Drought tolerance

WGIN Stakeholders meeting

Rothamsted Research 27 November 2012

Pedro Carvalho, John Foulkes

Drivers for increasing drought tolerance and WUE

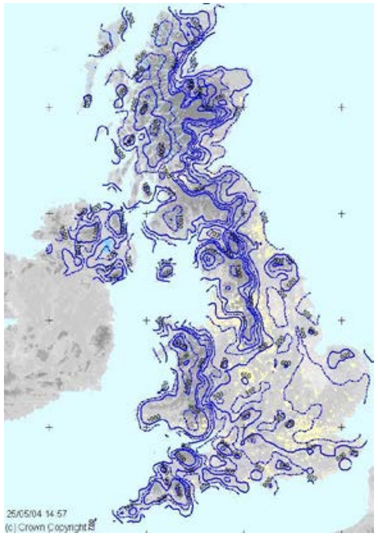
- **30% of UK wheat on drought-prone land, losses are 1-2 t ha^{-1} = >£50M per year.**
- **With climate change summer rainfall will decrease, potentially increasing these losses.**
- **Improving WUE will decrease crop water use in non-drought years, increasing water for:**
  - **use in irrigating other crops**
  - **increasing water flows in rivers and aquifer recharge.**

Impact of drought on UK wheat yields

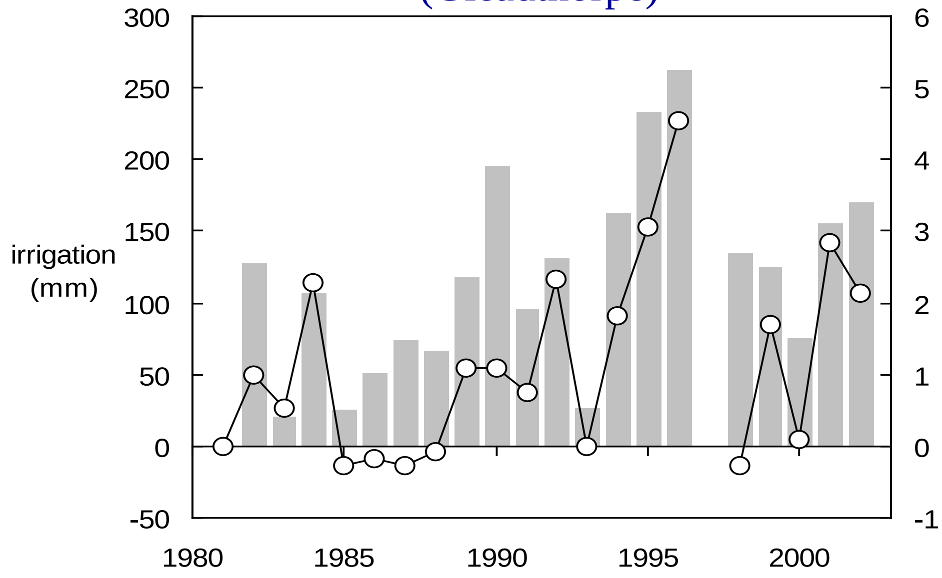
Distribution of available water to 1.2 m in UK wheat

Soil AWC mm	%
126-150	12
151-175	26
176-200	13
201-225	39
226-250	9

Rainfall contour map



Yield response to irrigation on light soil (Gleadthorpe)



Gleadthorpre Notts
AWC = 140 mm

Foulkes et al. 2001, 2002, JAg Sci; FCR 2007

How will UK weather change?

- Summer rainfall to decrease by 11 - 27% by 2080s; decrease 40% in S. England, less change in N. Scotland.
- Average summer temp. to rise by 3 - 4° C by 2080s; changes greatest in S. England (2.2 - 6.8°C) and least in N. Scotland (1.2-4.1°C).
- Sea levels are expected to rise by 36 cm by the 2080s.
- Extreme weather events are likely to become more common.

Predictions based UK Climate Projections (UKCP09)

WGIN Drought tolerance (2009-14)

OBJECTIVES

- **Identify traits for WUE and drought tolerance (DT) in elite winter wheat varieties. (*Yrs 1-2*)**
- **Identify QTLs for WUE and DT traits using one DH pop in an elite background. (*Yrs 2-3*)**
- **Develop one new DH pop for UK drought research. (*Yrs 2-4*)**

Traits associated with main drivers of yield under drought

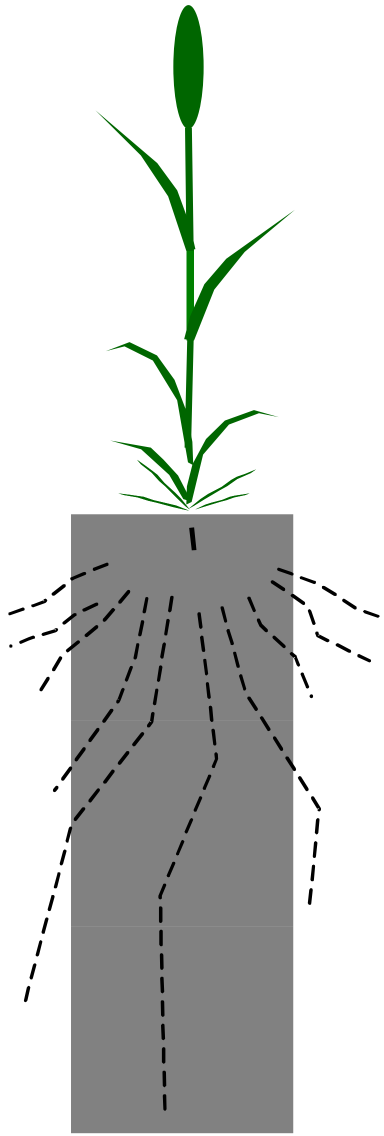
Yield = WU x WUE x HI

OPTIMIZE WUE

- WUE of leaf photosynthesis
- Low $^{13/12}C$ discrimination

MAXIMIZE HARVEST INDEX

- Pre-antheis partitioning to stem CHO reserves
- Functional stay green



MAXIMIZE WATER CAPTURE

- Increase root density at depth
- Distribute roots deeper
- Access to water by roots indicated by cooler canopy

EARLINESS

- Extend stem elongation phase
- Early onset GS31

WGIN Objective 9.1 Trait Identification

Drought tolerance trials 2009-10 & 2010-11

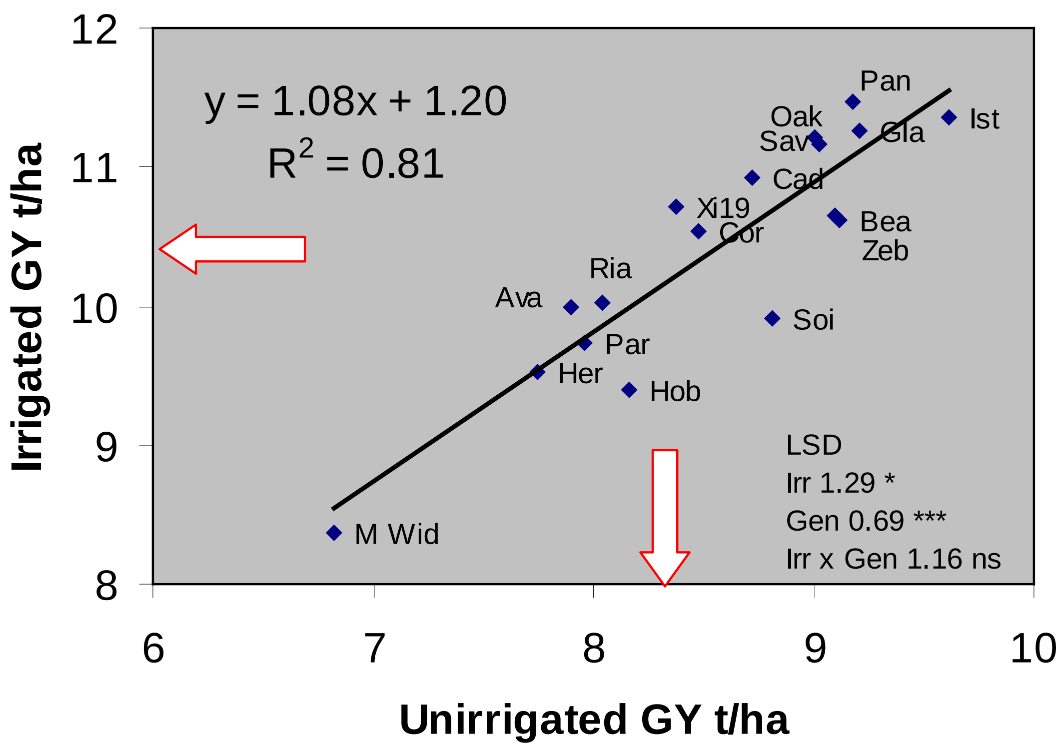
Split plot design (3 reps): plot size 1.6 x 12 m
Main plot: Fully irrigated (trickle irrigation)
Unirrigated

Split plot (variety):

1. Avalon *
2. Beaver
3. Cadenza *
4. Cappelle Desprez/Sterling
5. Cordiale
6. Glasgow
7. Hereward *
8. Hobbit
9. Istabraq
10. M. Widgeon *
11. Oakley *
12. Panorama
13. Paragon *
14. Rialto
15. Savannah
16. Soissons
17. Xi 19 *
18. Zebedee

* Common with NUE trial

Grain yield responses to Irrigation

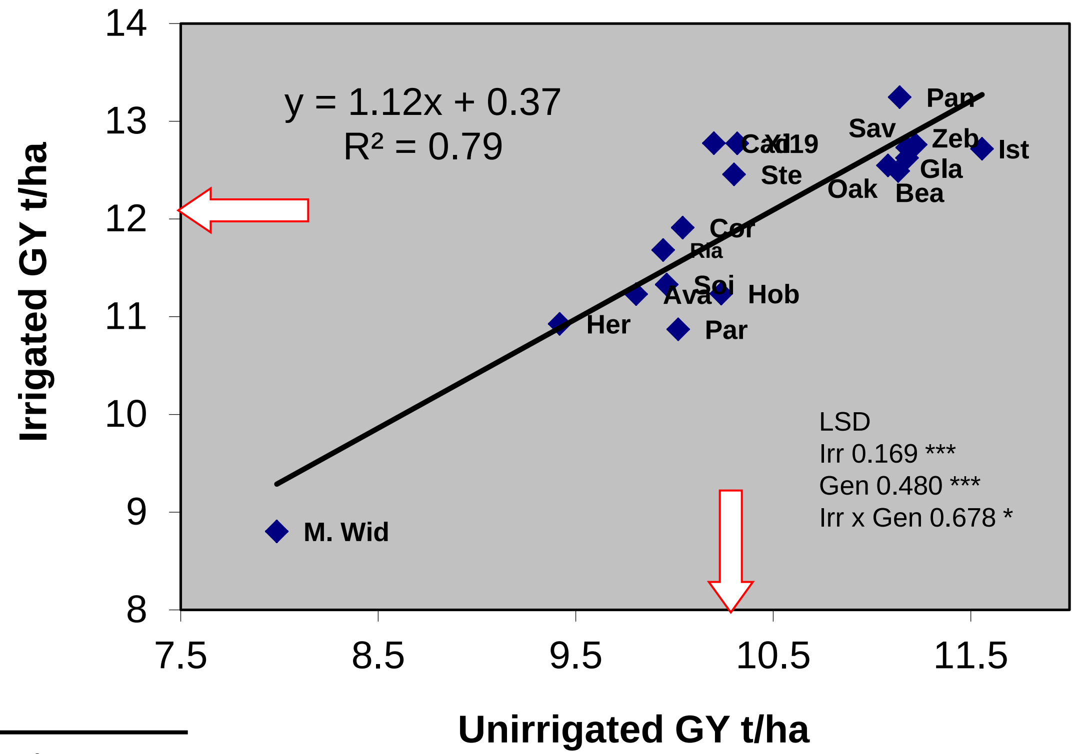


Rainfall (mm)		
	2010	LTM 75-09
Jan	33	54.1
Feb	41.6	43.4
Mar	36	45.7
Apr	24	44.4
May	18.2	45.6
Jun	69.2	58.7
Jul	42.6	49.8

Irrigated vs Unirrigated 19 July

Sutton Bonington 2010-11

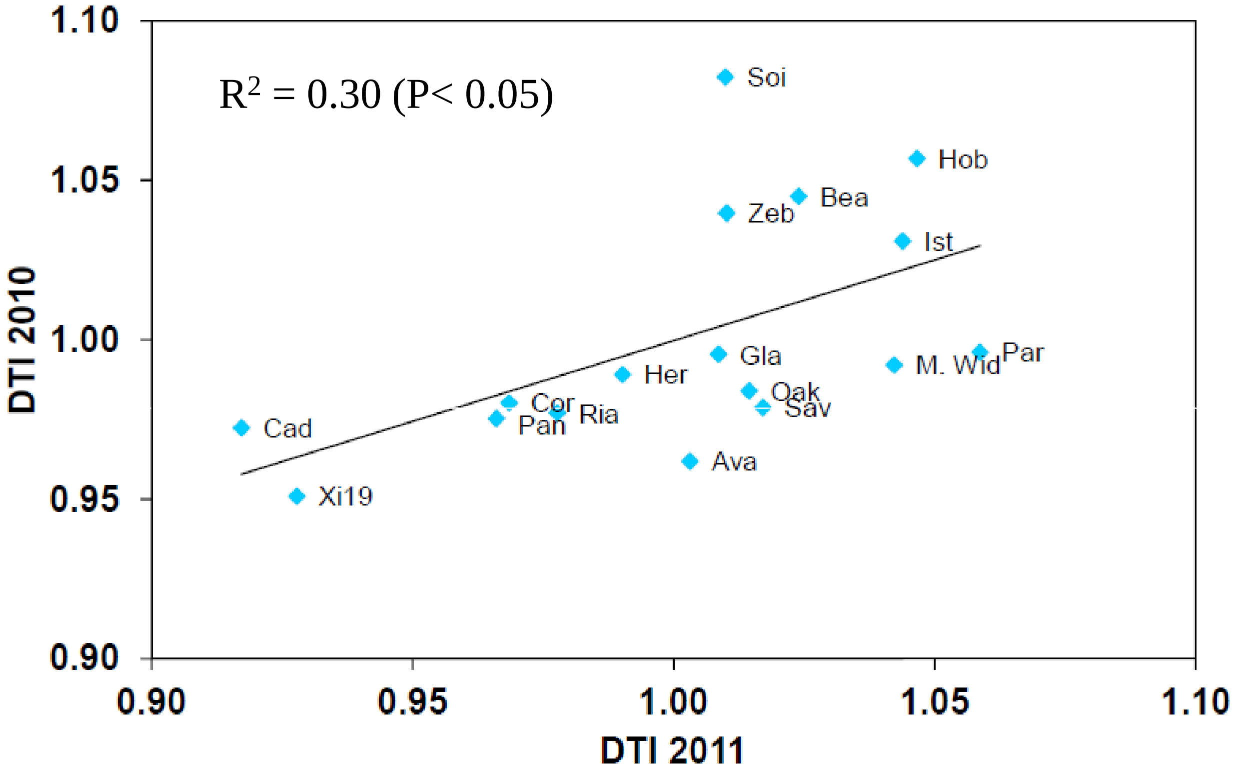
Grain yield responses to irrigation



	Rainfal (mm) 2011	LTM 75-10
January	33.0	53.4
February	44.6	44.0
March	1.2	54.1
April	23	43.4
May	27.8	45.7
June	45.4	45.6
July	17.8	49.8

Irrigated vs Unirrigated 11 July

Drought tolerance index: (Y_{Dr}/Y_{Irr}) / (mean Y_{Dr} / mean Y_{Irr})

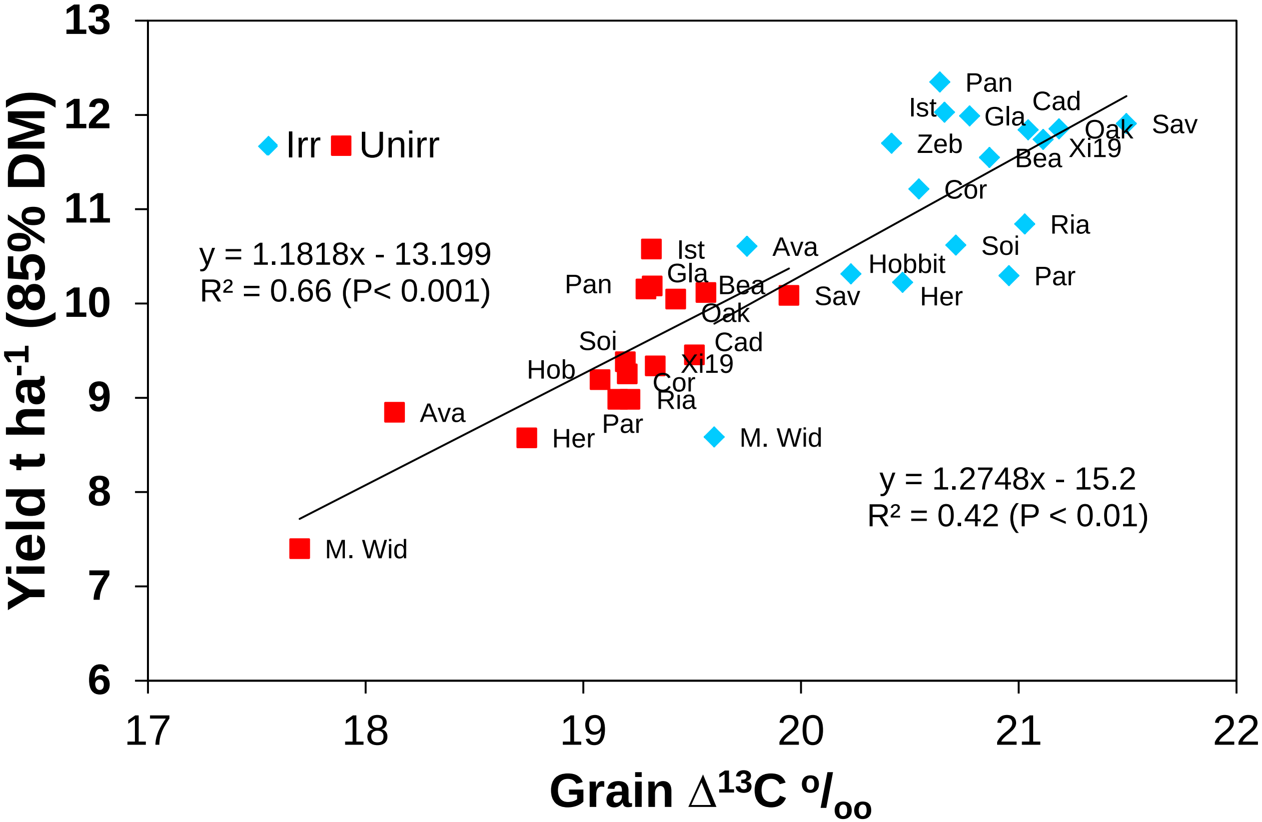


Wheat Genetic Improvement Network

Water use efficiency: definition and measurement

- **Water-use efficiency (WUE) is the ratio of above-ground dry matter production to evapotranspiration.**
- **$^{13}C/^{12}C$ isotope ratio of fixed CO_2 can be used as an indicator of WUE.**
- **Low discrimination against $^{13}CO_2$ → high WUE.**

$\Delta^{13}C$ vs grain yield in 18 wheat cultivars



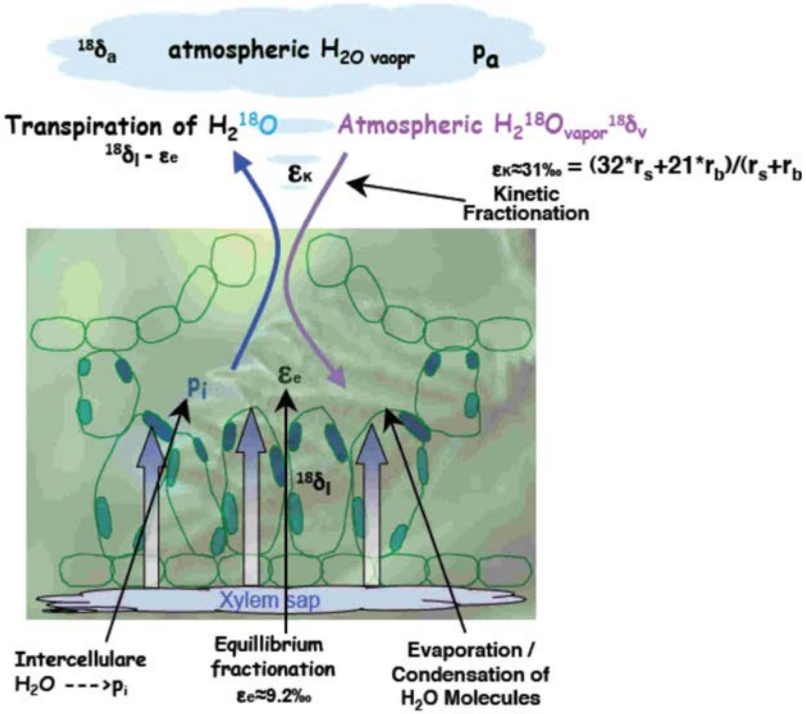
High WUE ← Low WUE

❖ ***Grain $\Delta^{13}C$ positively associated with yield under drought – indicator of ability to access water***

❖ ***Trade-off between WUE and season-long water use***

Sutton Bonington Mean 2009-10 & 2010-11

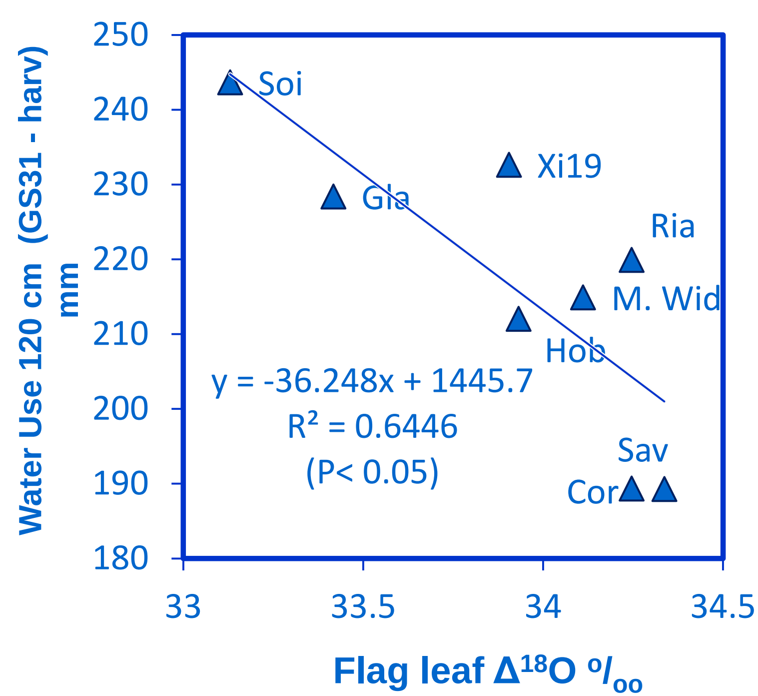
Oxygen isotope ratio technique ~ leaf transpiration



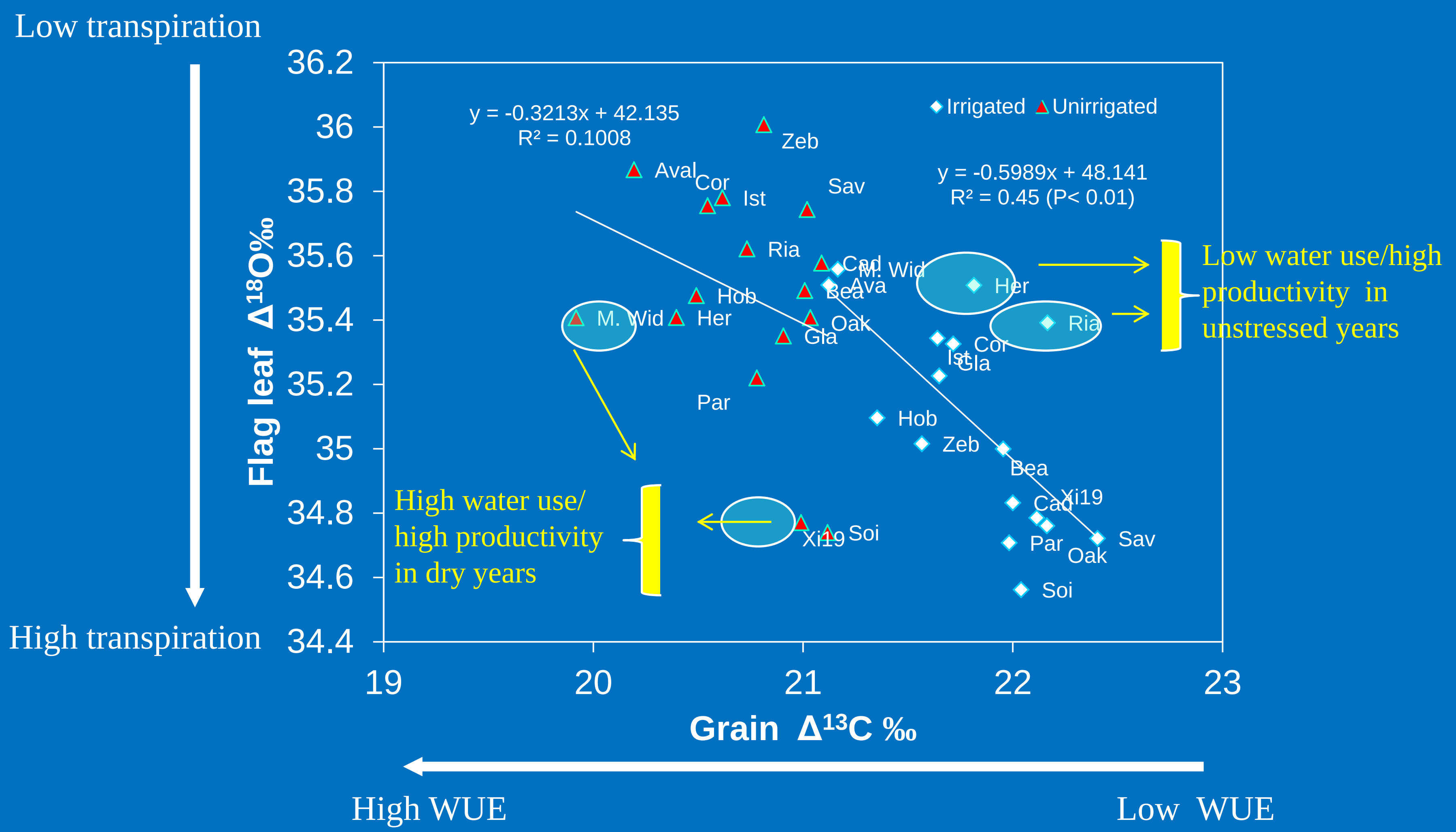
- **$^{18}O/^{16}O$ ratio determined by enrichment in the leaf water due to transpiration.**

- **Leaf water enriched due to preferential loss of the lighter $H_2{}^{16}O$ during evaporation.**

- **An increase in leaf transpiration decreases leaf T°C (hence intercellular vapour pressure) resulting in less $H_2{}^{18}O$ enrichment at the evaporating site.**

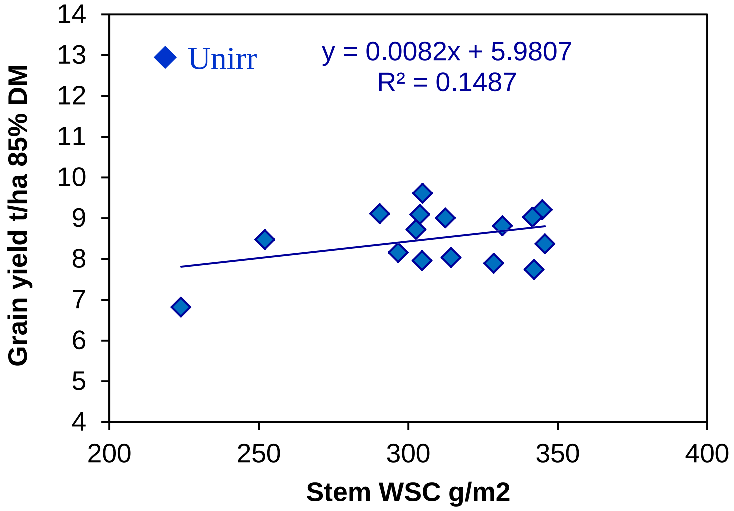


Relationship between $\Delta^{13}C$ and $\Delta^{18}O$ in 18 wheat cultivars (mean 2010 and 2011)

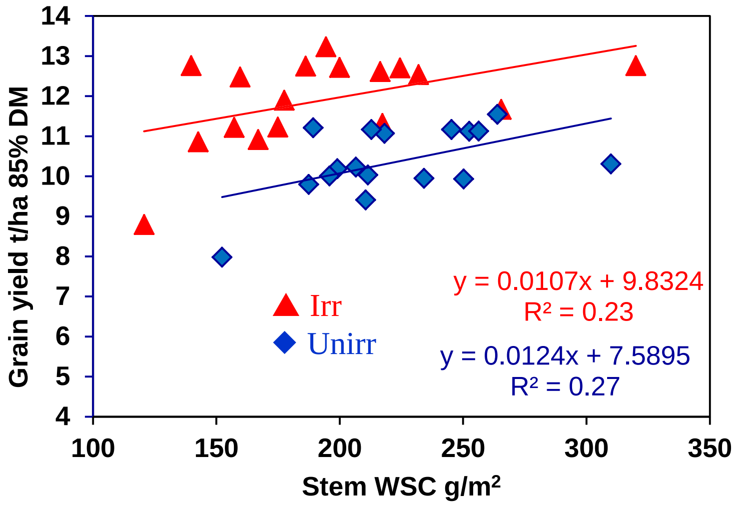


Other traits correlations: Stem WSC @ GS61+9d

Grain yield versus stem WSC reserves

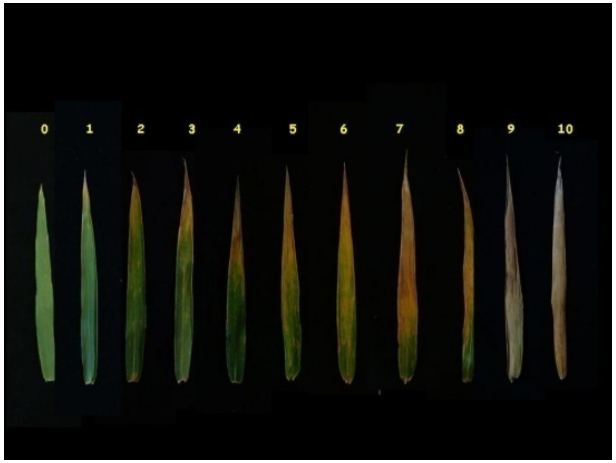


Sutton Bonington 2009-10



Sutton Bonington 2010-11

Flag leaf senescence score



Fitting the senescence data

$$score = p0 + p1*(1-\exp((-p2*STA/p1)) + (10-p1-p0/(1+\exp(-4*p4(STA-p5)/(10-p1-p0)))$$

score : visual senescence score

STA : thermal time after anthesis (°C.days)

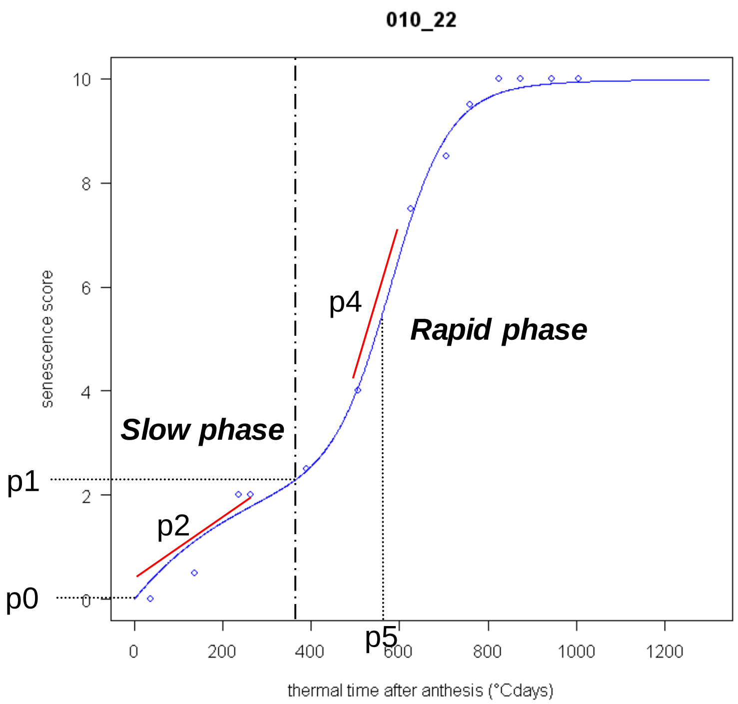
p0 : score at anthesis

p1 : score at the end of the slow phase

p2 : max rate of the slow phase

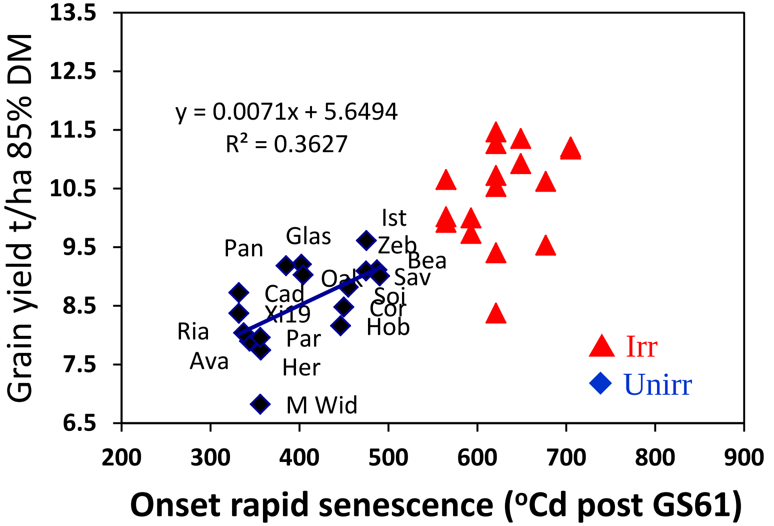
p4 : max rate of the rapid phase

p5 : date at which p4 is reached

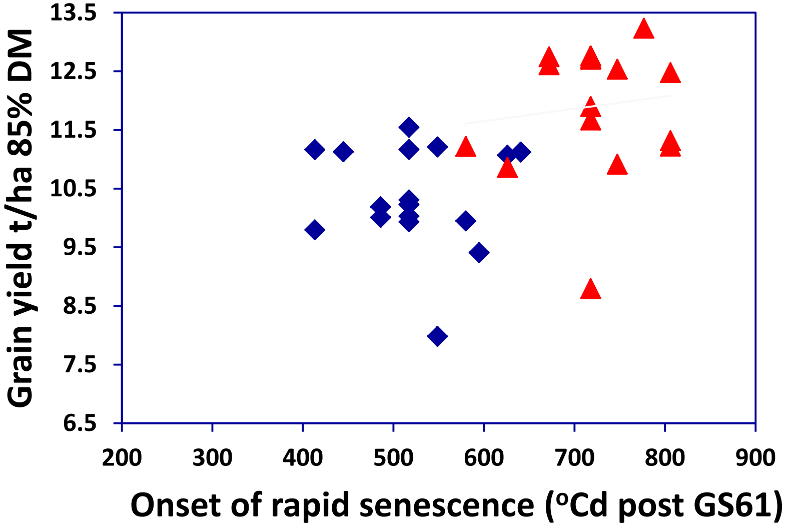


Other traits correlations: Flag leaf senescence

Grain yield versus Onset of Senescence



Sutton Bonington 2009-10



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Traits summary

Estimated value of traits to avoid or minimise effects of drought in UK

Variety character	**How it might work**	**Value**
High $\Delta^{13}C$ grain	Captures extra water	High
Flag leaf 'stay-green'	Extends grain filling during late drought	High
Low canopy $T^{o}C$/ deep roots	Captures extra water	High
High stem sugars	Buffers effects of post-flowering drought on grain filling.	Moderate
Early flowering	Advances grain filling before the drought risk period.	Neutral
Awns	Use less water per unit growth.	Slight

WGIN Objective 9.2 QTL Detection

<u>2010-11 and 2011-12 expts</u>

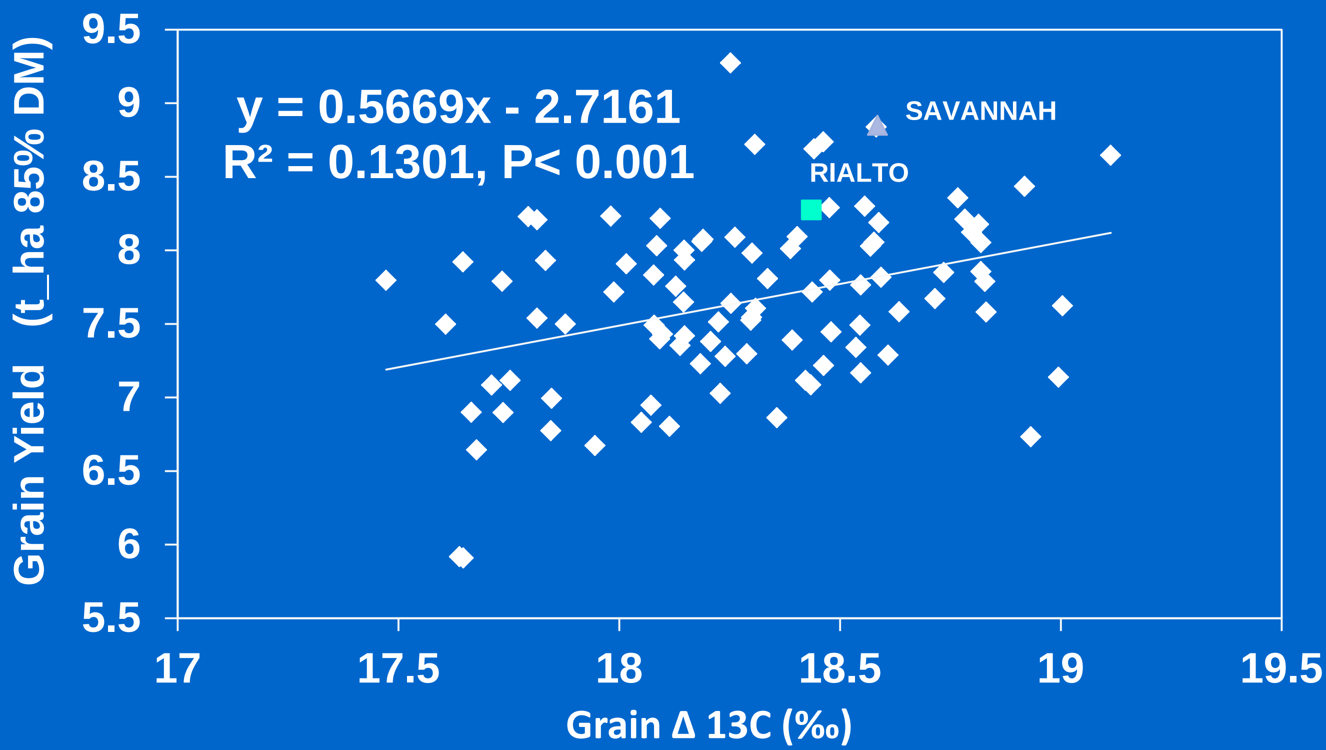
• Rialto x Savannah DH population for phenotying for yield physiological traits (94 lines and 2 parents)

• 2 sites: Nottingham - irrigated & unirrigated; JIC - unirrigated

• Target traits

- $\Delta^{13}C$ grain
- senescence kinetic
- stem WSC

Δ ^{13}C vs grain yield: Savannah x Rialto DH 2010-11



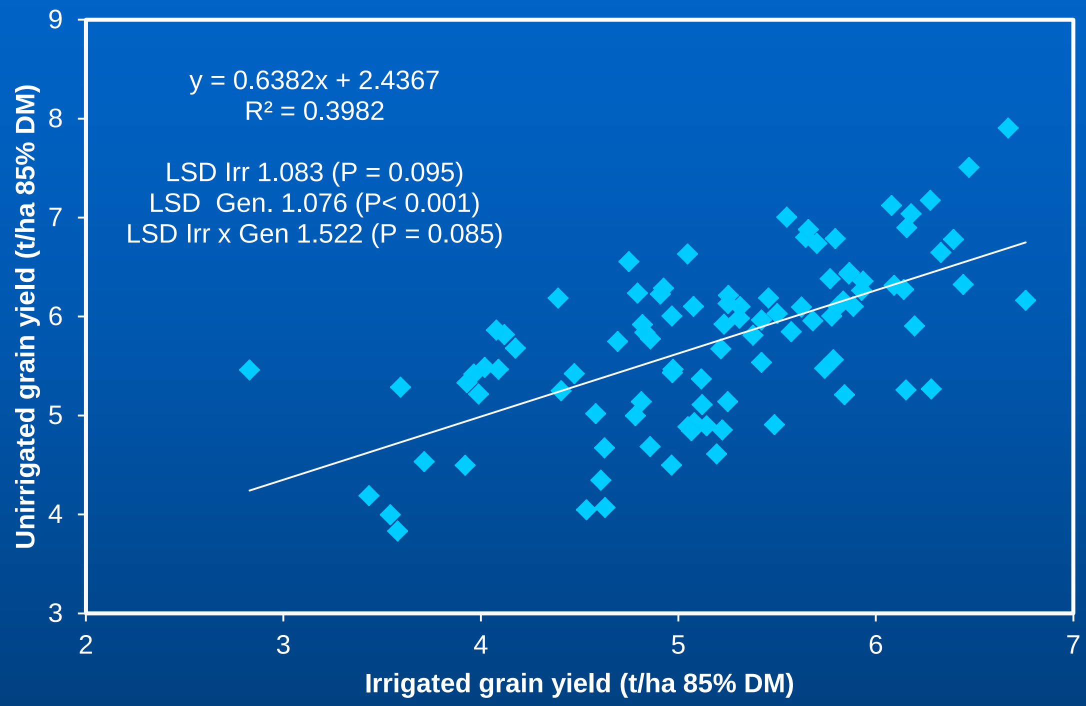
High WUE ← Low WUE

L2

L39

L47

Rialto x Savannah DH exp 2011-12



	Rainfall (mm)	
	2012	LTM 75-09
January	54.2	54.3
February	13.2	44
March	24.4	46.2
April	111.4	46.8
May	26.2	44.3
June	110.6	58.7
July	107.1	49.8

Preliminary Conclusions

- **Consistent differences in Drought Tolerance Index identified amongst panel of 18 cultivars.**
- **Ability to access water appears to be a key driver for productivity under UK drought.**
- **High $\Delta^{13}C$ correlated with grain yield under drought. Physiological basis ~ increased stomatal conductance, deeper roots?**
- **Measurement of stable isotopes in plant dry matter may be a useful phenotypic tool for speeding up breeding**
  - **Grain $\Delta^{13}C$**
  - **Flag leaf $\Delta^{18}O$**
- **Work is ongoing to:**
  - **identify opportunities to break linkage between WU and WUE**
  - **develop high-throughput screens for breeding**
  - **Understand the genetic basis of drought tolerance and WUE traits (QTL detection)**

WGIN Objective 9.3 Develop SSD Pop

- Paragon x Garcia (contrasting for drought tolerance traits)
- Population segregating for *Ppd1a*:
  - use WGIN resource to select against *PpdD1a* - ie make the pop photoperiod sensitive.
  - keep the pop large, so we can have flowering time strata and perform analysis within them
- F3 sown in October 2012, population is in excess of 350 lines

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