New wheat genetics for improving adaptation to changing climates

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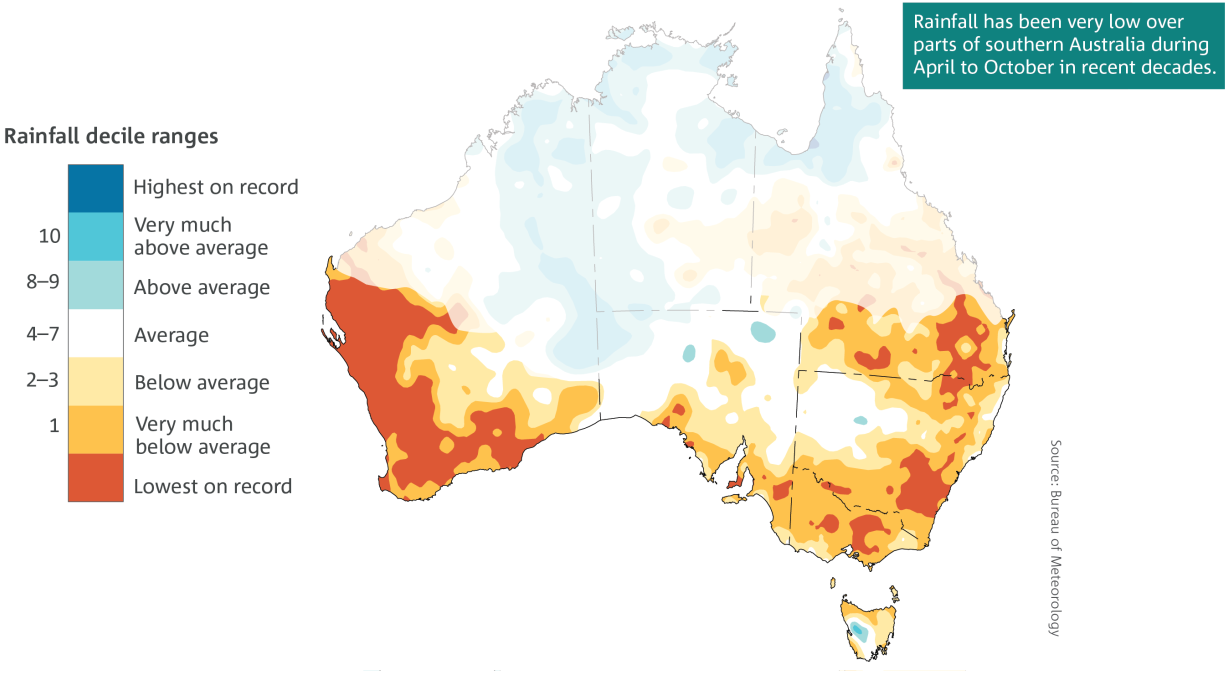
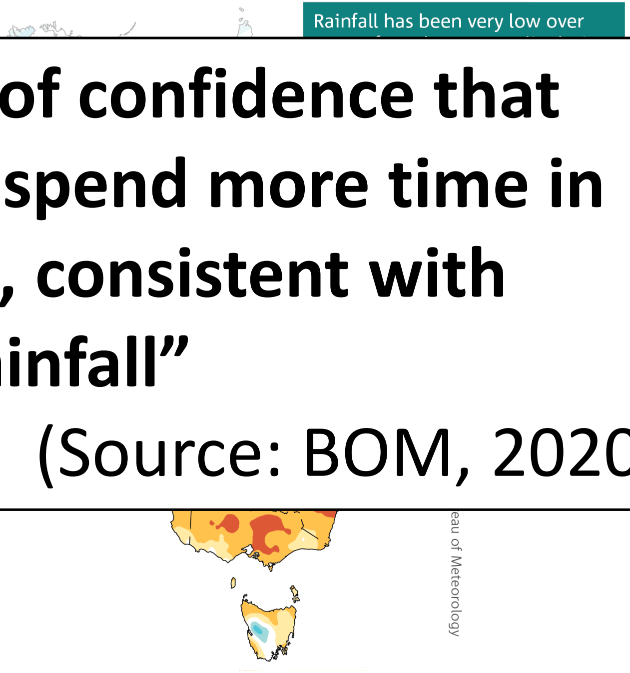
CSIRO

Changes in April-October rainfall



Above average, average or below average winter cropping rainfall for the period 1998 to 2018, in comparison with the entire rainfall record from 1900.

…..and the future



"There is a high degree of confidence that southern Australia will spend more time in drought in future years, consistent with projected declines in rainfall"

(Source: BOM, 2020)

April to October rainfall deciles for the last 20 years (1999–2018). A decile map shows where rainfall is above average, average or below average for the recent period, in comparison with the entire rainfall record from 1900. Areas across northern and central Australia that receive less than 40 per cent of their annual rainfall during April to October have been faded.

Current focus on breeding 'resistance' to climate change

In Australia, future climates are predicted to be characterized by:

- greater atmospheric concentrations of CO_2
- warmer air and soil temperatures (throughout growth and particularly at sowing and through grain-filling)
- earlier and more intense frost events
- prolonged drought (reflecting more frequent but smaller rainfall events)

Solutions to breeding for climate change in the literature include:

- Small breeding cycles to rapidly select adaptation genes in keeping with climate changes (Atlin et al. 2017)
- Evolutionary breeding using on-farm participatory engagement (Ceccarelli et al. 2010)
- Target 'stress alleles' from wild relatives to meet challenging environmental changes (Dempewolf et al. 2014)
- Trait-based focus to improve tolerance/resistance to heat and drought (Hunt et al. 2018)

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Climate change and the challenge with ‘resistance-based’, trait-breeding

Climate constraint	Trait(s)	Value proposition?	Genetic control?	Genetic variability available?	Ease of selection
Frost/heat	Grain number (fertility), grain size	Unknown – High?	Complex	No	Difficult
Heat	Leaf architecture/ orientation	Unknown – Small?	Largely simple	Yes	Largely simple
Heat	Photosynthesis	Unknown – High?	Complex	Some	Difficult
Heat	Respiration	Unknown – Small?	Complex	No	Difficult
Heat	Development	Unknown – High?	Simple	Yes	Simple
Heat	Tillering/biomass	Unknown – High?	Complex	Some	Difficult
Drought	Many (e.g. WUE, WSC, VPD-responsiveness)	Unknown – High?	Complex	Yes	Difficult
CO_2	Grain yield/protein	Unknown – High?	Complex	Some	Difficult

+ potential for high temperatures to challenge existing disease-breeding targets and duration/effectiveness

A need to focus on breeding now for adaptation to future changing climates

Future climate impacts on crop growth appear complex (interactions in temperature extent and duration, VPD, rainfall, and CO_2)(Mark Howden pers. comm.)

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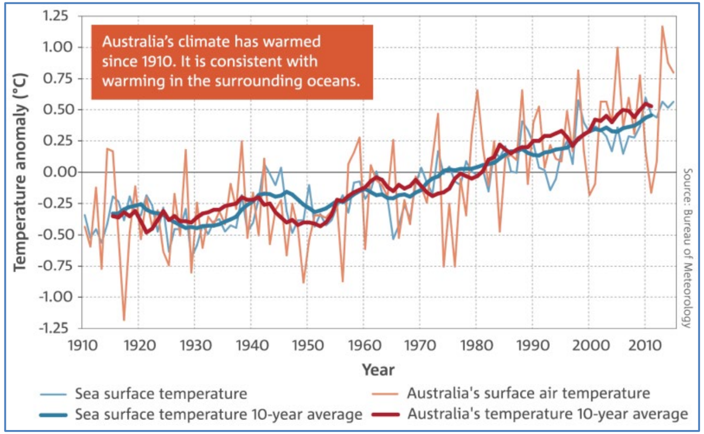
Future climate = ‘reliably predictable’ + significant climate variability



(source: www.climatechangeinaustralia.gov.au)

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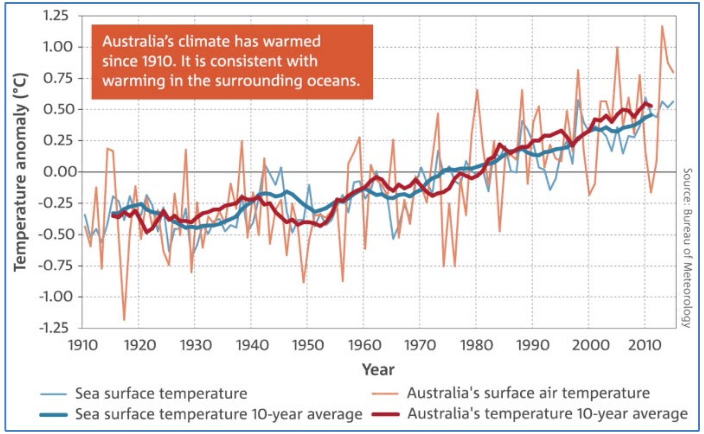
So, the question in breeding remains ‘how much of this forecast change is predictable across long breeding cycle timespans?’ Can we be confident that genes under selection with breeding <u>now</u> will be retained when needed in future climates?



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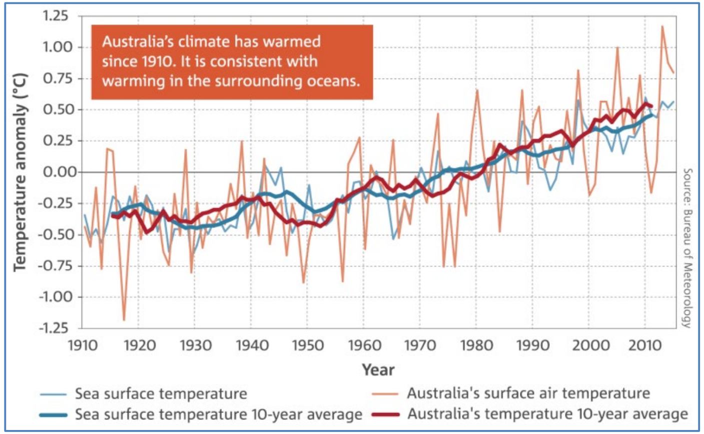
Do we need to change our thinking away from 100+ years of farming in reliable albeit rainfed systems? Is there need and is there opportunity to breed and develop cropping systems containing crop varieties that are more *opportunistic* than *resist* against climate change?



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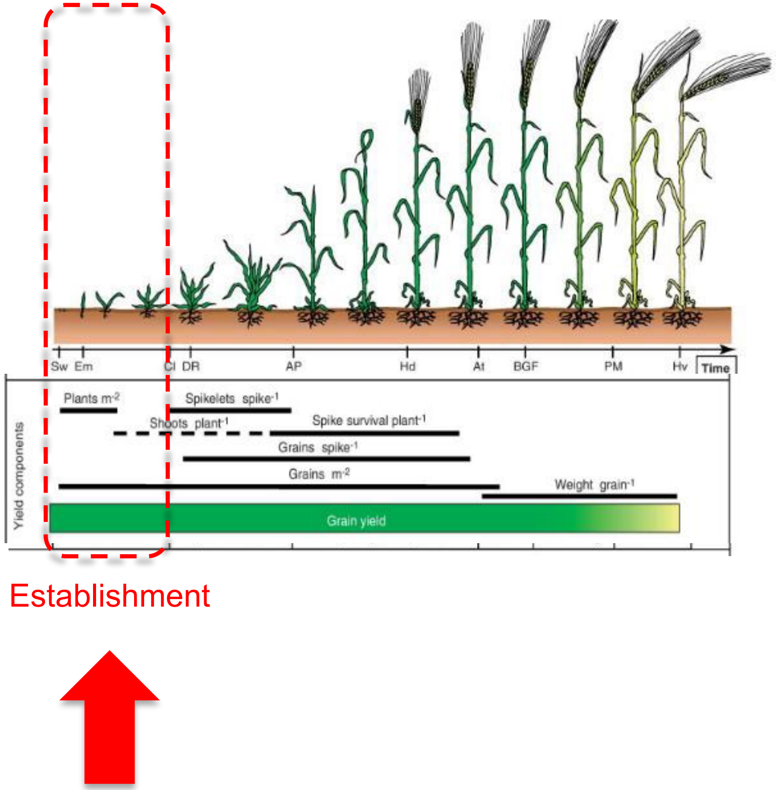
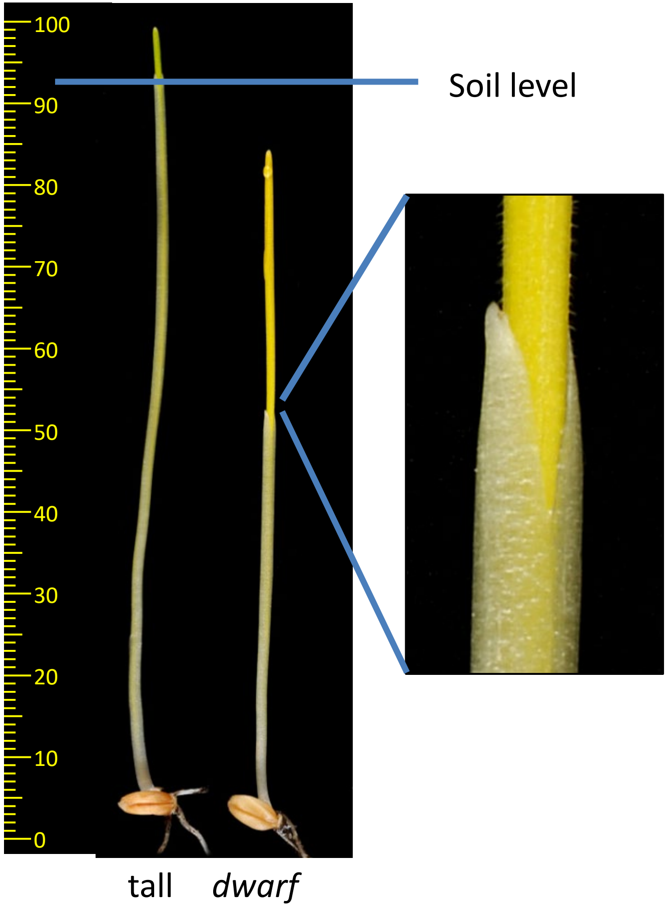
Opportunity breeding - Optimising crop establishment



The coleoptile: genetics to better link seed to soil surface



Coleoptile length determines how deep seed can be sown

Challenges in successful wheat establishment with changing climates

Declining autumn rainfall (April-May)

- later germination and risks with dry sowing
- greater reliance on stored moisture (deep sowing)

Early sowing of longer season varieties

- soil temperature can increase by 10-15^{o}C
- high soil temperatures reduce coleoptile length

Soil factors

- furrow in-fill with wind and rain

Key trait: long coleoptiles that ensure timely emergence and assured crop establishment

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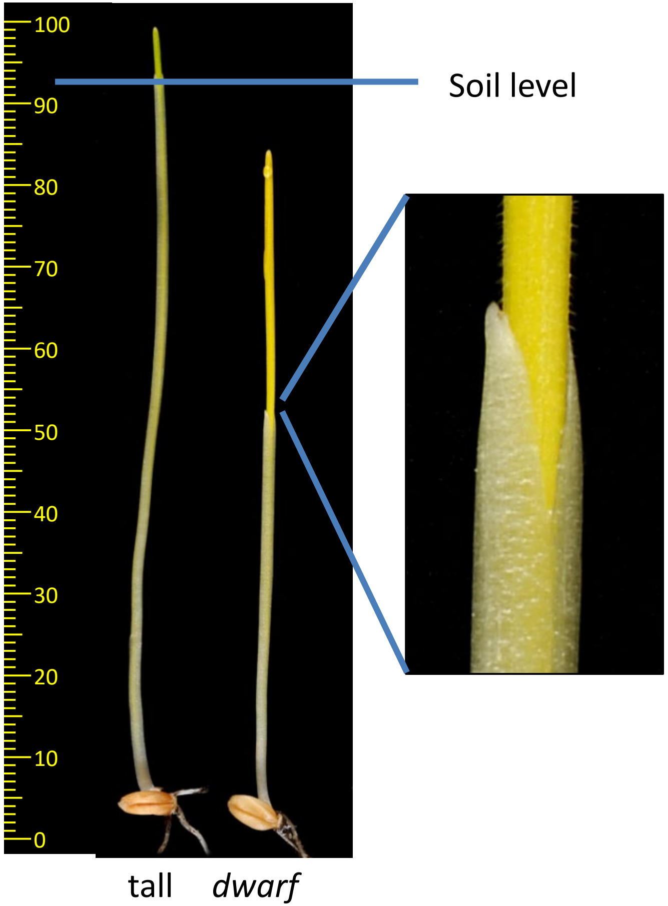

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Dwarfing 'height' genes affect coleoptile length:

Since the early 1960s, coleoptile length was known to be shortened and establishment reduced with Green Revolution dwarfing genes and particularly in warmer soils (Allan et al. 1962)

Replacing green Revolution with new dwarfing genes to increase coleoptile length – here sowing at 12cm depth

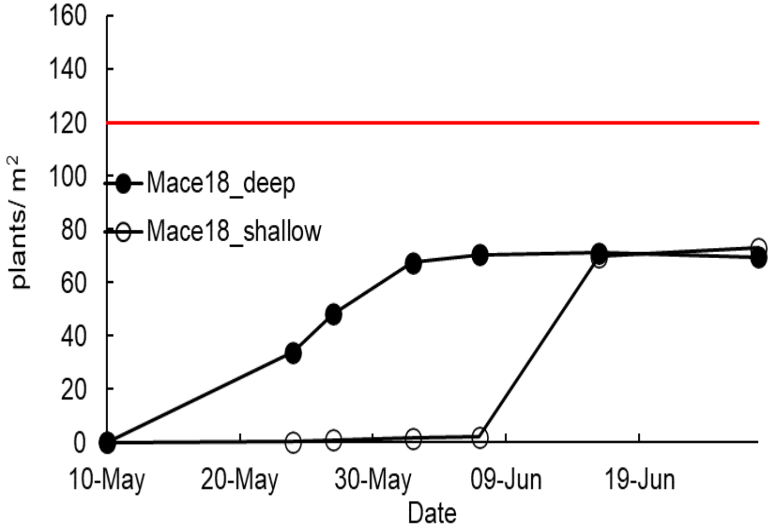
Green revolution *Rht2* dwarf

New Rht18 dwarf

Mike Lamond (SLR)

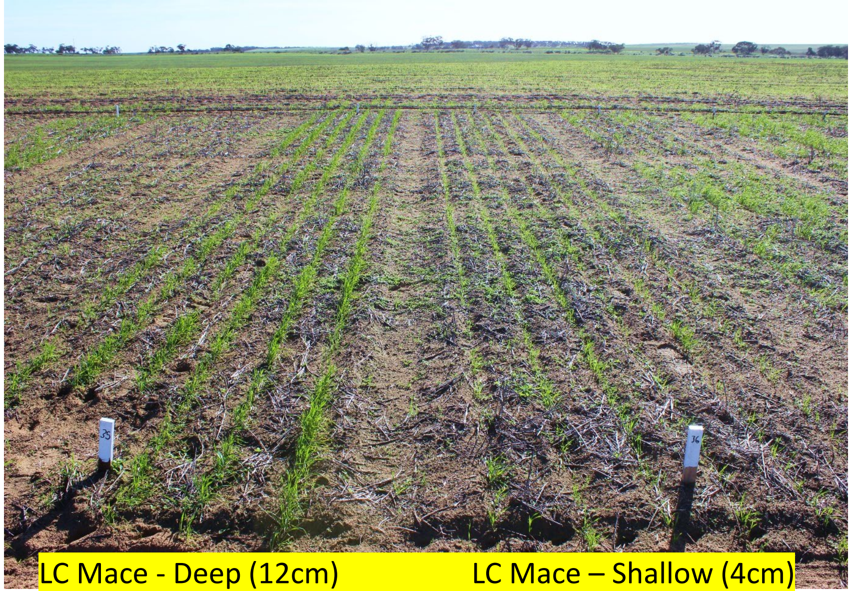
Accessing subsoil moisture for early germination and growth

Sowing Date: 10 May (seasonal break 31 May)



Source: Dr Bonnie Flohr, CSIRO

Summer fallow rainfall (Nov-Mar): 77 mm



Earlier shoot and root growth with sowing into deep moisture
(note increased weed numbers with late emergence of shallow depth)

Accessing subsoil moisture for early germination and growth

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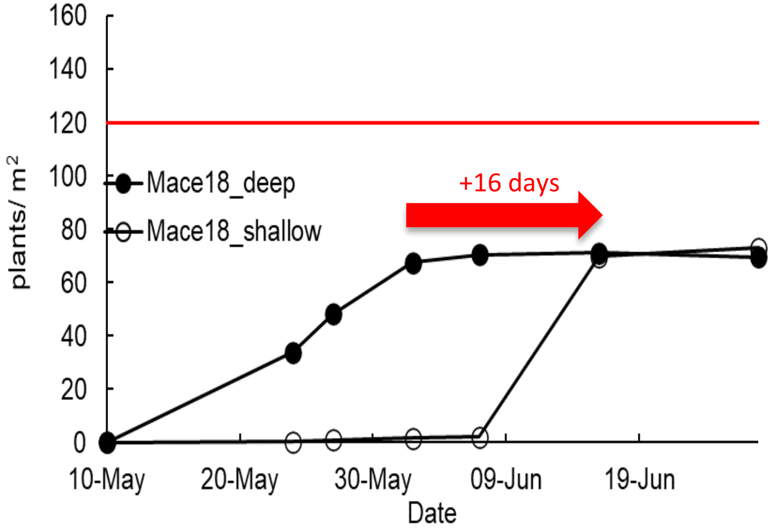

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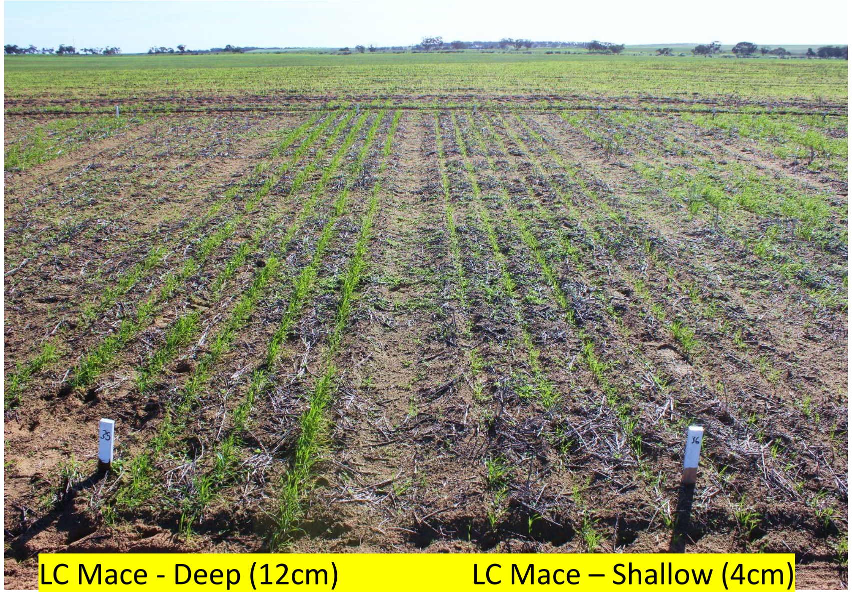

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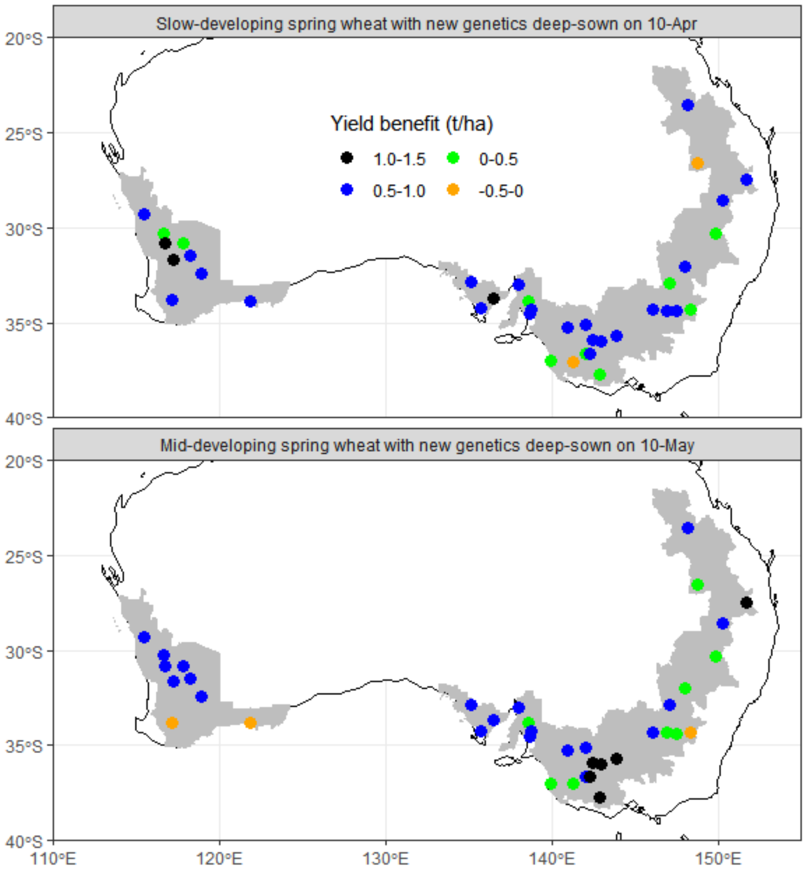
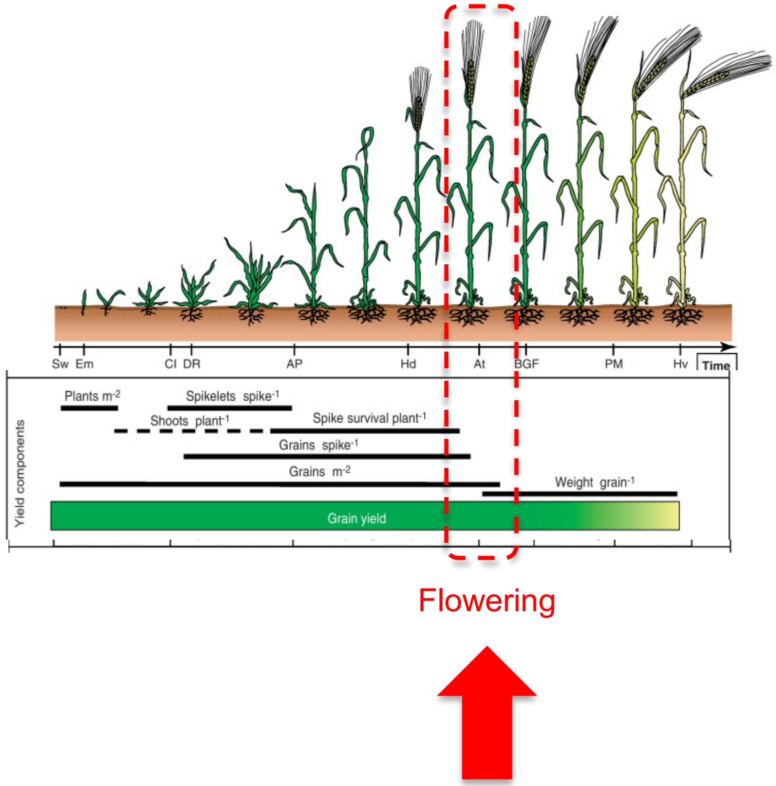
Modelled Yield Benefit of Long Coleoptiles Across Australia for Future Climates



18-20% mean annual yield benefit (1901-2020) of wheat with new genetics (long coleoptiles and greater early vigour) sown at 120mm depth compared to baseline wheat sown at 45mm depth at 37 sites

(Zhao et al. 2022; *Nature Climate Change*)

Opportunity breeding - Awnless wheats for changing climates



Removing awns for frost-, heat- and drought-prone wheat regions

Awns damage animals mouths to reduce the value of frost-, heat- and drought-affected crops for animal feed

Grower returns can be high for awnless, high soluble-sugar hay

Frost-damaged wheat crop

Wheat bailed as hay for feed

Reducing financial risk – delivery of new CSIRO-bred, awnless wheat varieties ‘LRPB Bale’ and ‘LRPB Dual’ for grain or hay/grazing

Key messages

Breeding for climate change (**and changing climates**) must be in train now but will be challenging:

- Target environments will be climatically complex
- With adequate genetic variation, breeding cycles still take time
- Selection relies on an established environment types (‘TPE’) - progress will be slower in breeding for variable climates than where change is unpredictable and less directed
- Risk potential loss in key climate adaptation alleles in absence of a reliable stress (and particularly if there is a performance cost in its absence!)

Clear evidence of climate change (and variability) now:

- Genetic variation exists that provides and prepares for climate adaptation now and into the future (e.g. long coleoptiles for deep sowing, development genes for targeted sowing dates, greater early vigour for late sowing opportunities, awnless wheats for grazing/hay etc.)
- Provide farmers with genetic options that best fits their farming system and allows them to ‘play the season’ while reducing financial and environmental risk

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