Water and heat stress through the crop cycle

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WGIN Stakeholders Meeting

Rothamsted Research 17 November 2010

The University of Nottingham

John Innes Centre

ADAS

Drivers for increasing drought tolerance and WUE

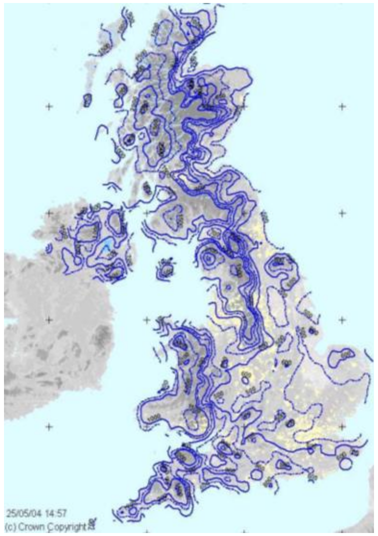
- **30% of UK wheat on drought-prone land, losses are 1-2 t ha^{-1} = >£50M per year.**
- **With climate change summer rainfall will decrease, potentially increasing these losses.**
- **Improving WUE will decrease crop water use in non-drought years, increasing water for:**
  - **use in irrigating other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

Impact of drought on UK wheat yields

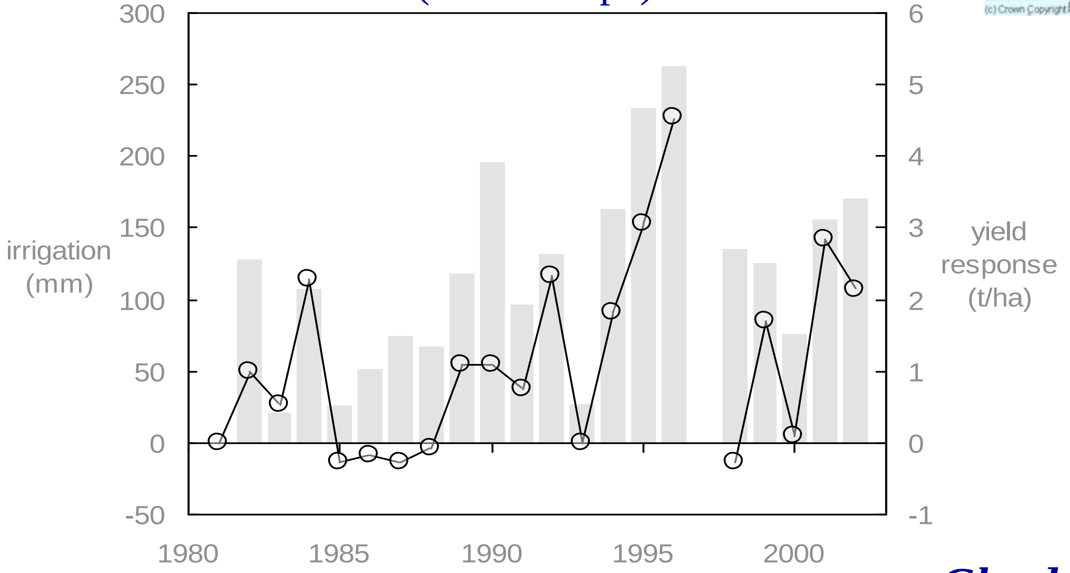
Distribution of available water to 1.2 m in UK wheat

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

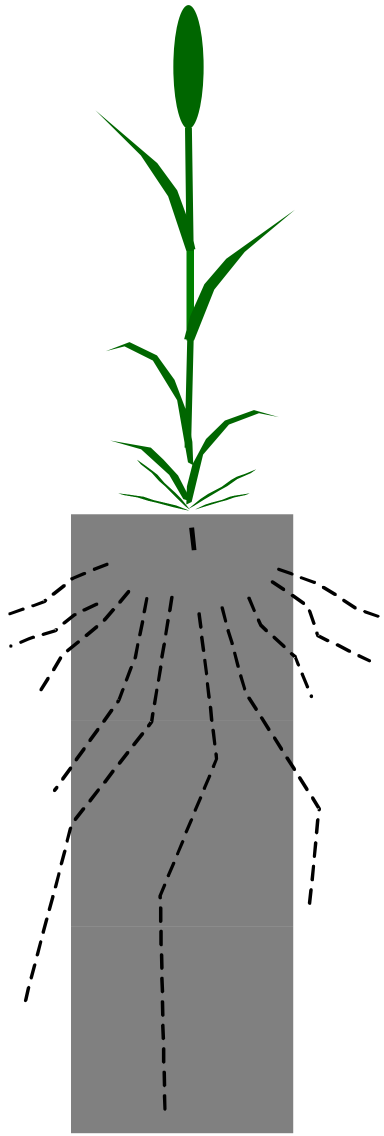
How will UK weather change?

- 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 (2.2-6.8ºC) and least in N. Scotland (1.2-4.1ºC).
- 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)

Traits associated with main drivers of yield under drought

$$Yld = WU \times WUE \times HI$$



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

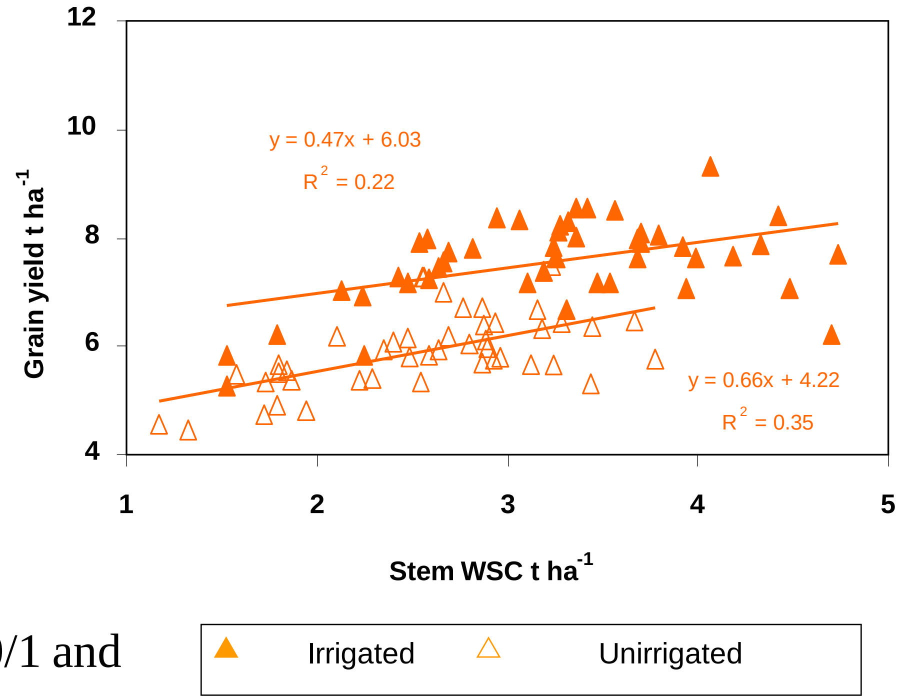
Controlled irrigation trials at Gleadthorpe and Sutton Bonington, Nottinghamshire, UK

Parental characterisation

Beaver x Soissons DHs (58 lines)

Trait	Parental expression	
	Beaver	Soissons
WUE ($^{12/13}$C discrim. $^{o}/_{oo}$)	18.5	17.5
Stem CHO reserves g m^{-2}	345	328
Stay-green	_	+
Rht genes	Rht2	Rht1
Awn 5A allele	Unawned	Awned
Ppd gene	ppd-D1	Ppd-D1

Stem water soluble CHO vs drought performance in Beaver x Soissons DH pop



Gleadthorpe Mean 2000/1 and 2001/2

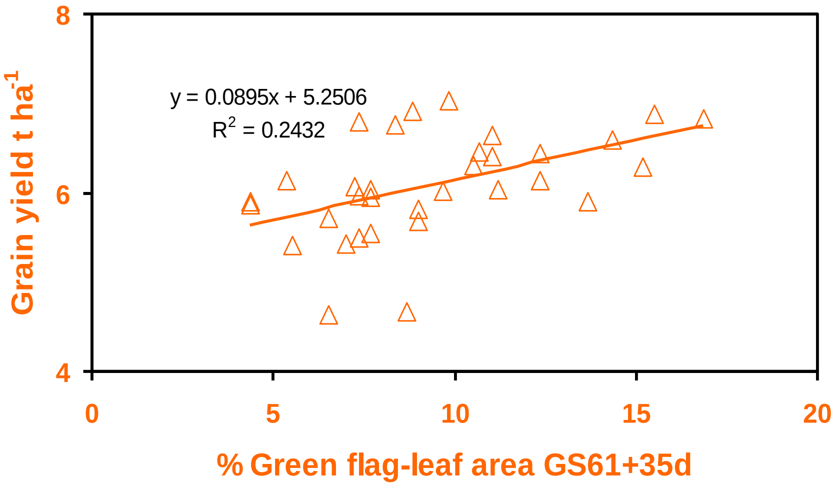
→Larger stem sol. CHO confers yield improvement under irrigation <u>and</u> under drought (not a drought-resistance trait per se)

Foulkes et al. 2007 FCR

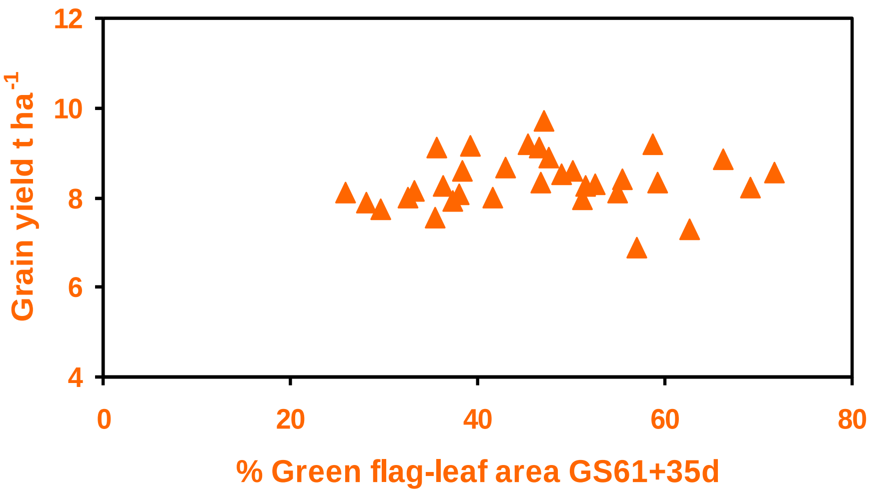
Relationship between stay green and drought performance

Beaver x Soissons DH population

Unirrigated



Irrigated



→ ***Delayed senescence confers yield improvement under drought <u>and</u> no disadvantage under irrigation***

Gleadthorpe Mean 2000/1 and 2001/2

Verma et al. 2004 Euphytica; Foulkes et al. 2007 FCR

Water use efficiency: definition and measurement

- **Water-use efficiency (WUE) is the ratio of above-ground dry matter production to evapotranspiration.**

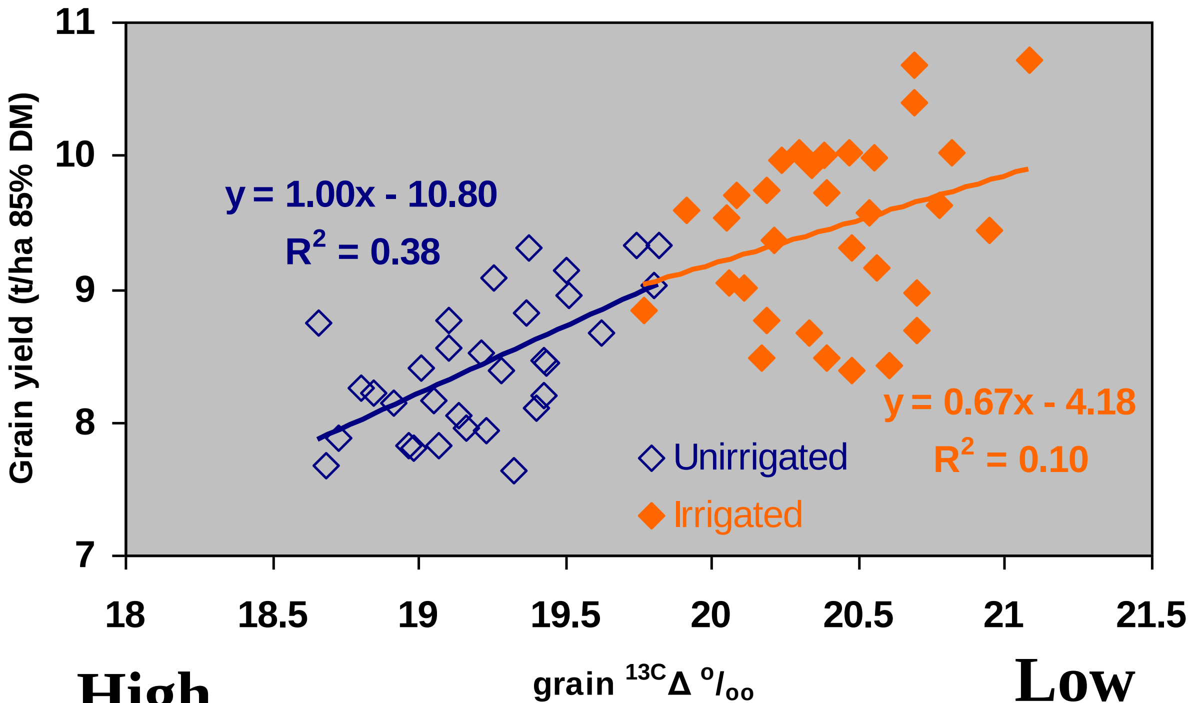
- **^{12}C1/^{13}C isotope ratio of fixed CO_2 can be used as an indicator of WUE**

- **Low discrimination against $^{13}CO_2$ → high WUE**

Beaver x Soissons DH population

Gleadthorpe Mean 2000/1 and 2001/2

WUE vs grain yield: Beaver x Soissons DH population



High WUE ← **Low WUE**

→grain $^{13C}\Delta$ positively associated with yield under drought – indicator of ability to access water
→ trade-off between WUE and season-long water use

Mean GL 2002-3 and SB 2004-5

Kumar et al. J Agric Sci 2010

Effects of major breeding changes on grain $^{13}\Delta$ $^{o}/_{oo}$ (WUE)

Irrigated :

–	- awns	no change
–	+ Rht2	+ 0.09* (WUE ↓)
–	+ 1BL.1RS	+ 0.31 ** (WUE ↓)

Unirrigated :

–	- awns	no change
–	+ Rht2	+ 0.22 * (WUE ↓)
–	+ 1BL.1RS	+ 0.30 ** (WUE ↓)

→ modern UK wheat cultivars may have lower WUE during grain filling than their predecessors, and therefore may require more water to fulfil their yield potential.

Beaver x Soissons DH population

Gleadthorpe Mean 2000/1 and 2001/2

Traits summary

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

Variety character	How it might work	Value
High ^{13}C Δ 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.	Slight
Early flowering	Advances grain filling before the drought risk period.	Neutral
Awns	Use less water per unit growth.	Slight

Traits for adaptation to heat stress

- Heat stress around flowering predicted to increase with climate change
  - > 31ºC reduce grain number (Ferris et al. 1998 Ann Bot)
  - > 27ºC reduce grain size (Wheeler et al. 1996 J Exp Bot)
- Warmer conditions could result in wheat flowering 3 weeks earlier by 2055 helping to avoid drought (Semenov et al. 2010 Nat. Prec.)
- Therefore increasing interest in development of wheat varieties which are tolerant to high temperature

Traits for adaptation to heat stress

- **Many drought-adaptive traits also useful under heat stress:**
  - **Canopy T°C ~ evaporative cooling**
  - **Stay-green ~ photosynthesis/chlorosis**
  - **Leaf glaucousness ~ reduce heat load**
  - **Awns ~ maintain photosynthesis**

- **Some traits specific to heat tolerance**
  - **Membrane thermostability ~ maintain membrane integrity/reduce ion leakage from cell**
  - **Flowering window ~ reduce spikelet sterility**
  - **Starch synthase activity ~ reduce inhibition of SS**

Activity 9, Drought tolerance (2009-14)

Obj 1. **Identify traits for WUE and drought tolerance (DT) in elite winter wheat varieties. (*Yrs 1-2*)**

Obj 2. **Identify QTLs for WUE and DT traits using one DH pop in an elite background. (*Yrs 2-3*)**

Obj 3. **Develop one new DH pop for drought research. (*Yrs 2-4*)**

Obj 4. **Identify novel genes and alleles for WUE and DT using the AE Watkins and Gediflux collections. (*Yrs 2-4*)**

Obj 5. **Collate a diverse germplasm (cvs, advanced lines) for future association genetics studies. (*Yrs 4 -5*)**

WGIN 2 (9.1, Trait identification)

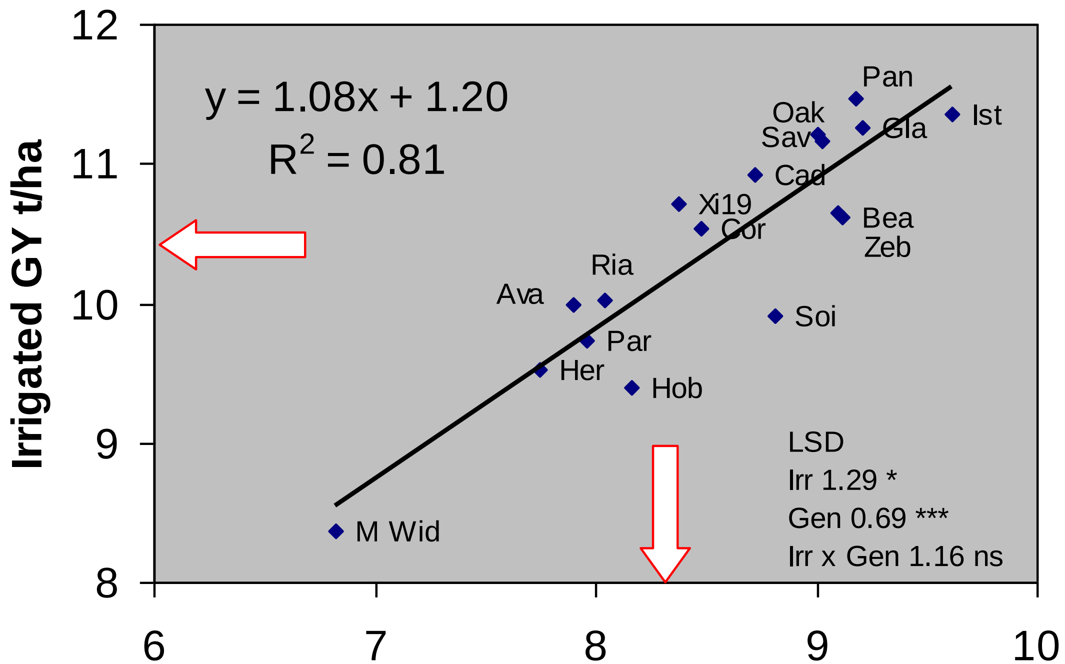
<u>2009-10 and 2011-12 expts</u>

18 elite cultivars phenotyped for yield and physiological traits

~ Nottingham - irrigated (trickle irrigation) and unirrigated

Varieties tested:	
1. Avalon	10. M. Widgeon
2. Beaver	11. Oakley
3. Cadenza	12. Panorama
4. Capelle Desprez	13. Paragon
5. Cordiale	14. Rialto
6. Glasgow	15. Savannah
7. Hereward	16. Soissons
8. Hobbit	17. Xi19
9. Istabraq	18. Zebedee

Grain yield responses to irrigation



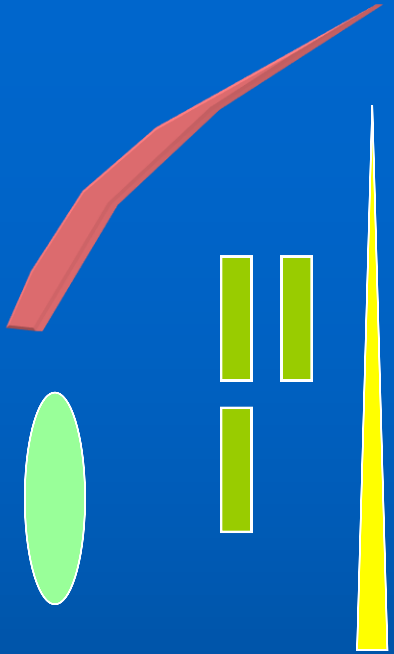
Sutton Bonington 2009-10

	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

Glasgow Irrigated vs Unirrigated 19 July

Measurements

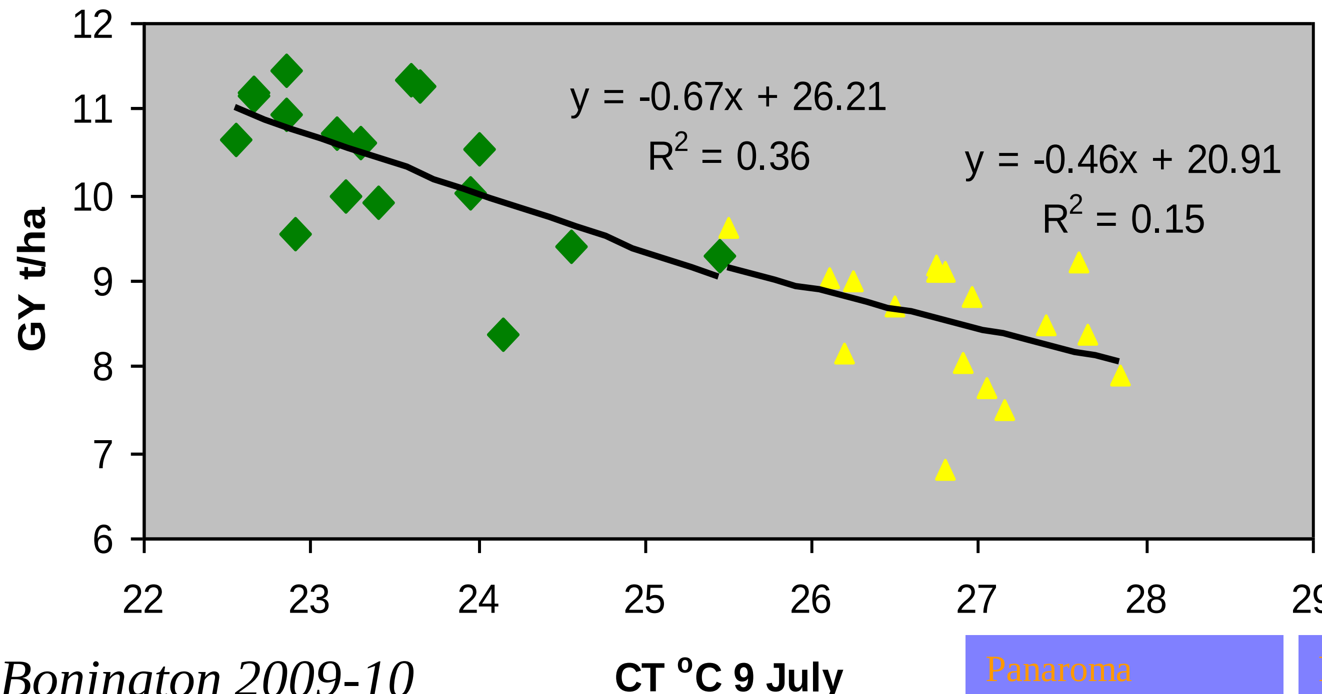
- **Combine grain yield, yield components**
- **DM & partitioning at GS31, GS61, harvest**
- **% stem WSC at GS61+10d**
- **Leaf senescence kinetics for L1, L2 and L3.**
- **Stomatal conductance/photosynthetic rate using Licor (unirrigated)**
- **Canopy temperature**
- **Water use ~ gravimetric analysis of soil cores (unirrigated, 18 varieties)**
- **^{13}C Δ grain ~ leaf WUE**
- **^{18}O Δ flag leaf ~ leaf transpiration**



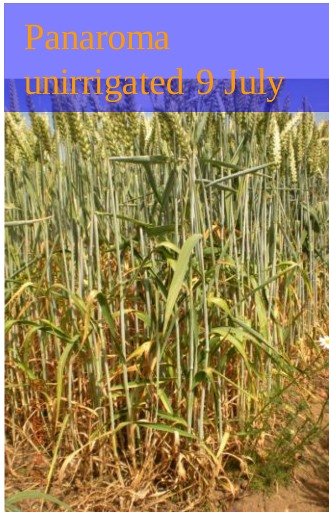
Leaf gas exchange

Canopy temp.

Canopy Temperature (indicative of access to water) post-anthesis vs grain yield



Sutton Bonington 2009-10



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

	R^2	Prob
Canopy T°C vs DTI	**0.16**	**0.11**
Anthesis date vs DTI	**0.04**	**0.43**
Plant height vs DTI	**0.01**	**0.81**

WGIN 2 (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
- Extend molecular map as necessary with Dart and SSR
- Target traits
    - $^{13}C\ \Delta$ grain
    - senescence kinetics
    - canopy temperature
    - stem WSC

WGIN 2 (9.3, Develop new DH pop)

- Development of one DH population for UK drought research
- Candidate F1(s) made at JIC (June 2010)
- Cross to maize (Dec 2010)

Conclusions

- **Ability to access water appears to be key driver for productivity under UK drought.**
- **Grain $^{13}C\ \Delta$ positively correlated with yield under drought. Physiological basis ~ more open stomata during grain filling: deeper rooting?**
- **Senescence correlated with Drought Tolerance Index. Physiological basis ~ dehydration postponement, deeper roots?**
- **Work is ongoing to:**
  - **test traits as components of drought tolerant ideotype: $^{13}C\ \Delta$ grain, $^{18}O\ \Delta$ leaf, canopy T°C, stay-green, stem WSC …**
  - **identify opportunities to break linkage between WU and WUE**
  - **develop high-throughput screens for breeding**
  - **Understand the genetic basis of traits (QTL detection, association genetics)**

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