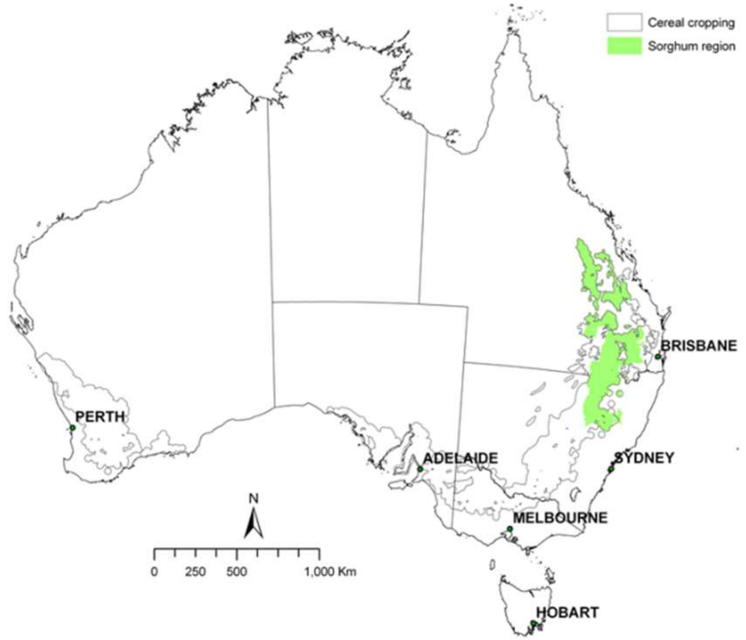
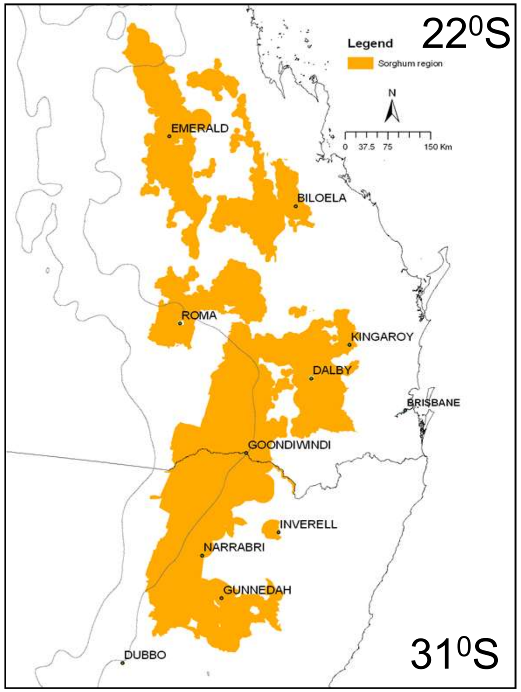
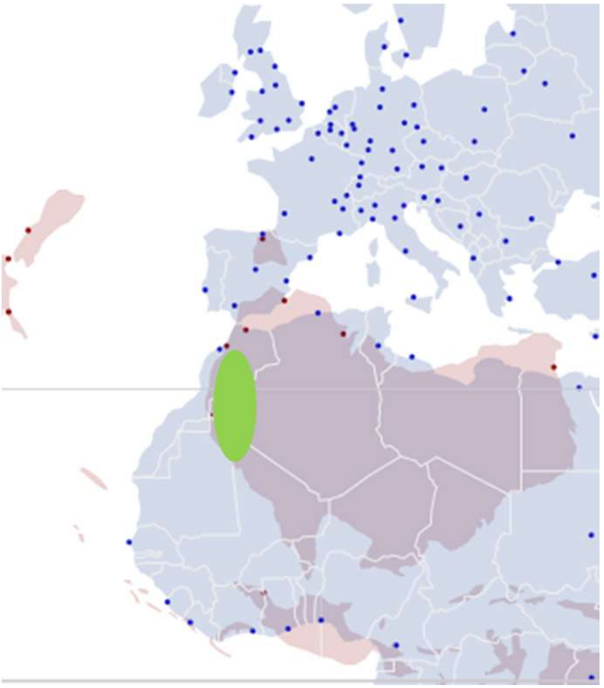
Sorghum In Australia: production area

- Rain fed crop which relies on stored soil moisture
- Large geographic area (~1000km North-South) subtropics
- Diversity of management systems (planting time, row spacing etc)
- Relatively small planted area (~600,000 ha) but 11x > than the maize area
- Production of ~1.8 M tonnes





Milan = 45.46° N



Sorghum In Australia: climate

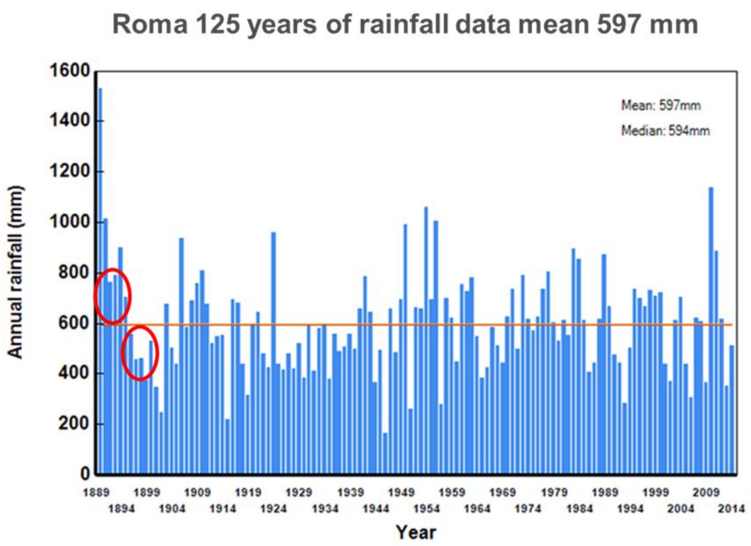
Current

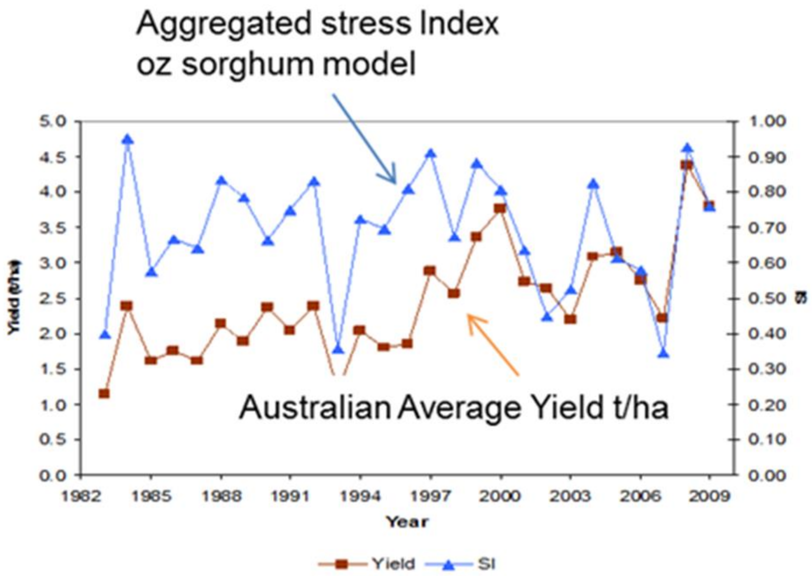
- High levels of climate variability and drought
- Yields of 0-10 t/ha

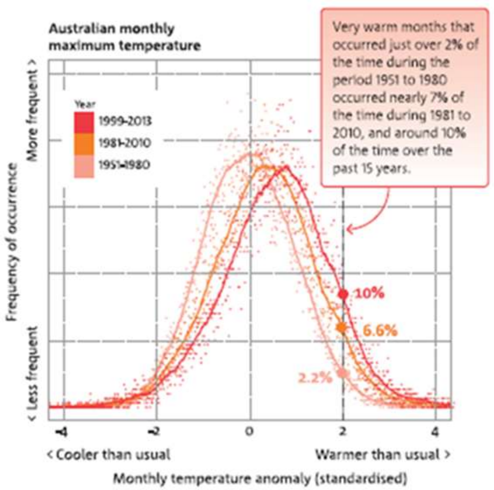
Future

- Higher levels of climate variability
- More frequent extreme temperatures

Water is the primary limiting factor now but high temperature at flowering will become a major limitation

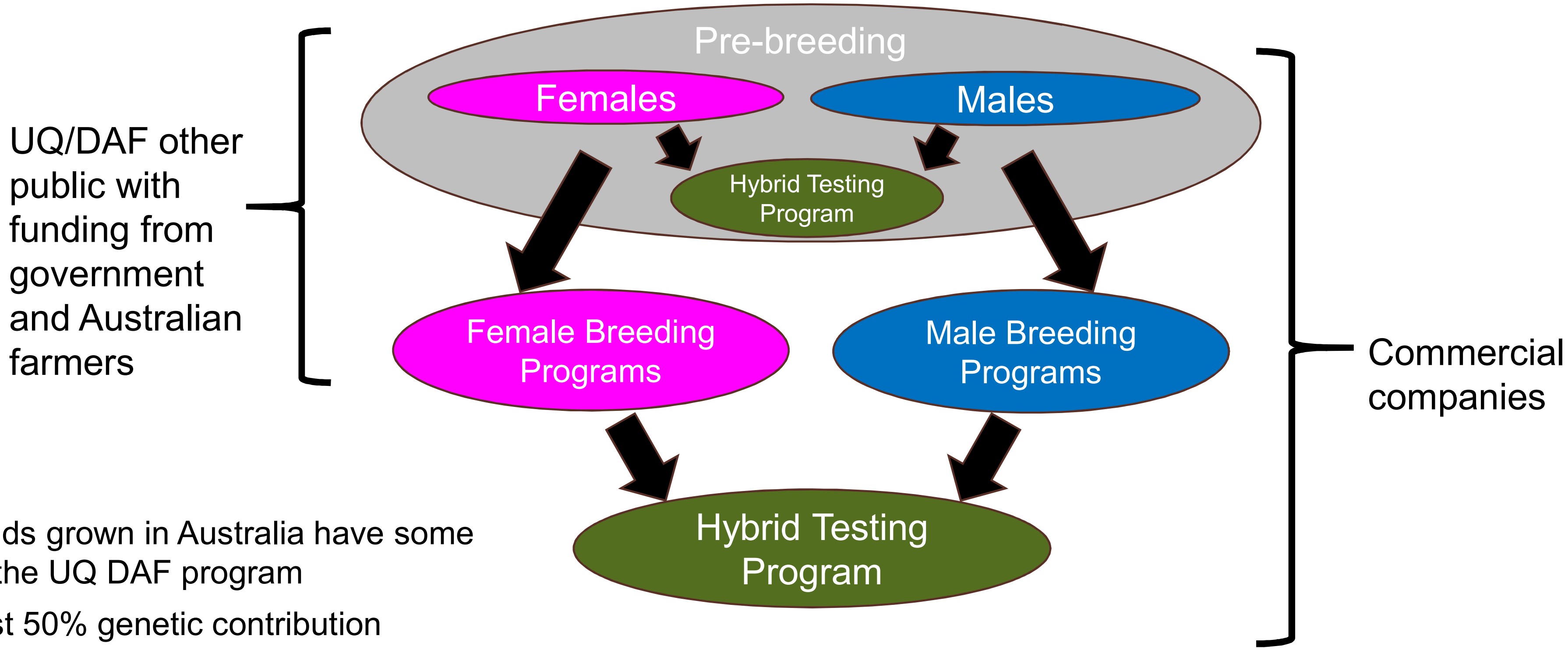






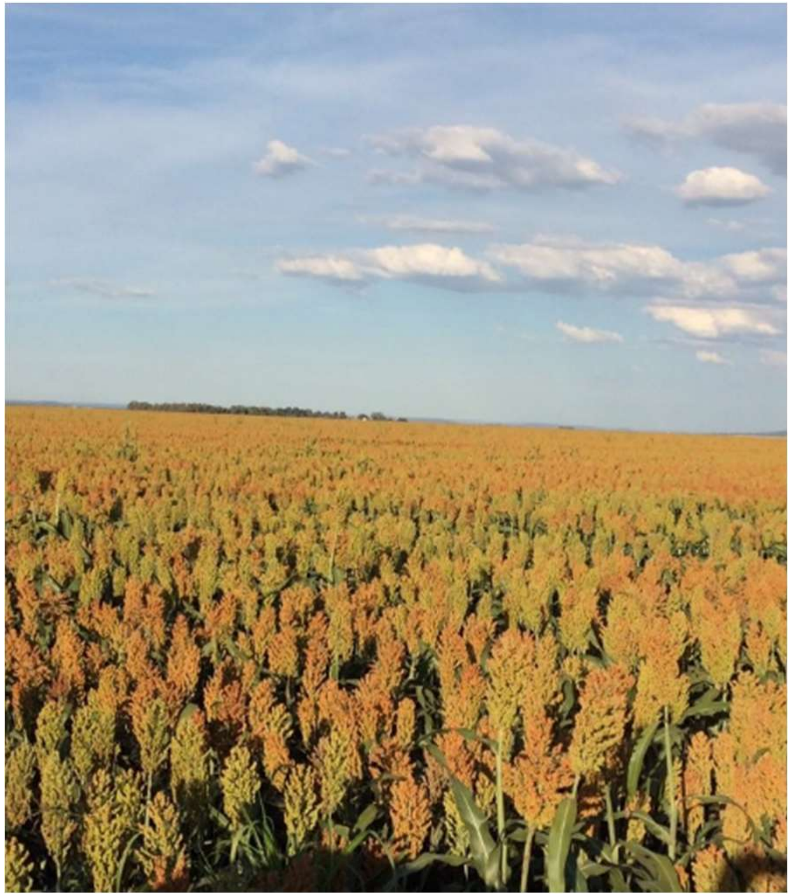

2nd European Sorghum
Congress 2018

HYBRID SORGHUM BREEDING IN AUSTRALIA

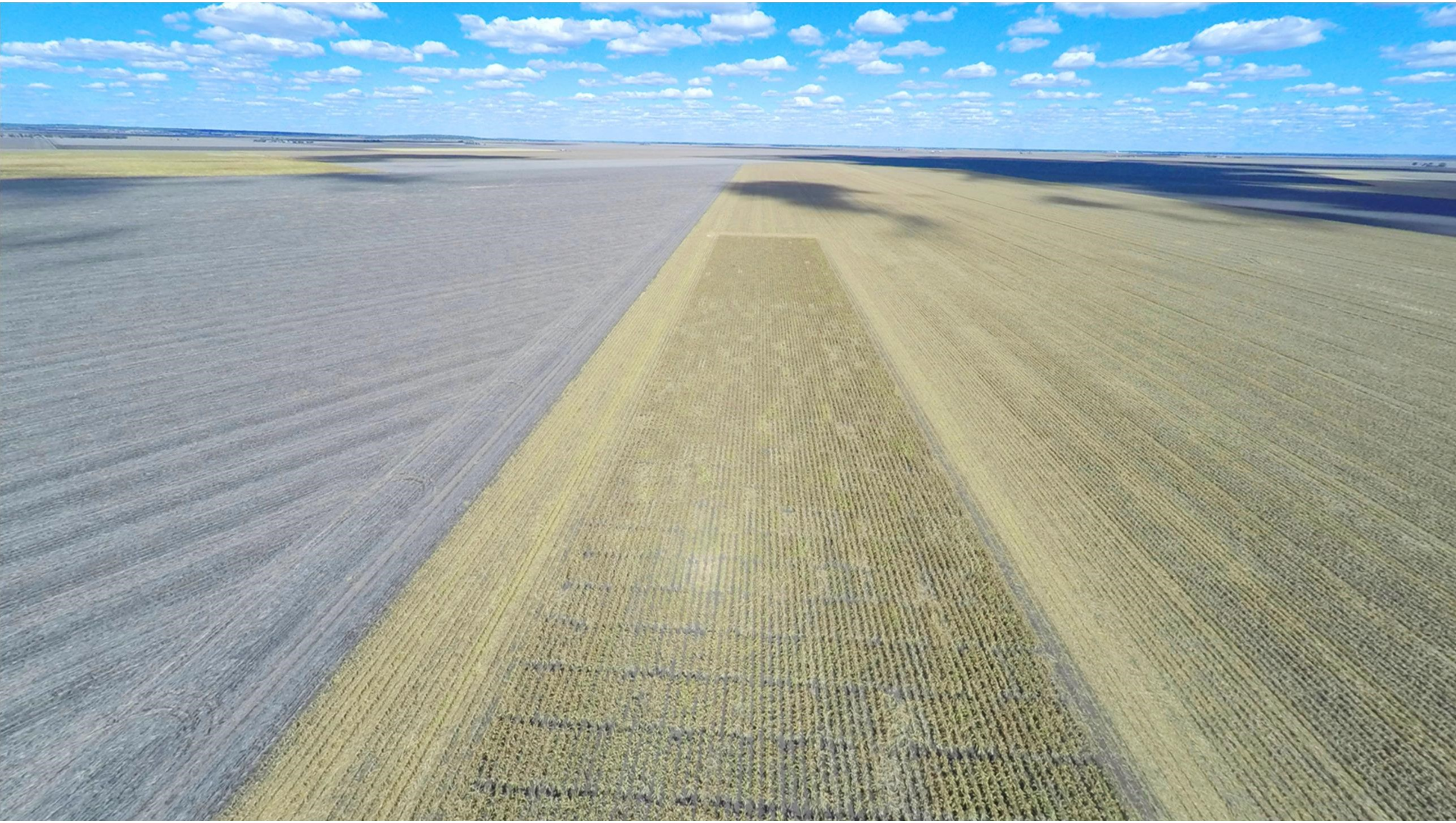


- 100% of the hybrids grown in Australia have some germplasm from the UQ DAF program
- Most have at least 50% genetic contribution
- Commercial hybrids with genetics from the program are grown in most hybrid sorghum markets internationally

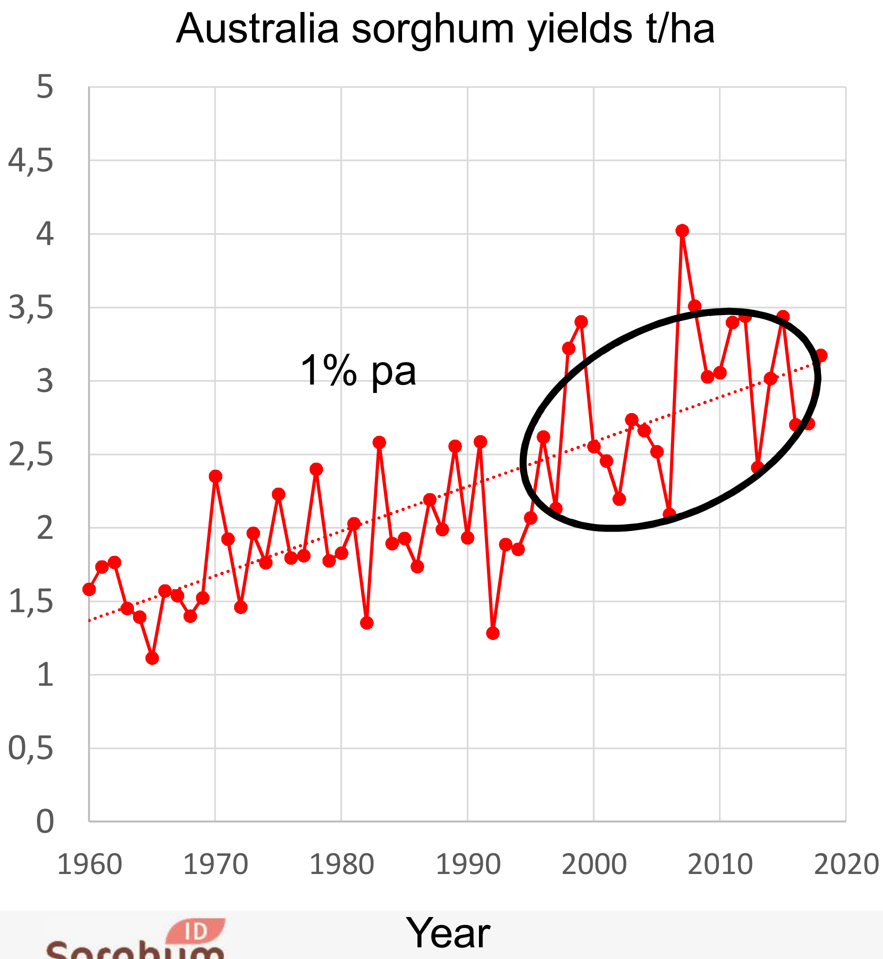
TARGETS FOR AUSTRALIAN SORGHUM BREEDING PROGRAMS



- Increasing yield (water productivity)
- Yield protection (sorghum midge resistance, heat & drought)
- Increasing crop value (grain quality). Opportunities emerging through technologies such as gene editing and through the development of specialist uses

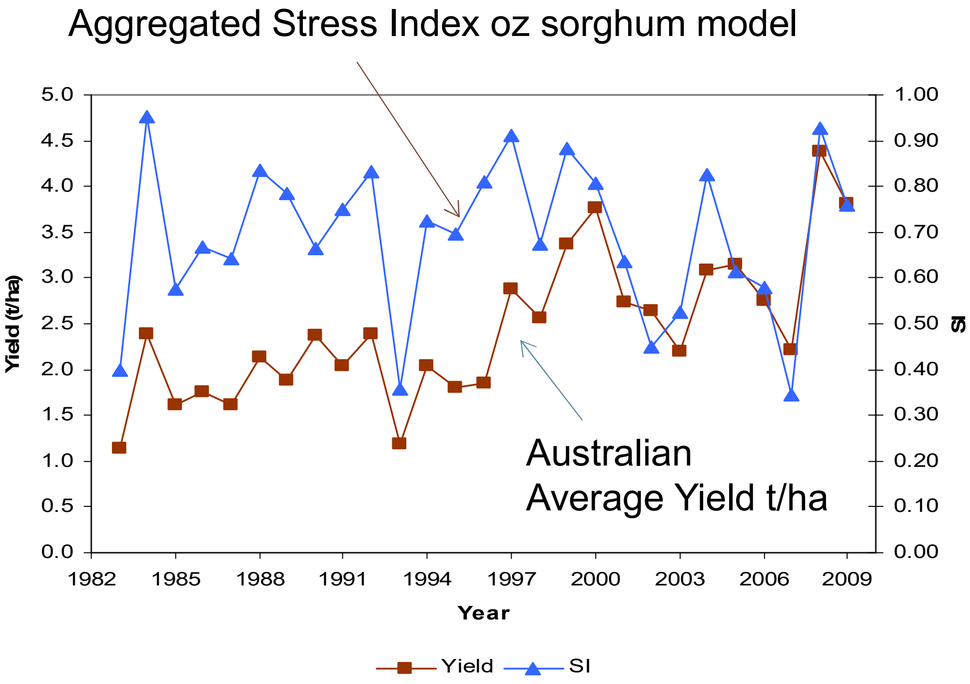


AUSTRALIAN SORGHUM YIELD TREND IN THE LAST 60 YEARS



- Continued productivity gain of ~1% per year over a ~60 year period (since hybrids) compared with ~0.6% in the USA in the same period
- 1% per year productivity gain over 60 years is lower than we would like but seasonal variation makes estimation of shorter term trend difficult

AUSTRALIAN SORGHUM YIELD TREND IN THE LAST 60 YEARS



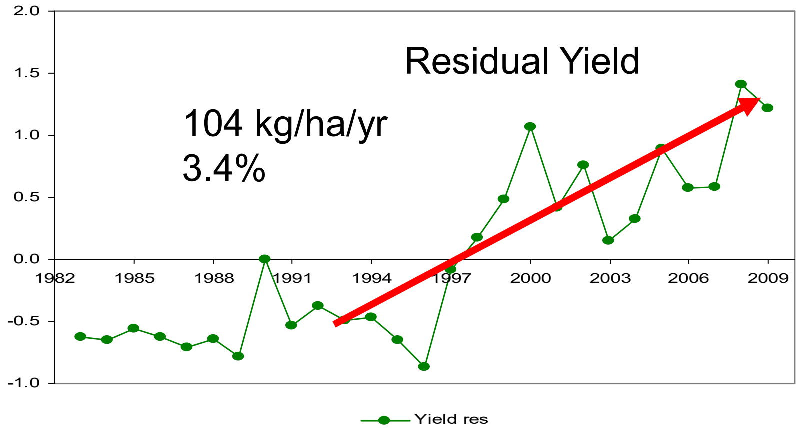
- Australian sorghum yields are strongly driven by seasonal variation
- Crop modelling provides a way of removing the seasonal effects to get to the underlying yield trend

How productive was the crop given the climate it experienced ?

AUSTRALIAN SORGHUM YIELD TREND IN THE LAST 20 YEARS

Stephens et al 2012

Australian sorghum yield trend adjusted for aggregate stress index t/ha



Productivity gain sorghum vs wheat

Mean change in Yield	kg/ha/year	% per year
Australian sorghum	**104**	**3.9**
Wheat QLD	14.6	1.1

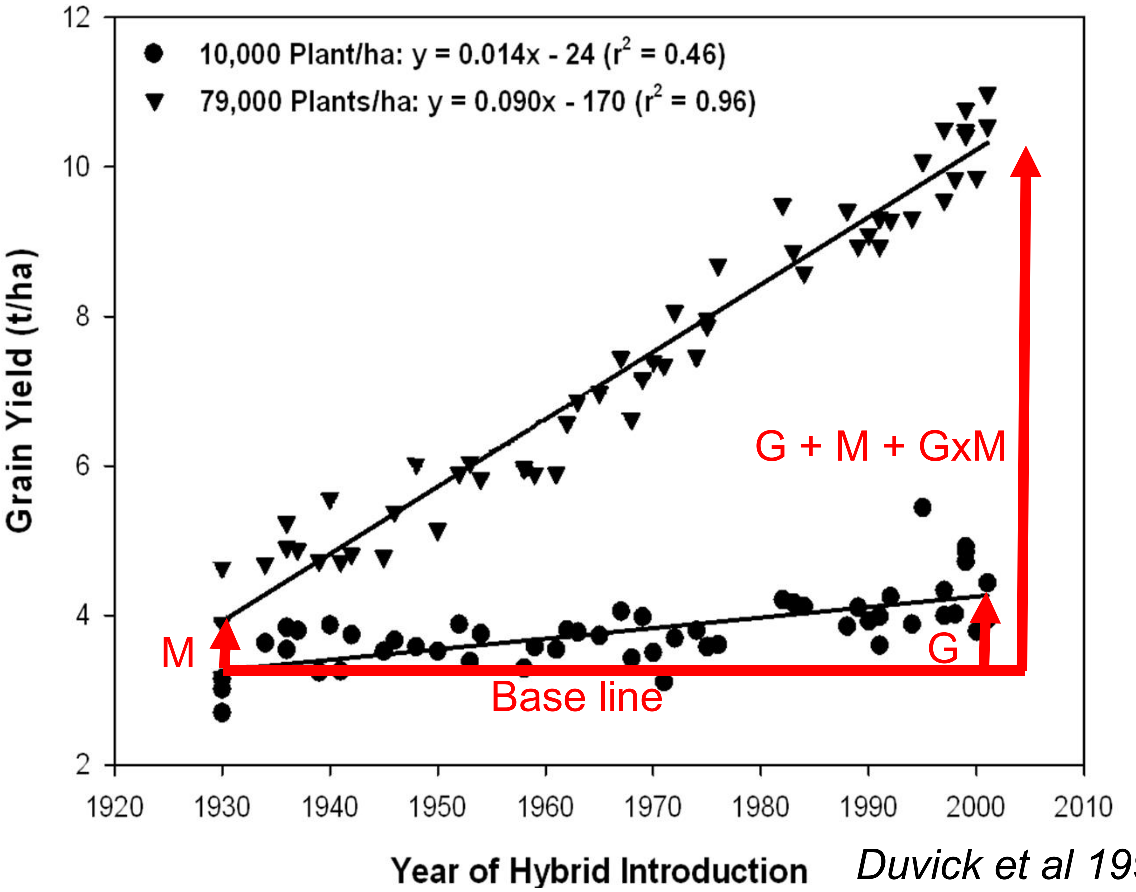
Productivity is 2x higher in high stress compared with low stress (Potigieter et al 2016)

Where has the improvement in productivity come from ?

Breeding (G) ?

Management (M) ?

WHERE DOES IMPROVED PRODUCTIVITY OF CEREALS COME FROM?



Duvick et al 1997

- US Maize yields have more than doubled in 70 years.
- Productivity gain of 2.3% per year
- This has been due to a combination changes in management systems and genetics.

AUSTRALIAN SORGHUM YIELD TREND IN THE LAST 20 YEARS

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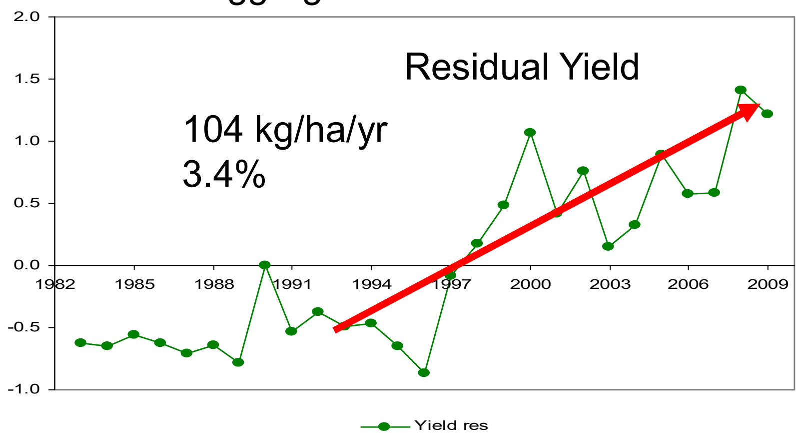

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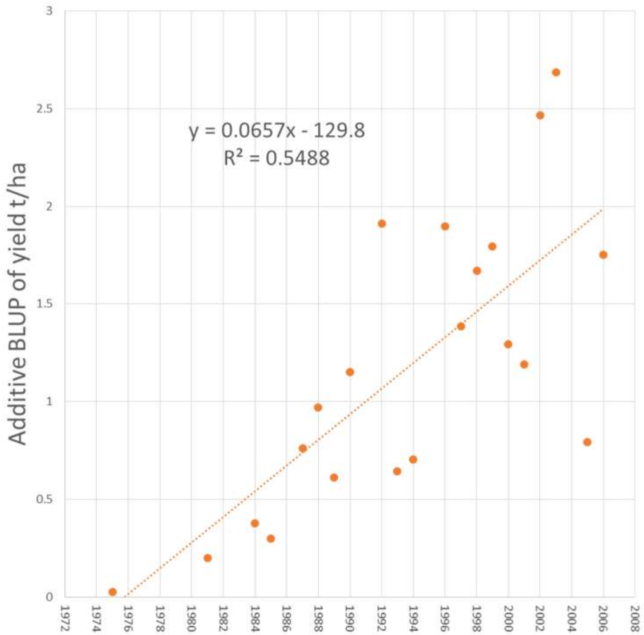
Reason for productivity gain

- Management
  - +N, min tillage, controlled traffic, row spacing and populations, seed treatment and planting equipment, weed control
- Genetics
  - Selection for yield per se
  - Midge resistance
  - Stay-green
- Genetics x Management
  - eg Midge resistance allows more flexible planting times
  - eg Hybrids with better water use characteristics in combination with appropriate agronomy (population and row spacing)

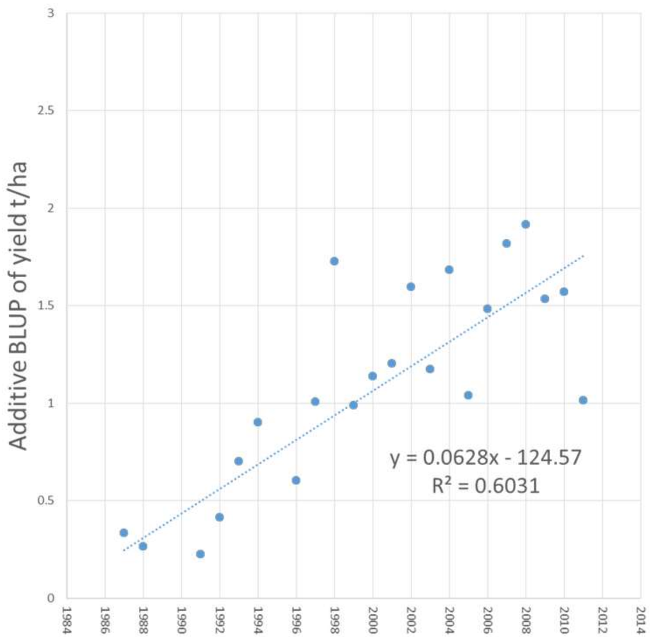
GENETIC GAIN FOR YIELD IN THE DAF UQ PRE-BREEDING PROGRAM

Breeding values of best DAF/UQ inbred lines plotted against year of cross

Male parent lines



Female parent lines



Mean change in Yield	kg/ha/year	% per year
Males	**63.0**	**1.1**
Females	**65.7**	**1.2**

mean yield was ~6t/ha cf Australian average of 3.5 t/ha

*Data from 14 and 26 trials respectively (males and females) including high and low yielding environments. The samples of trials was biased towards higher yielding sites (mean yield was ~6t/ha cf average of 3.5). Our program has focused on water limited environments and **we expect our % gain is higher in low yield environments***

SORGHUM MIDGE RESISTANCE

- The sorghum midge is one of the major pests of sorghum in Australia
- Genetic breeding for resistance has reduced the need for spraying and allowed a wider spread of planting dates

The biggest impact of the resistance trait was not the direct reduction in damage but the yield increase associated with more flexiplility in planting times GxM

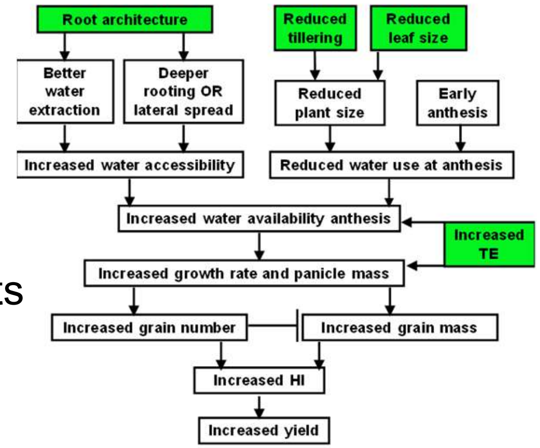
TRAIT DISSECTION AND CROP DESIGN

GENOTYPE X MANAGEMENT X ENVIRONMENT (G X E X M)

We are trying to identify favourable combinations of varieties (traits packages) and management practices in a complex system where the resources available to search for these combinations are limited.

IDENTIFICATION AND PRIORITIZATION OF POTENTIALLY USEFUL TRAITS

Understand environments
Identify targets



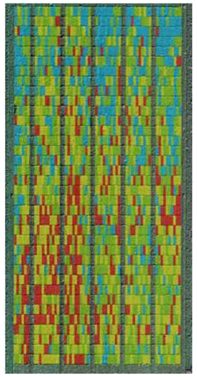
Predict consequences of GxM

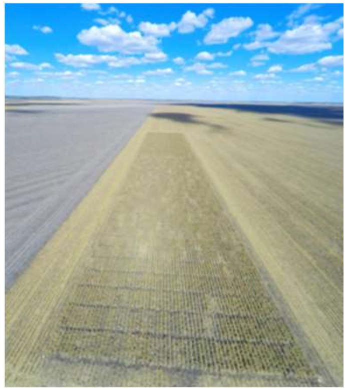
Candidate traits

Search for genetic variation

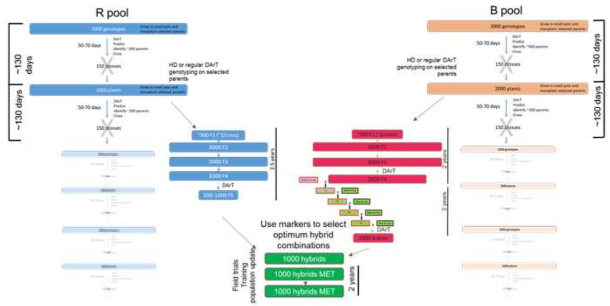
Identify favourable variation

Traits
Screening methods
Breeding methods

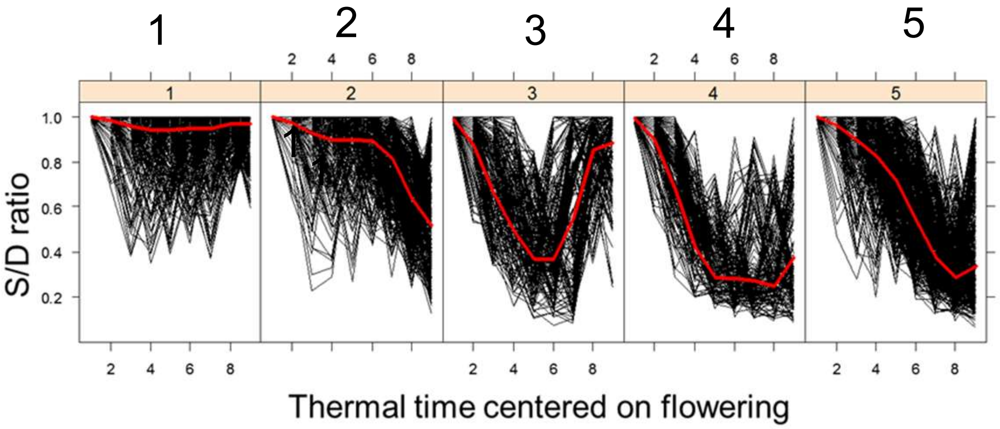




Deploy



UNDERSTANDING THE TARGET POPULATION OF ENVIRONMENTS

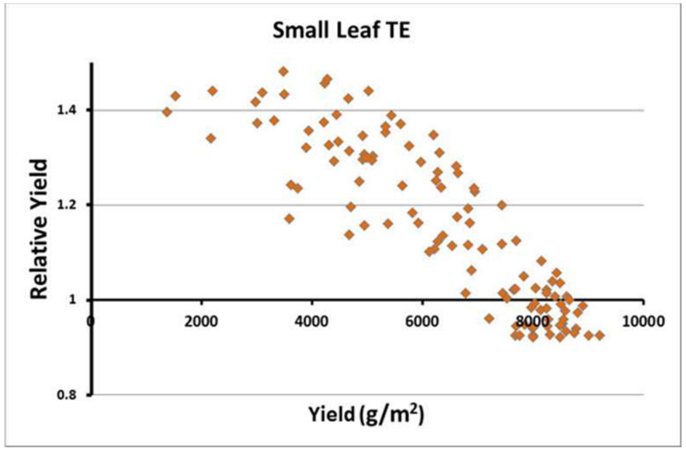


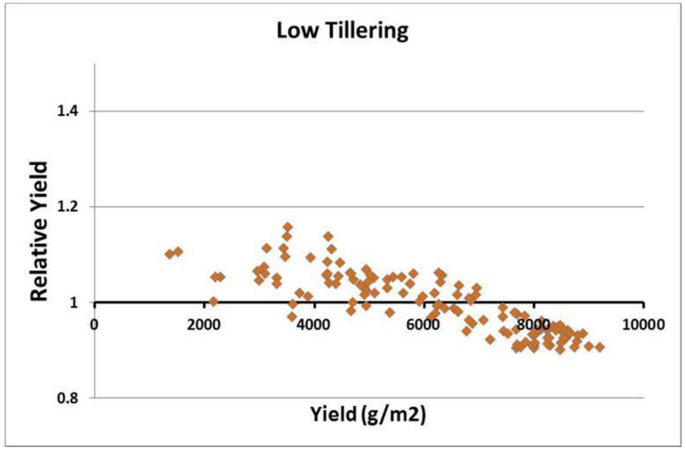
Use crop modelling to understand the types and frequencies of environments by simulating crop growth for a representative set of soils, genotypes and management combinations using 100 years of historical climate data

Environment Type	Region			Overall
	CQ	SQ	NNSW	
1 - No Stress	0.50	0.38	0.25	0.38
2 - Late Onset Terminal	0.13	0.14	0.14	0.14
3 - Late Onset Relieved	0.17	0.19	0.24	0.20
4 - Early Onset Relieved	0.09	0.12	0.12	0.11
5 - Early Onset Terminal	0.11	0.16	0.25	0.17

Identify likely traits or management interventions to improve performance

IDENTIFICATION AND PRIORITIZATION OF POTENTIALLY USEFUL TRAITS AND TRAIT X MANAGEMENT INTERACTIONS

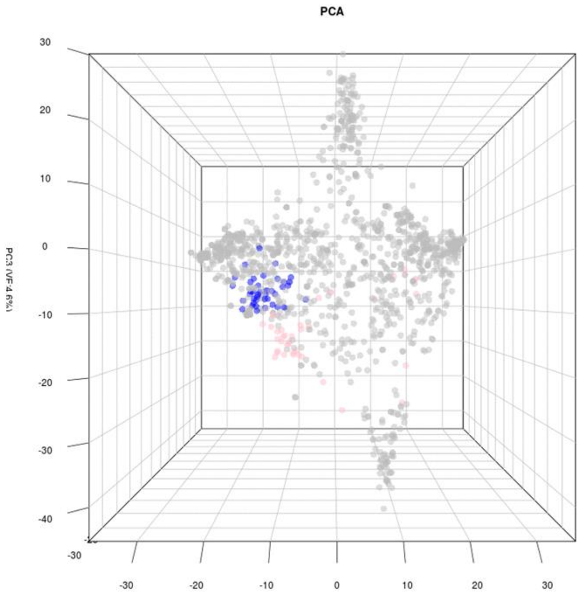




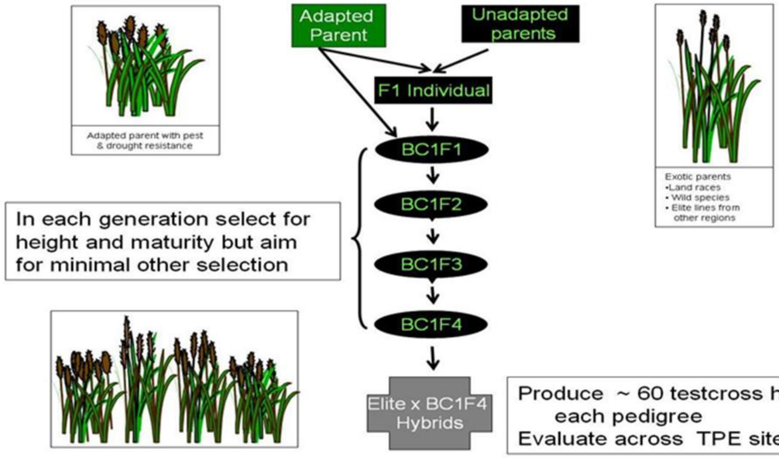
- Use crop modelling to identify potentially useful trait variation that could be of value in the target environments using historical climate data (or future climate projections

Prioritize best bet traits and search for natural variation

EXPLOITING GENETIC DIVERSITY

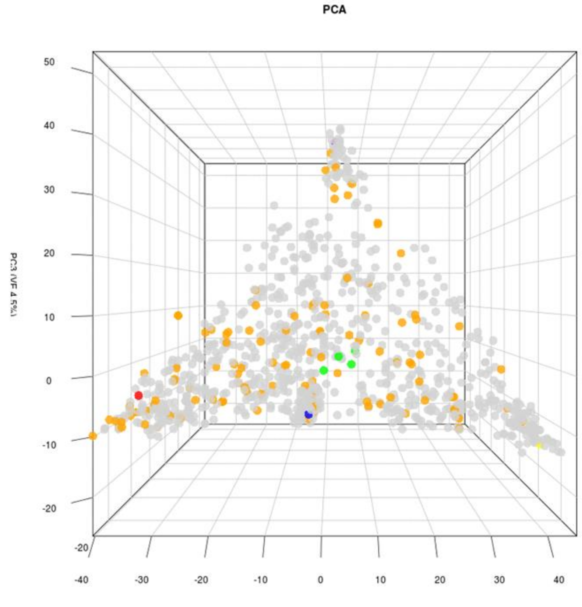


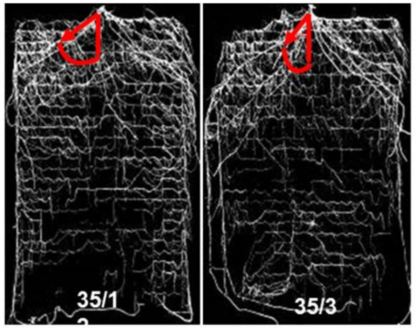
Backcross nested association mapping BC NAM population



In each generation select for height and maturity but aim for minimal other selection

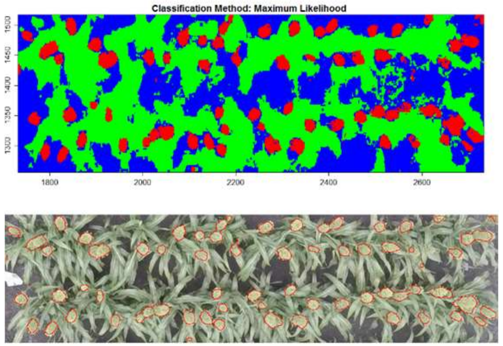
Produce ~ 60 testcross hybrids for each pedigree
Evaluate across TPE sites



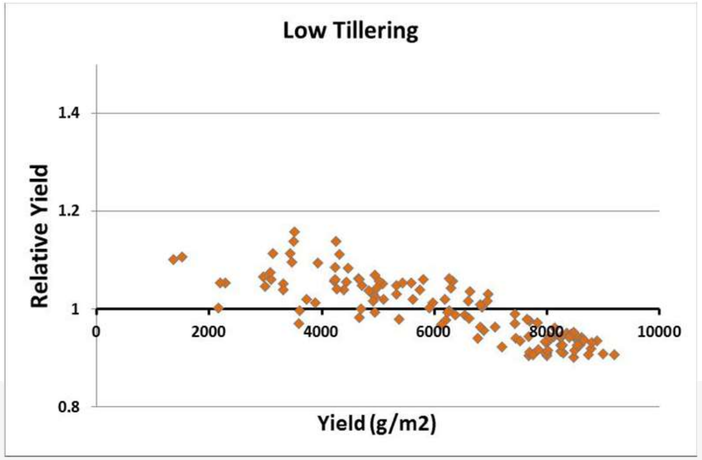


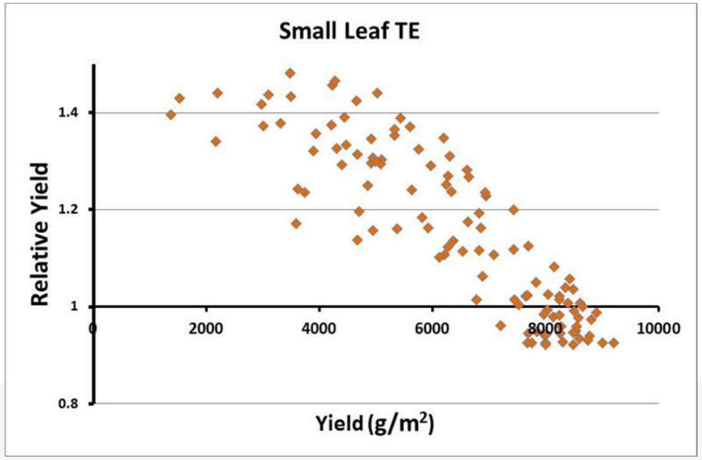
USE TRAIT VARIATION OBSERVED IN DIVERSE GERMPLASM TO PARAMETERISE CROP MODELS TO ESTIMATE TRAIT VALUE IN THE AUSTRALIAN TPE

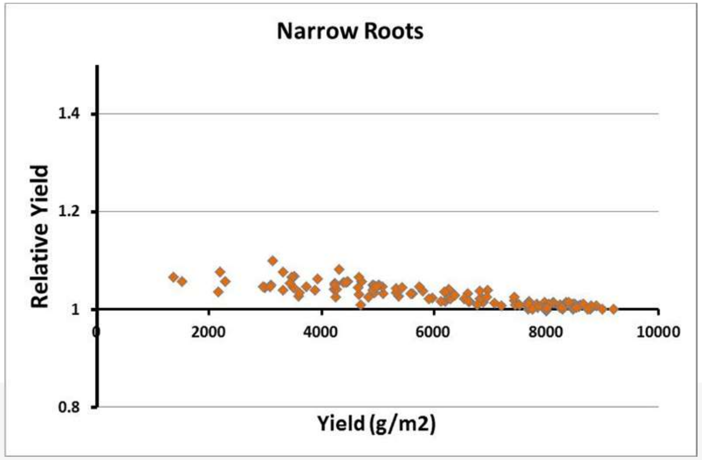
HTP systems to screen for candidate water productivity traits



Simulating the consequences of different water use traits on grain yield at a single location using 100 years of weather data

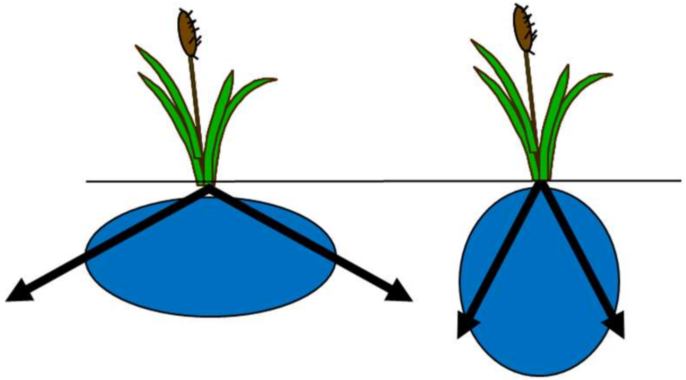






IDENTIFICATION OF USEFUL TRAIT AND MANAGEMENT COMBINATIONS FOR PARTICULAR ENVIRONMENTS

Interaction of nodal root angle with soil depth and row spacing



GxM for shallow soils
Wide rows x with wide but shallow roots

GxM for deep soils
Narrow rows x with narrow but deep roots

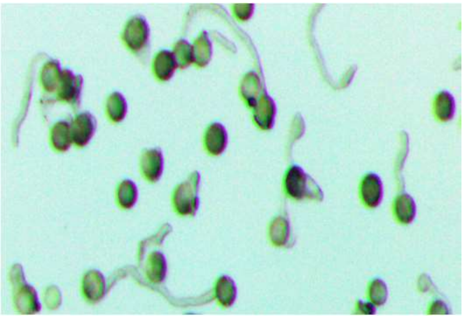
- Changes in nodal root angle are likely to influence water capture in different environments by modifying horizontal and vertical exploration of the soil
- Modelling with “best bet” assumptions indicated substantial yield gains in some environments if correct root architecture was deployed in our typical MxE

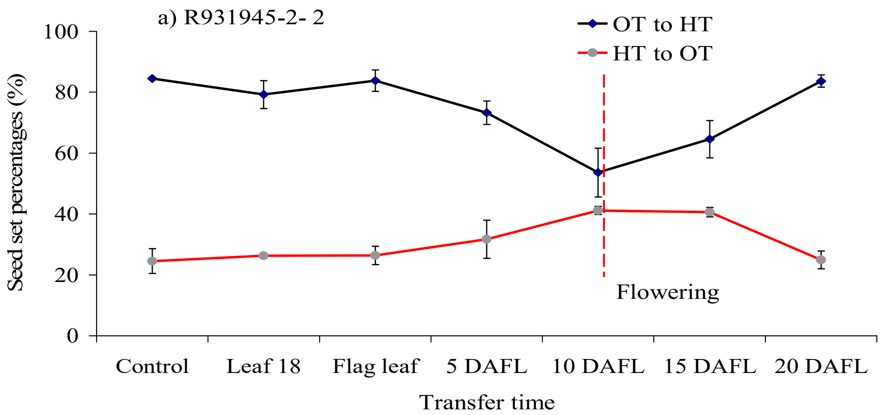
Different architectures are suited to different soils x environments x management systems

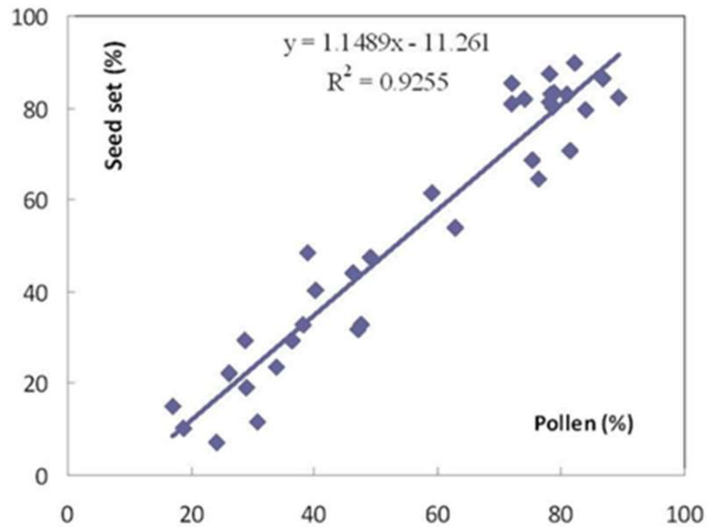
BREEDING FOR FUTURE CLIMATES

High temperature effects in sorghum

- Sorghum is tolerant of high temperatures at most growth stages except around flowering.
- In susceptible genotypes temperatures >38^0 C for 3 days cause pollen sterility and reduced seed set



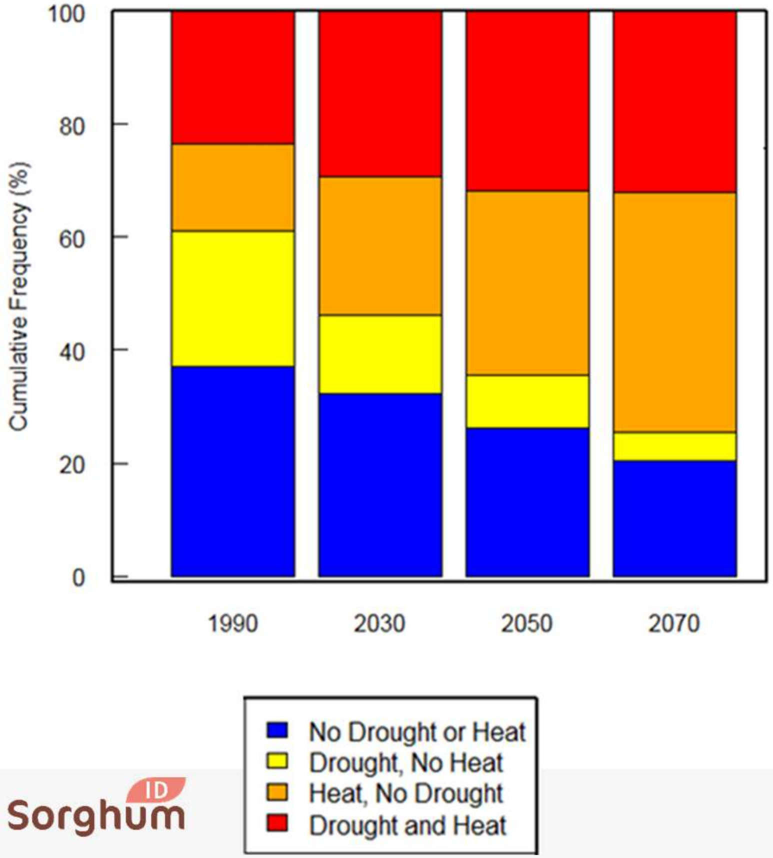




Chuc et al. Functional Plant Biology, 2013, **40**, 439–448

BREEDING FOR FUTURE CLIMATES

Modelled change in the frequency of environments effected by drought, heat and the combination under likely climate scenarios

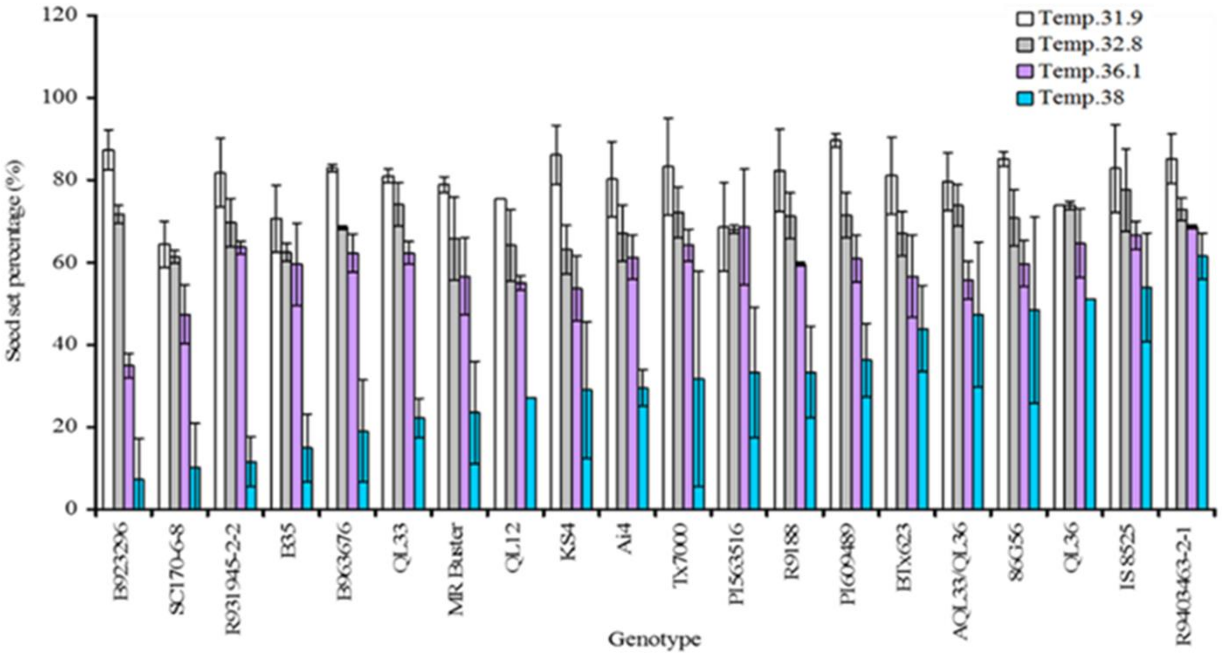


- Currently severe economic losses due to heat damage are relatively rare although modelling indicates hidden losses
- Future climates will have a greater frequency of high temperature events
- Scenarios based on hybrids with current levels of high temperature tolerance indicate that heat will be of growing importance in Australian environments

Selecting for high temperature tolerance is critical for future security of the crop

HIGH TEMPERATURE EFFECTS ON SORGHUM

- Considerable genetic variation for tolerance of high temperatures exists
- Variation is highly heritable

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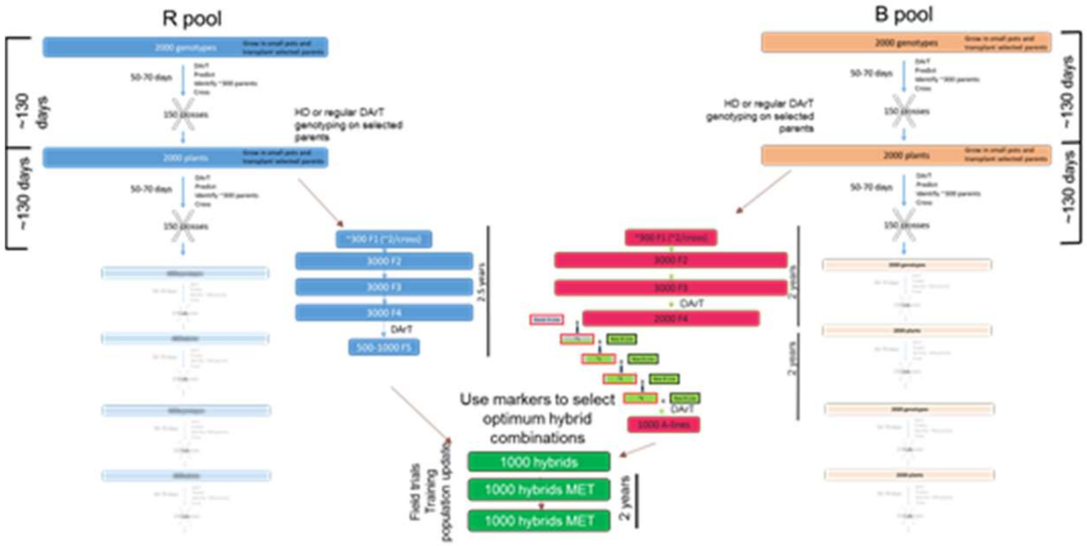
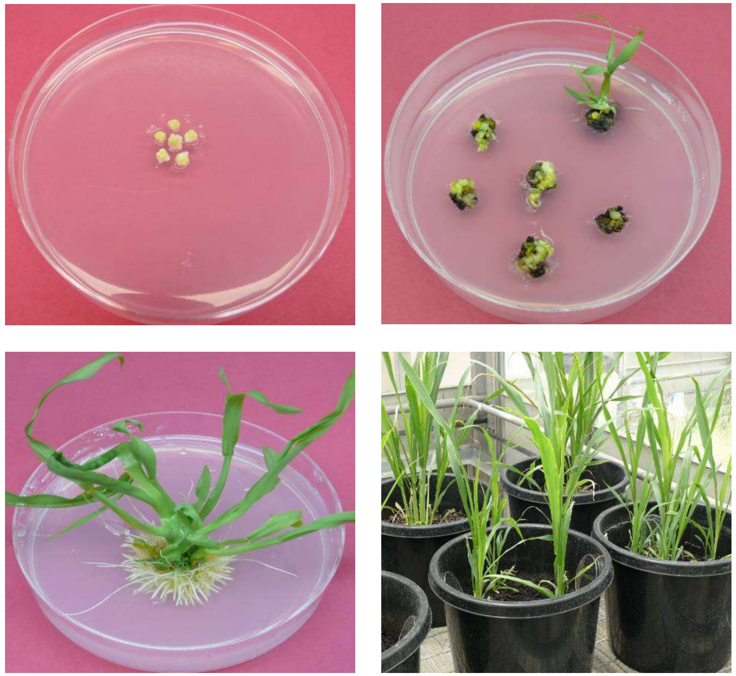
DEPLOYMENT

Genomic selection

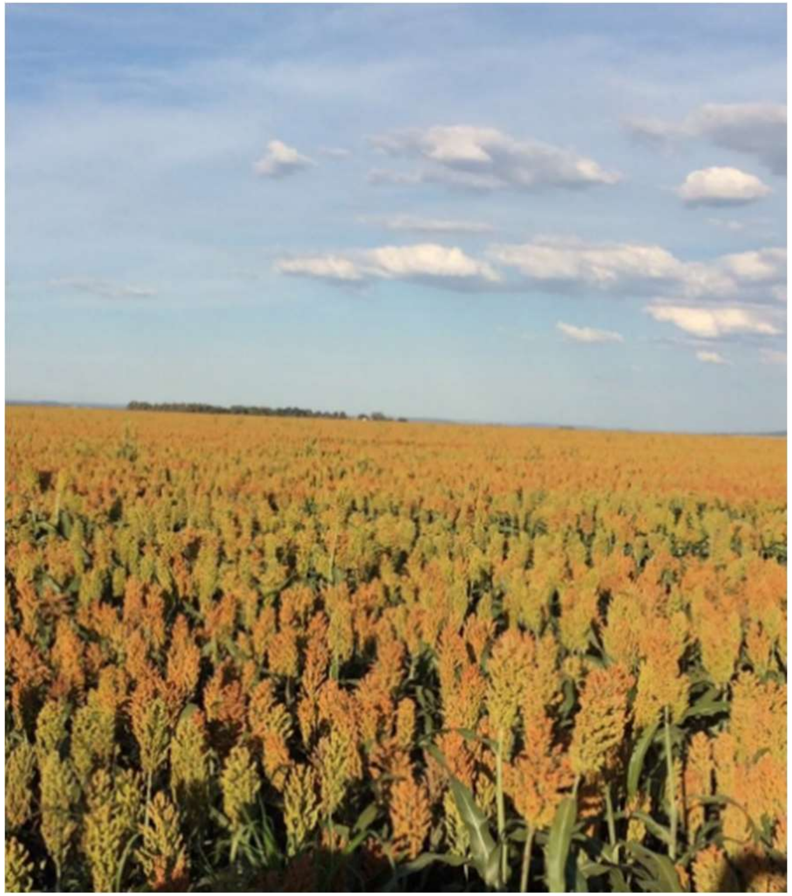


Gene Editing



- Opportunities for more rapidly deployment of traits in new hybrids via genomic selection
- In future gene editing will make a major contribution particularly for fine tuning GxM combinations

CONCLUSIONS



- Considerable improvements in productivity have been achieved in Australian sorghum in the last 20 years through a combination of GxExM
- Large opportunities exist to exploit the wealth of genetic diversity in sorghum to increase productivity
- New strategies integrating technologies to enable iterative cycles of prediction, exploration and deployment will be required

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