JIC update

WGIN Management

Sutton Bonington 6th November 2012

WGIN gene discovery

UK adapted

Historic European (winter)

Landrace (Watkins)

Phenotyping

Germplasm → Segregating populations → **Q**uantitative **T**rait **L**oci → **N**ear **I**sogenic **L**ines → Gene cloning

Genotyping

The value to breeding of single loci

QTL validation using NILs – Heading date Church Farm 2012

QTL plots on website

QTL	trait	stream	BCparent	no A	no B	t-stat	df	Ava mean	Cad mean	p.val	signif	
1B	DTHD	AC104-96-10	Cad	6	6	-4.04	9.9	2.8	4.7	0.0024	***	Avalon early
1B	DTHD	AC104-96-3	Cad	3	3	-2.12	4	2.7	3.7	0.1012		
1B	DTHD	AC104-64-10	Cad	3	3	-1.06	4	4.3	5.3	0.3486		
1D	DTHD	AC33-36-2	Cad	6	6	5.28	8.5	8.2	5.2	0.0006	***	Cadenza early
1D	DTHD	AC33-11-5	Cad	3	6	4.78	6.8	5.7	3	0.0022	***	
1D	DTHD	AC120-28-1	Cad	6	6	3.31	9.7	7.5	5.3	0.0081	***	
1D	DTHD	AC120-7-1	Cad	3	3	7	2	5.3	3	0.0198	**	
1D	DTHD	AC158-14-1	Cad	6	3	2.65	4.4	8.3	5	0.0516	*	
1D	DTHD	AC163-12-1	Cad	3	3	2	2	5.3	4	0.1835		
1D	DTHD	AC120-7-3	Cad	3	3	1.41	4	4.3	3.7	0.2302		
6A	DTHD	AC104-6-8	Cad	9	9	-4.57	12	2.1	4.1	0.0006	***	Avalon early
6A	DTHD	AC89-5-1	Cad	9	9	-2.97	12.6	3.4	5.2	0.0111	**	
6A	DTHD	AC104-6-9	Cad	9	9	-1.34	15.9	2.2	3.4	0.1986		
6B	DTHD	AC75-101-3	Cad	12	12	-5.33	21.4	2.5	5	0	***	Avalon early
6B	DTHD	AC75-101-6	Cad	6	3	-1.54	7	3.7	4.7	0.1678		
6B	DTHD	AC113-106-3	Cad	9	9	-0.96	16	3	3.6	0.3524		
6B	DTHD	AC75-101-1	Cad	3	6	-0.8	3.6	3.3	4.2	0.4708		




Avalon x Cadenza large plot trial 2012/2013

Avalon x Cadenza NILs

3 x reps of 600 entries including controls

	Avalon Background	**Cadenza background**
Number of lines	225	342
QTL	1B ear emergence	1B ear emergence
	1D ear emergence	1D ear emergence
	2A height	2A height
	2D height	2D height
	2D yield	3A height
	3B height	3B height
	5A yield	3B yield
	6A height	6A height
	6B height	6B ear emergence & height
	6B height &7D yield	
	1D ear emergence & 5A yield	
	7B yield	
	7D yield	

- Difficult drilling conditions, 1 rep in so far
- Will measure
    - height
    - heading
    - yield
    - yield components
- Second season in ’13-14

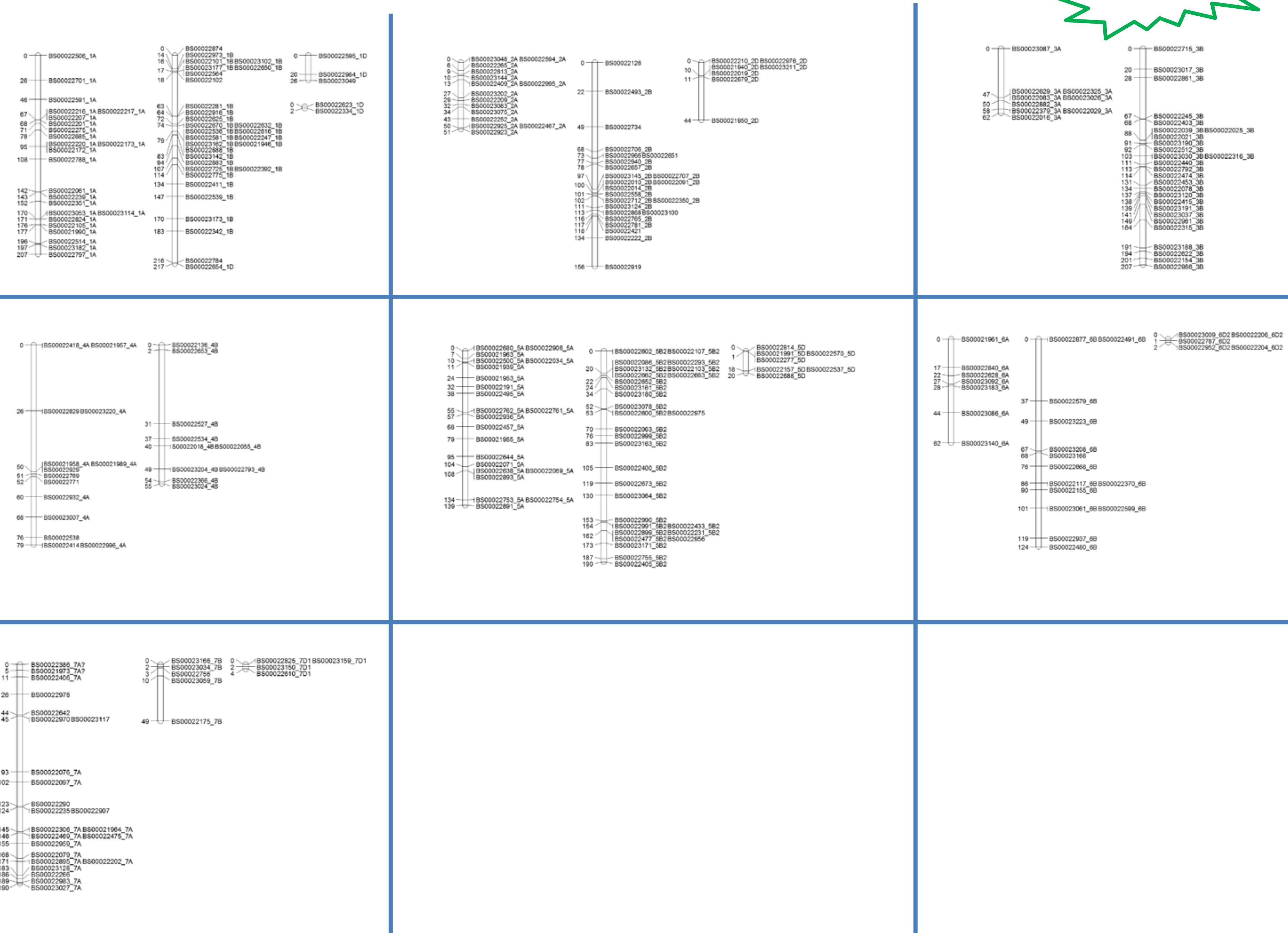
New populations

- Chinese Spring x Paragon, 287 F8 individuals
  - Map produced as part of CiRC-
  - 257 KASP markers mapped

- Paragon x Synthetic
- Paragon x Garcia
  - Target size 250
  - F_4 seed now

Chinese Spring x Paragon Map 18/5/12

map on website



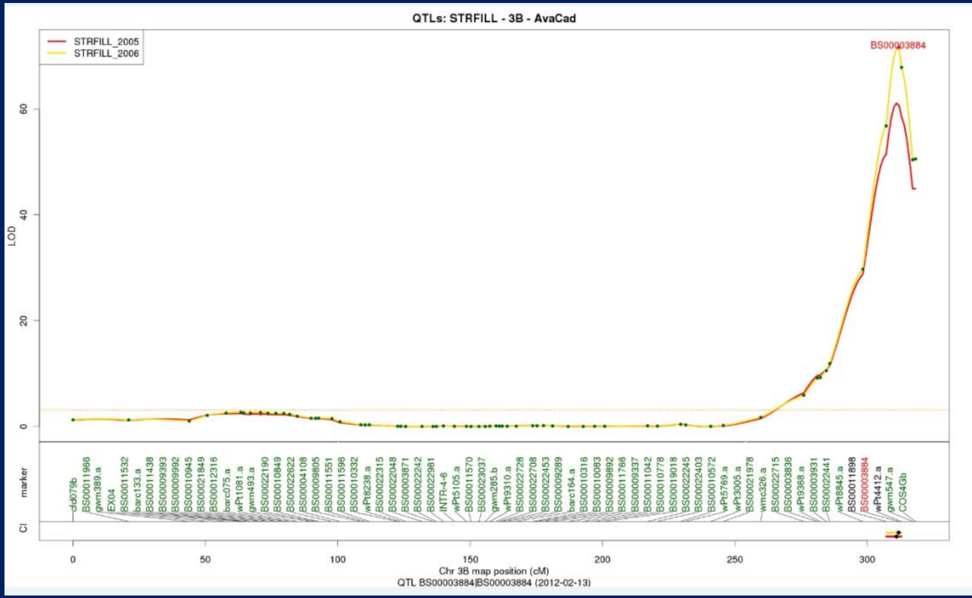
The other WGIN NILs

<u>1. Straw Wall NILs</u>:

Phenotypic differences in straw wall thickness were not confirmed in the 2D and 7D NILs, following trials in both field and glasshouse.

More success with 3B QTL; NILs which appear to have thin walls in a Cadenza background have been drilled in replicated trials this autumn (BC_2F_4), and those with thick walls in an Avalon background have been sown in the field for the first time (BC_2F_3).

Data provided to INRA for 3B meta analysis



QTL

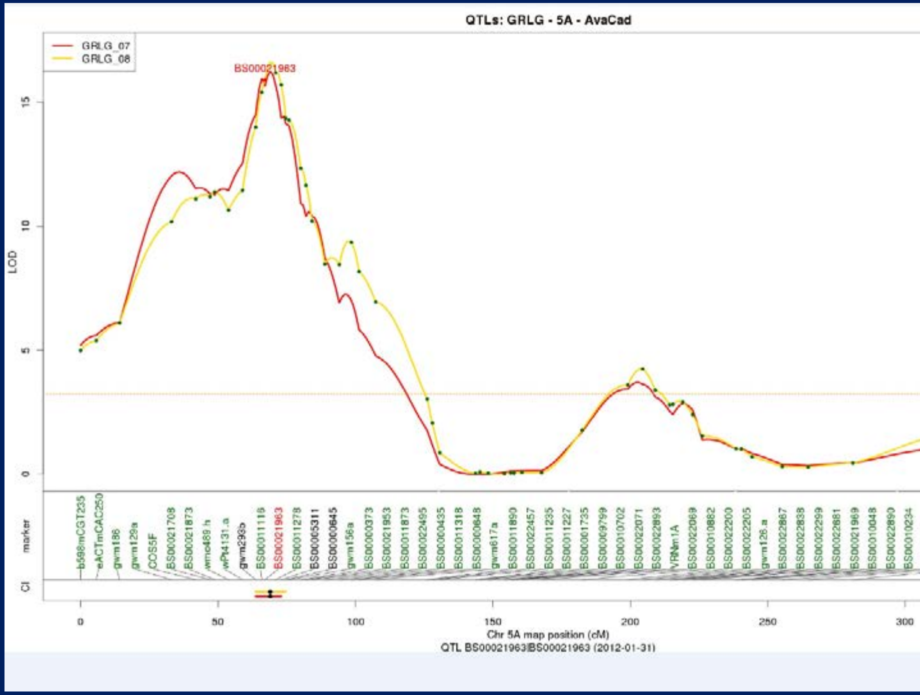
and

major gene

The other WGIN NILs

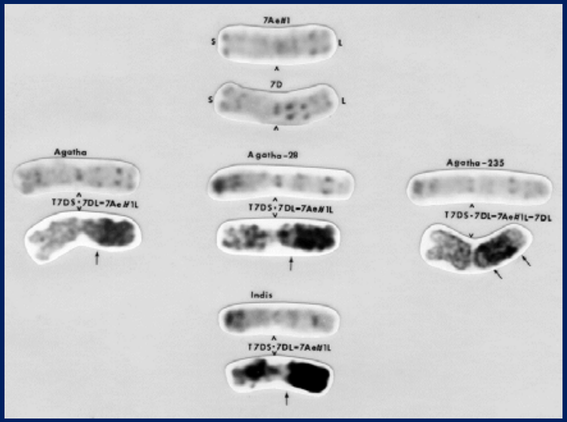
<u>2. Grain Size NILs:</u>

Most NILs for grain size from Shamrock x Shango (7A) and Avalon x Cadenza DH lines (3B & 5A) have reached BC_4 and homs will be sown in the field in autumn 2013. 3 further AC 5A NILs are at BC_2.



The other WGIN NILs

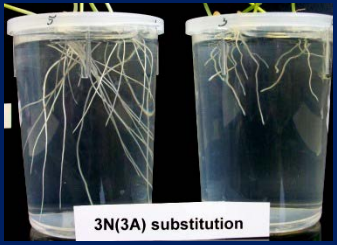
Agropyron on 7D



<u>3. Lr19 NILs</u>:

Lr19 NILs are at BC_4 using Oasis, Kamb1 and Wheatear sources into Paragon and Alchemy backgrounds, and homs will be field sown autumn 2013.

The other WGIN NILs



4. CS3N Aluminium tolerance

Crossing has returned to lines with reliable marker data at BC_1, due to problems with later generations. 3 recombinant lines are being used for backcrossing into Cordiale, Napier and Robigus.

The other WGIN NILs

5 **Malacca x Hereward breadmaking functionality NILs**

Cross	**Chr**	**Trait**	**Markers used BC3F2**	**Number of plants Hom a**	**Hom b**	**Notes**
MH100 x Malacca[4]	1B	Number of cells	gwm264 and barc8	11	25	
MH58 x Hereward[4]	2B	Firmness	wmc257t and wmc317t	5	3*	* all plants wmc257t H Null
MH9 x Malacca[4]	2D	Loaf volume	gwm102t,wmc18,gwm139t	3	4*	* all plants gwm 102t H/Het
MH1 x Malacca[4]	4D	No cells L*	barc98t,gdm129t	18	10	
MH19 x Hereward[4]	4D	L*	barc98t, gdm129t	10	14	
MH70 x Malacca[4]	6A	No of cells	g334	34	26	gdm36 (18cM) and barc3 (26cM) fixed as Malacca last time
MH60 x Malacca[4]	7A	Wall thickness,cell diameter,volume,loaf volume	psp3001	14	31	
MH39 x Hereward[4]	7B	loaf vol	gwm537t,gwm577, barc182t	6	3	barc182t fixed Hereward

1m² plot field sown from each plant 2012-13, multiplication for replicated sowings 2013-14 for test baking

Current WGIN team and recent contributors

Sue Freeman

Luzie Wingen

Michelle Leverington-Waite

Cathy Mumford

Simon Orford

Richard Goram

Objective 8 – Nitrogen update

M J Hawkesford

WGIN Management Meeting

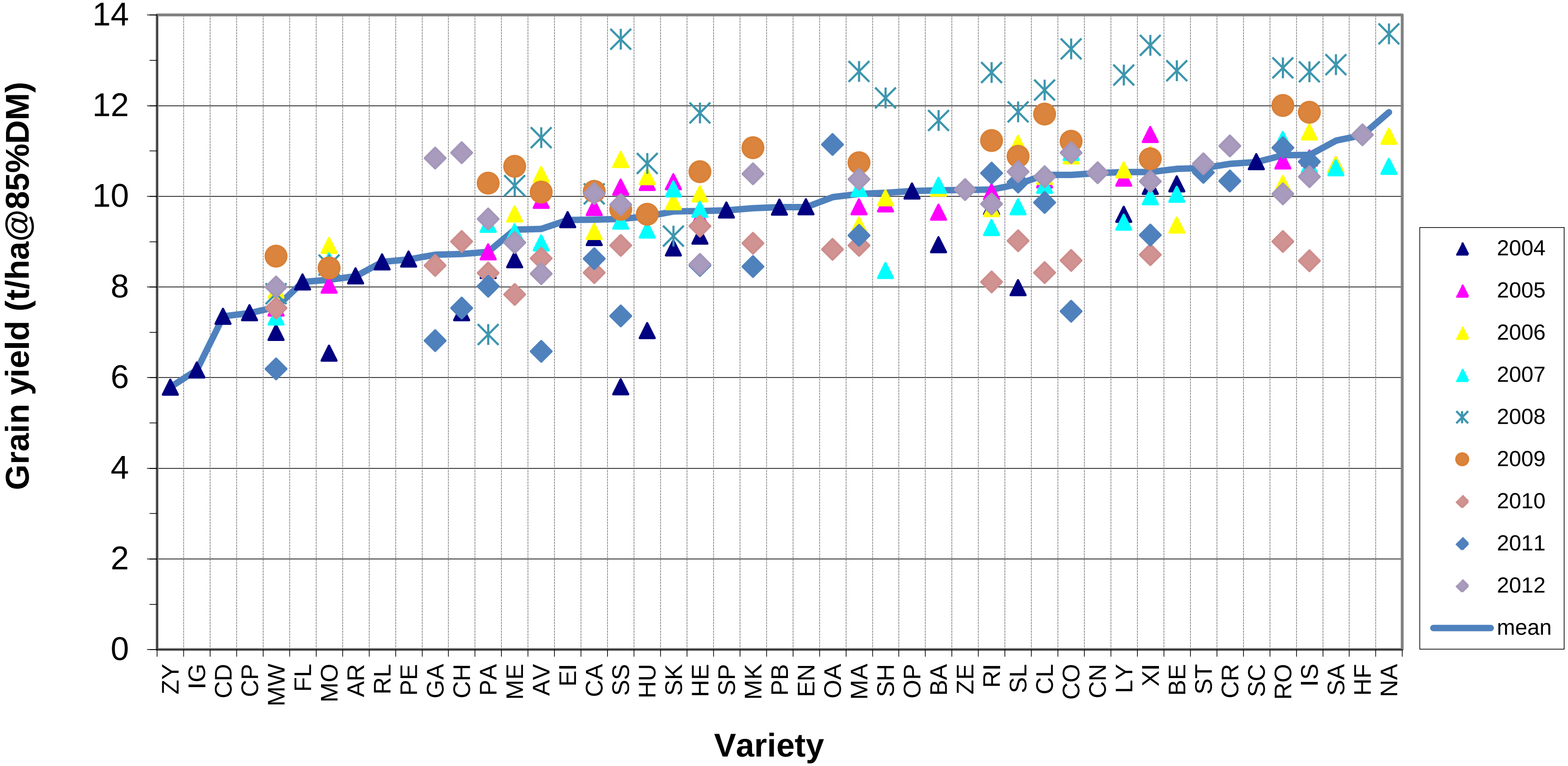
6^{th} November 2012

2012 trials

Diversity trial history

Trial	Year	Varieties (core of 9)	N-levels	kg N/ha	
1	2004	32	4	0,50,200,350	Blackhorse
2	2005	20	2	0,200	Fosters
3	2006	24	3	0,100,200	Meadow
4	2007	24	4	0,100,200,350	Blackhorse
5	2008	24	4	0,100,200,350	Meadow
6	2009	24 (include 6 x A x Cs)	4	0,100,200,350	Summadells
7	2010	25 (include 6 x A x Cs)	4	0,100,200,350	Blackhorse
8	2011	25 (include 4 x A x Cs)	4	0,100,200,350	Meadow
9	2012	25 (include WUE/take-all lines)	4	0,100,200,350	Summardell
10	2013	25 (include WUE/take-all lines)	4	0,100,200,350	Blackhorse

Rothamsted WGIN-N200 Combine Grain Yield (2004-12)



47 + some A x C lines

2013 harvest season (drilled 13th October)

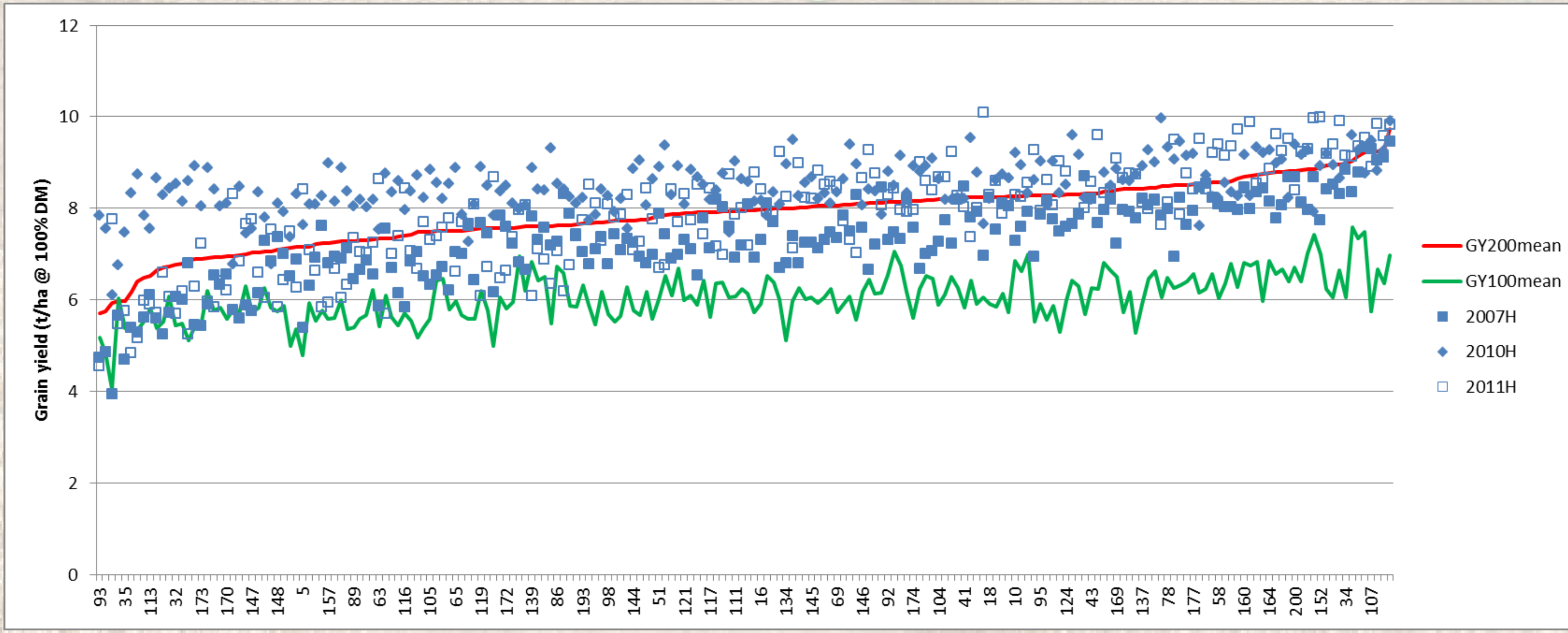
Wheat varieties for WGIN-NUE 2012/13 W=WGIN data, D=desk study

Variety	Source	Code	Nabim	Rationale	inclusion in trial requested by	Previous years of trials (harvest year)
1. A C Barrie	Premium Crops	AB		Canadian re wheat. Disease sensitive. Tall. High grain N. Low yield. Spring type.	MH	new
2. Avalon		AV	1	WGIN DH parent; Low NupE & NutE (D)	PB, RG, MJH	05-12
3. Cadenza		CA	2	WGIN DH parent; Best NupE (W)	PB, RG, MJH	04-12
4. Chablis	KWS	CH	2	SPRING variety (previous grown in 2004 trial) as very N-responsive variety	MH	only in 04, 10, 11, 12
5. Claire	LIM	CL	3	Was biggest area on RL; WGIN DH parent; Good second wheat	PB,PS	05-12
6. Cocoon	Agrii/Secobra	CC	3	Tall variety. High yield. 2010 introduction. Eyespot and rust resistant.	MH	New
7. Conqueror	KWS	CN	4	New Grp 4, very high yielding	MH	12
8. Cordiale	KWS	CO	2	Good second wheat. BBSRC Quality project	RG	06-12
9. Crusoe	LIM	CR	2	Carries dicoccoides. Shows the 'stay green' character		11, 12
10. Gallant	Syn	GA	1	new claimed high yield and high protein type	MH	10, 11, 12
11. Hereford	Syn	HF	4	Feed (not on RL), high yield, brown rust susceptible, possible low take-all build-up and good resistance. Multi trait.	KHK/RG	12
12. Hereward	RAGT	HE	1	Best protein on RL; benchmark bread variety. BBSRC Quality project	PB,PS	04-12
13. Istabraq	LIM	IS	4	Best yield on RL; Distilling cultivar; In LINK 'GREENgrain'; Good second wheat. BBSRC Quality project. WUE trial	PB,PS	05-12
14. Malacca	KWS	MA	1	Biggest Group 1 area; DH choice; Low NupE, high NutE (W). BBSRC Quality project	PS	04-12
15. Marksman	RAGT	MK	2	new for 2009, PRS request for BBSRC Quality project	PS	09-12
16. Maris Widgeon		MW	1	Tall (rht), old cultivar	PB, AM	04-12
17. Mercia		ME	1	Low NupE & NutE (desk); Low Canopy N requirement; In IGF micro-array. WUE trial. RHT series	RG	04, 06-12
18. Paragon	RAGT	PA	1	Spring variety; WGIN mutagenesis population; High NupE (W)	PB	04-12
19. Riband	RAGT	RI	3	WGIN DH parent; Distilling cultivar; In LINK 'GREENgrain'; High NutE (W)	RG	04-12
20. Robigus	KWS	RO	3	Best Group 3 yield; Best NUE, high NupE & NutE (D); Good second wheat. WUE trial	PB, AM	05-12
21. Stigg	LIM	ST	?4	Carries dicoccoides. High disease resistance. Shows the 'stay green' character		11, 12
22. Soissons	Elsoms	SS	2	WGIN DH parent; Early maturing; High NupE, low NutE (W)	PB,RG, AM	04-12
23. Solstice	LIM	SL	2	Biggest Group 2 area; DH choice; Worst NupE (W)	RG	04-12
24. Xi19	LIM	XI	1	Best Group 1 yield; High NUE, NupE, NutE (D); Low NupE (W). BBSRC Quality project. WUE trial	PB,PS	04-12
25. Zebedee	LIM	ZE	3	High WUE, grp 3. Multi trait.	JFoulkes	12

Avalon x Cadenza Trials

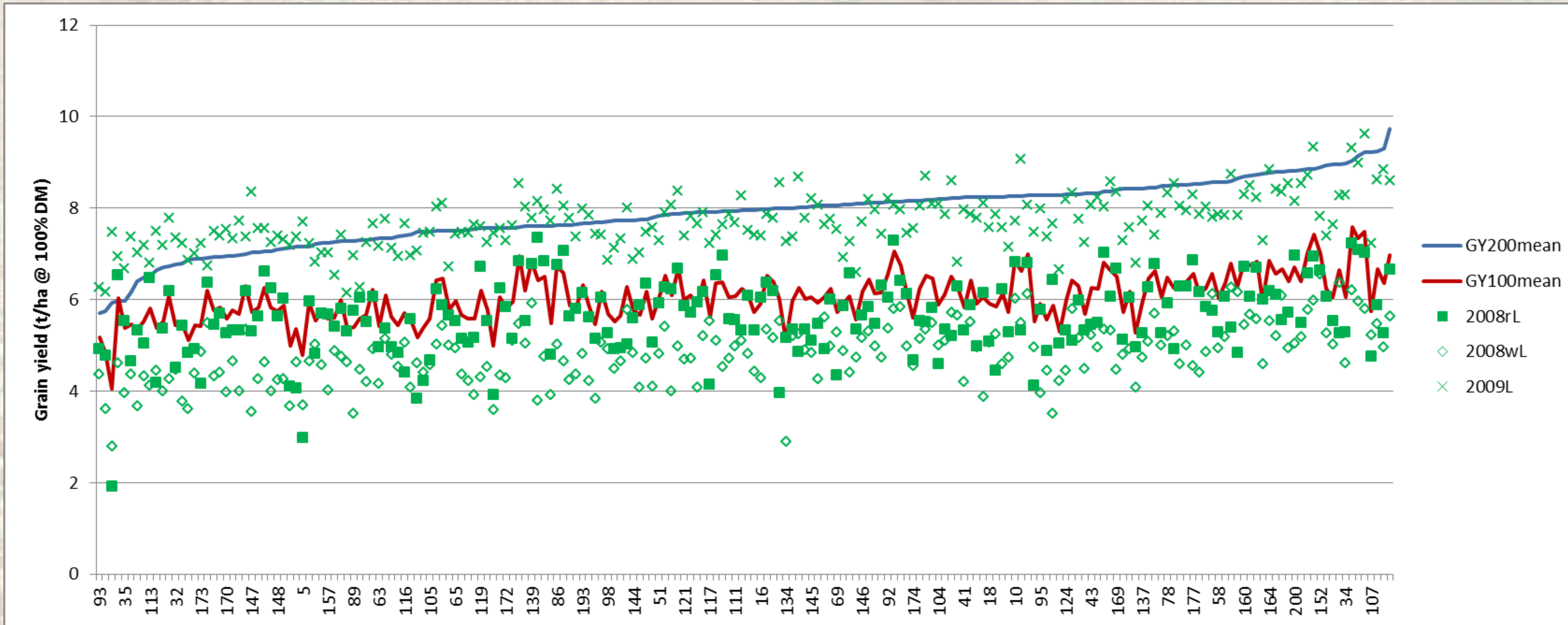
Trial	Harvest year	Sites	Notes	kg N/ha applied (+ c 50 kg/ha N_{min})	Soil N (kg/ha to 90 cm)
1 (719)	2007	Blackhorse		200	49.9
2, 3 (817; 851-3)	2008	Bones and Woburn	Woburn trial split	Both 100	78.3; 34.4,36.1, 36.7
4 (903, 904)	2009	Fosters/Summardells	Split over 2 fields (wet)	100	48.2; 40.7
5 (1035)	2010	Blackhorse	(very dry)	200	39.8
6(1103)	2011	Great Harpenden	(very dry)	200	44.0
7*(1202)	2012	Bones	(wet May/June)	50	69.5
8*(1319	2013	Blackhorse	Not yet drilled	50	

*= not directly WGIN funded



Monthly rainfall in spring and summer (mm) at Rothamsted in the years 2007-2011. Six-monthly totals and 30-year averages (1971-2000) are shown.

Year	March	April	May	June	July	August	Total
2007	57.6	2.8	135.8	72.4	86.8	64.4	**419.8**
2008	108.5	53.5	87	35.3	90.3	107.8	**482.4**
2009	37.3	46.7	24.8	68.1	73.3	63.4	**313.6**
2010	45.2	18.7	38.4	23.5	31.6	127.6	**285**
2011	10	5.2	23.6	83	44.6	81.2	**247.6**



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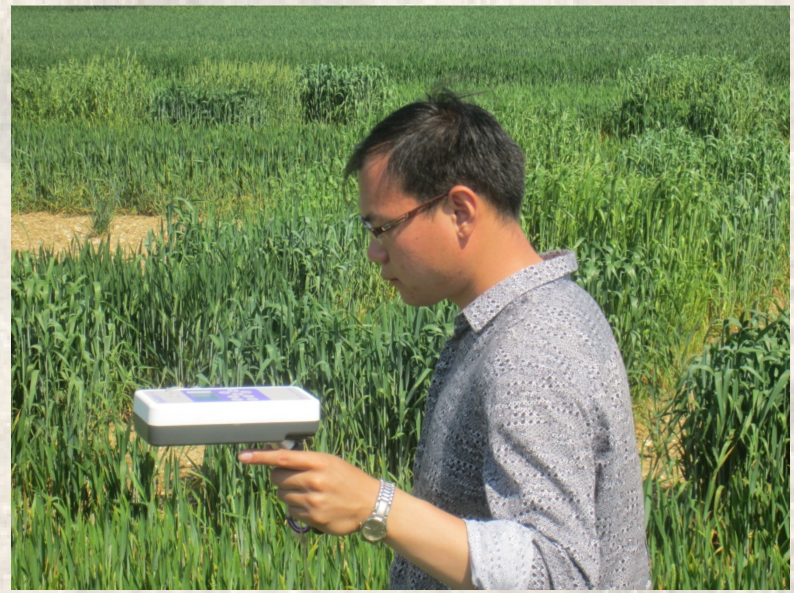
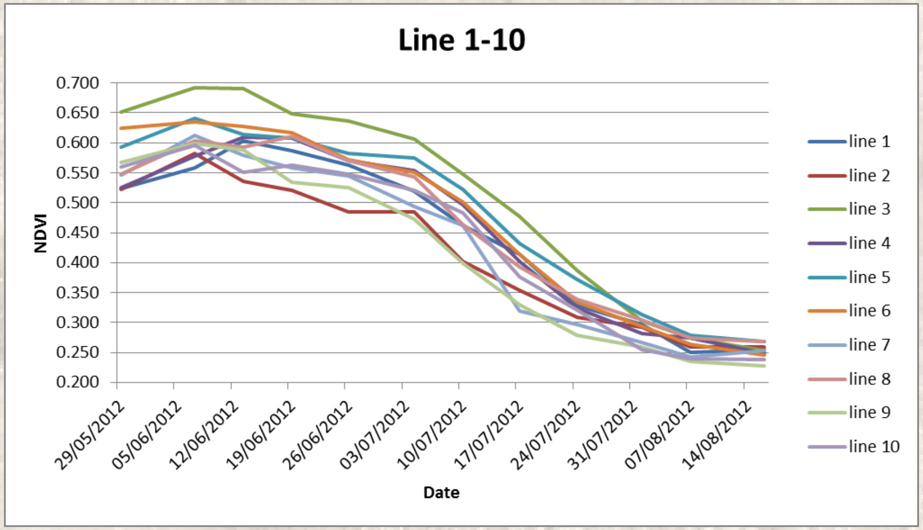
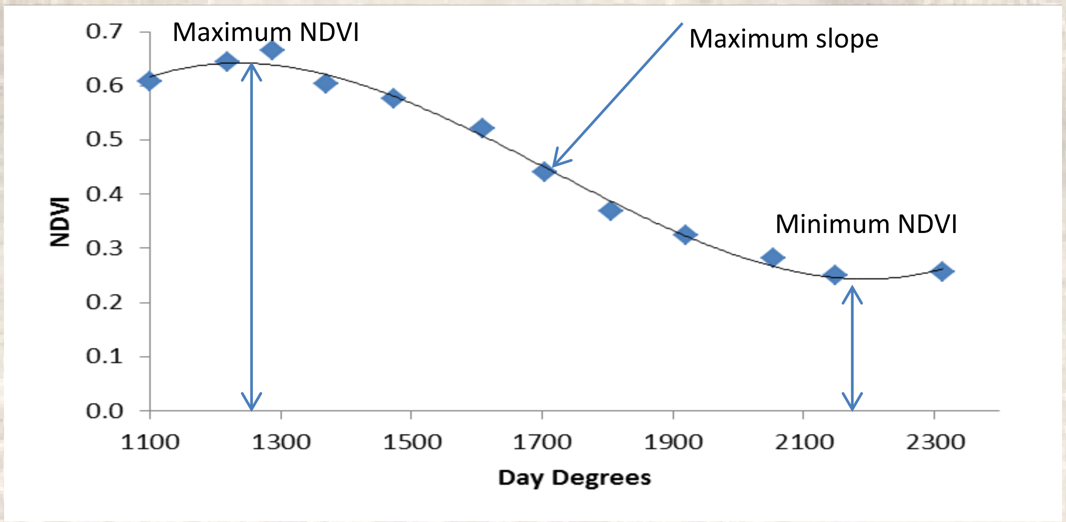
Canopy longevity as a target



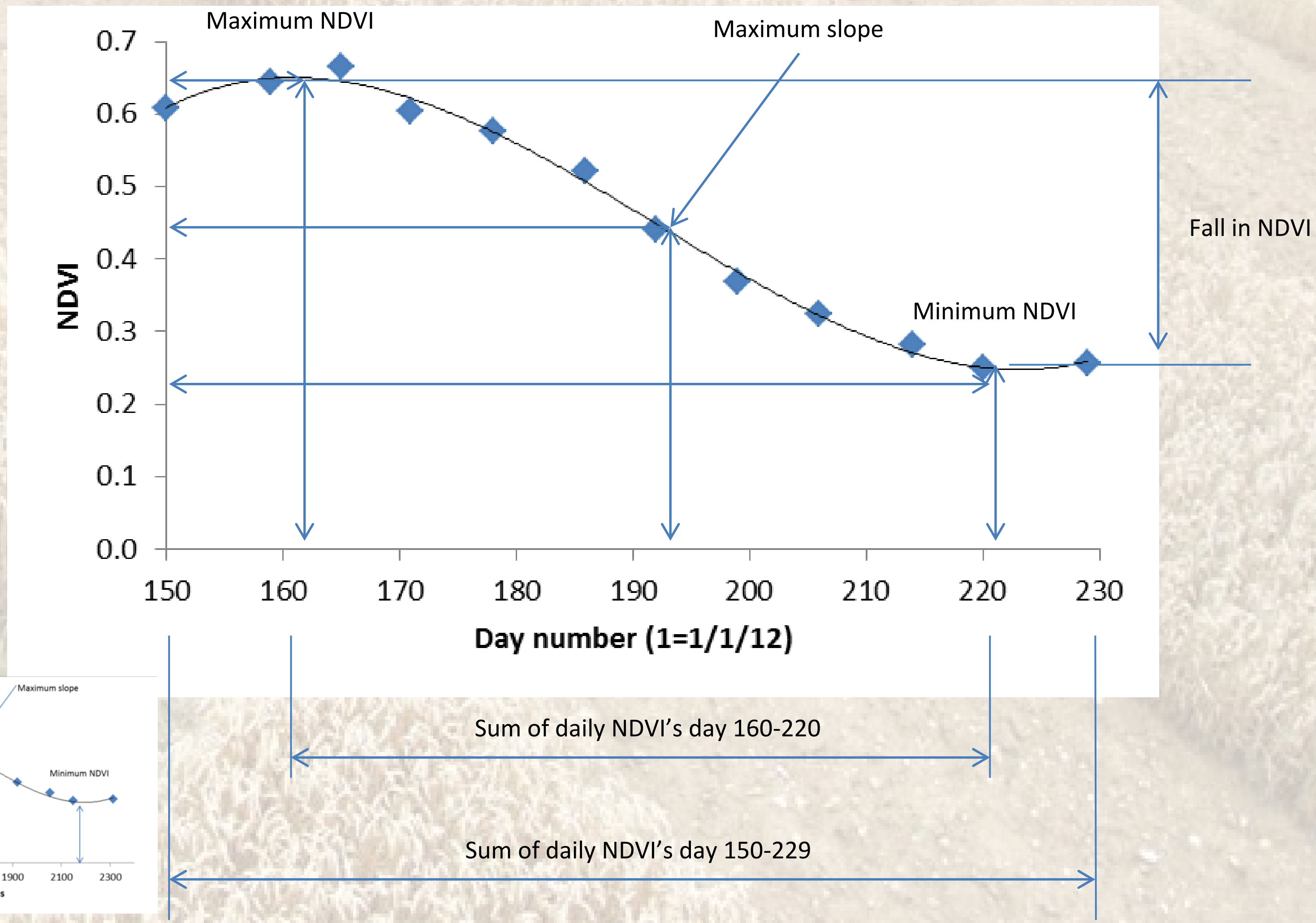
NDVI

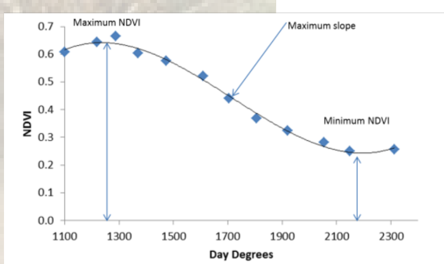
Quantifying senescence characteristics



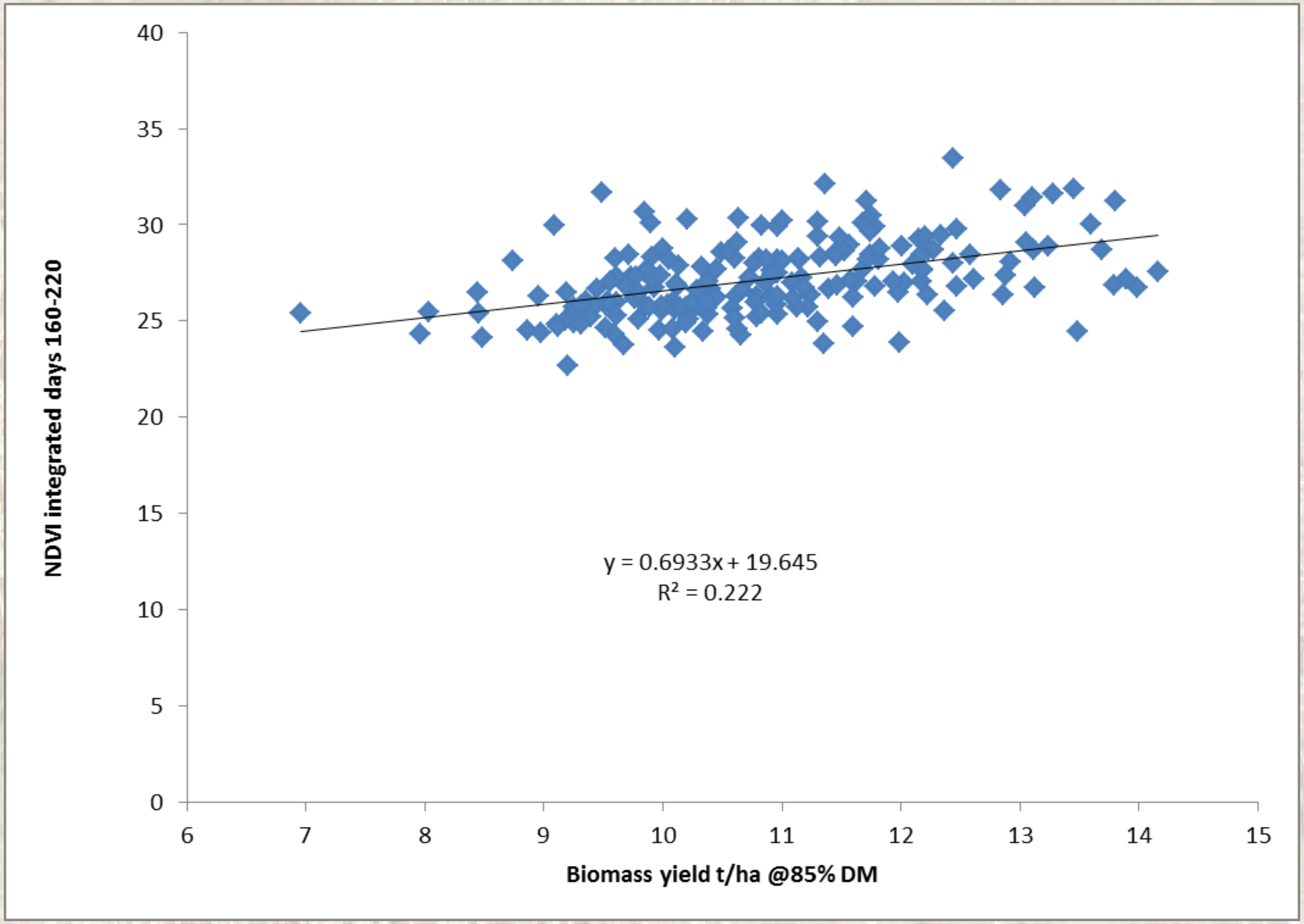


A x C senescence curve parameters



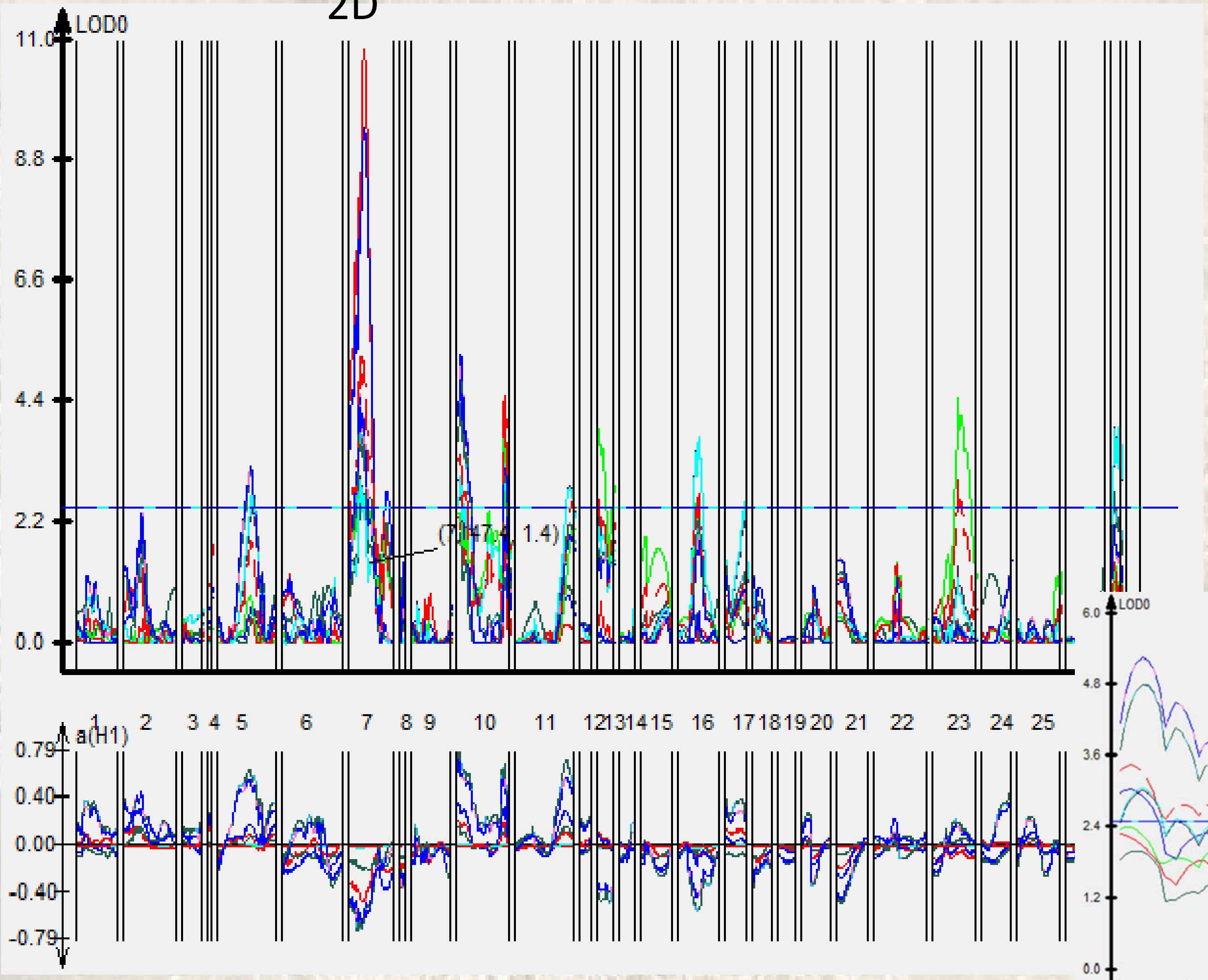


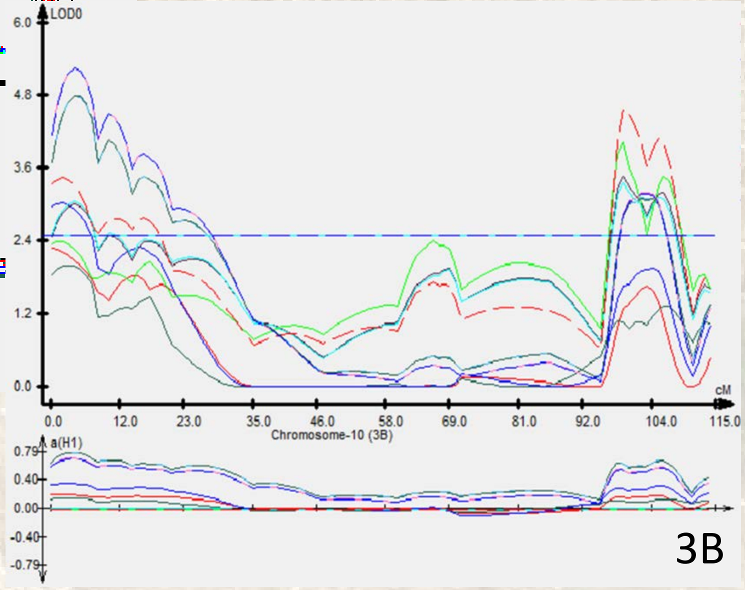
Integration relates to yield



Senescence and yield QTL

2D





3B

Thanks

- RRes Farm staff
- Peter Barraclough
- Peter Buchner
- Group and field team: Andrew Riche, Yongfan Wan, Jonathan Howarth, Mark Durenkamp, Saroj Parmar, Janina Jones, Dan Godfrey, Emmanuelle Cabannes, Adinda Derkx, Fumie Shinmachi, Caihong Bai + many summer students

Wheat Genetic Improvement Network

defra Department for Environment Food and Rural Affairs

BBSRC bioscience for the future

ROTHAMSTED RESEARCH

Drought tolerance

WGIN-2 SG meeting

Sutton Bonington 5 November 2012

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*)**

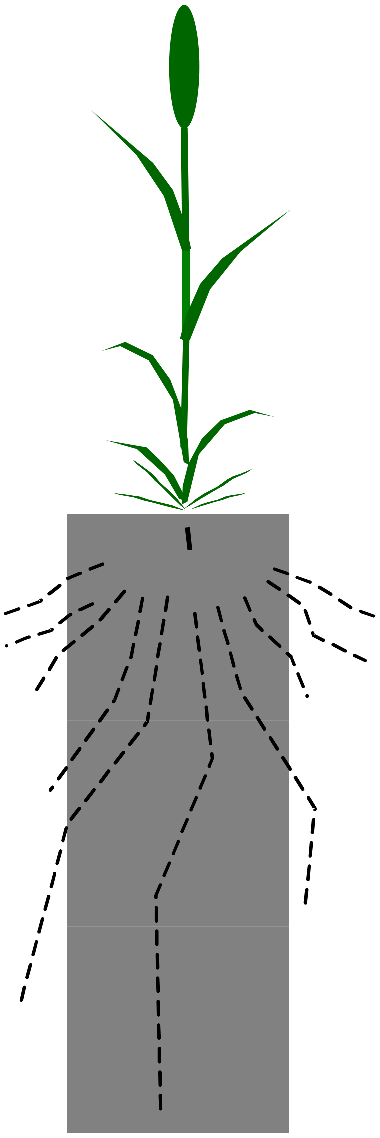
Ideotype for high sustainable yield under drought

OPTIMIZE WUE

- High $^{13}C\ \Delta$
- Pn capacity
- Specific leaf N

MAXIMIZE HARVEST INDEX

- Stem CHO reserves
- Stay green



MAXIMIZE WATER CAPTURE

- RLD at depth
- Low $^{18}O\ \Delta$
- β (distribute roots deeper)
- Specific root length

EARLINESS

- Extend stem elongation phase
- Early onset GS31

WGIN 2 (9.1 Trait Identification)

WUE trial 2009-10 & 2010-11

Split plot design (3 reps): plot size 1.6 x 12 m

Main plot:	Fully irrigated (trickle irrigation)
	Unirrigated

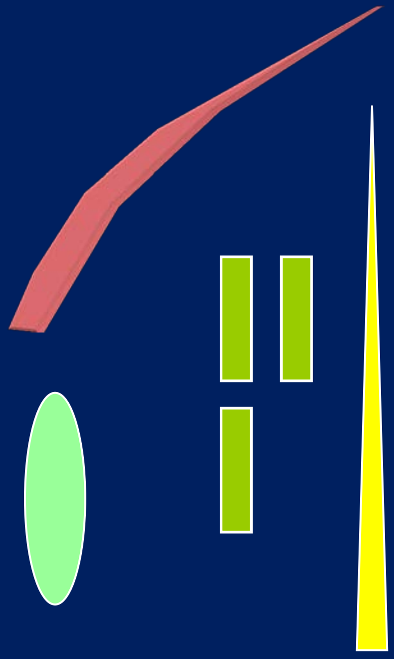
Split plot (variety):

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

Measurements

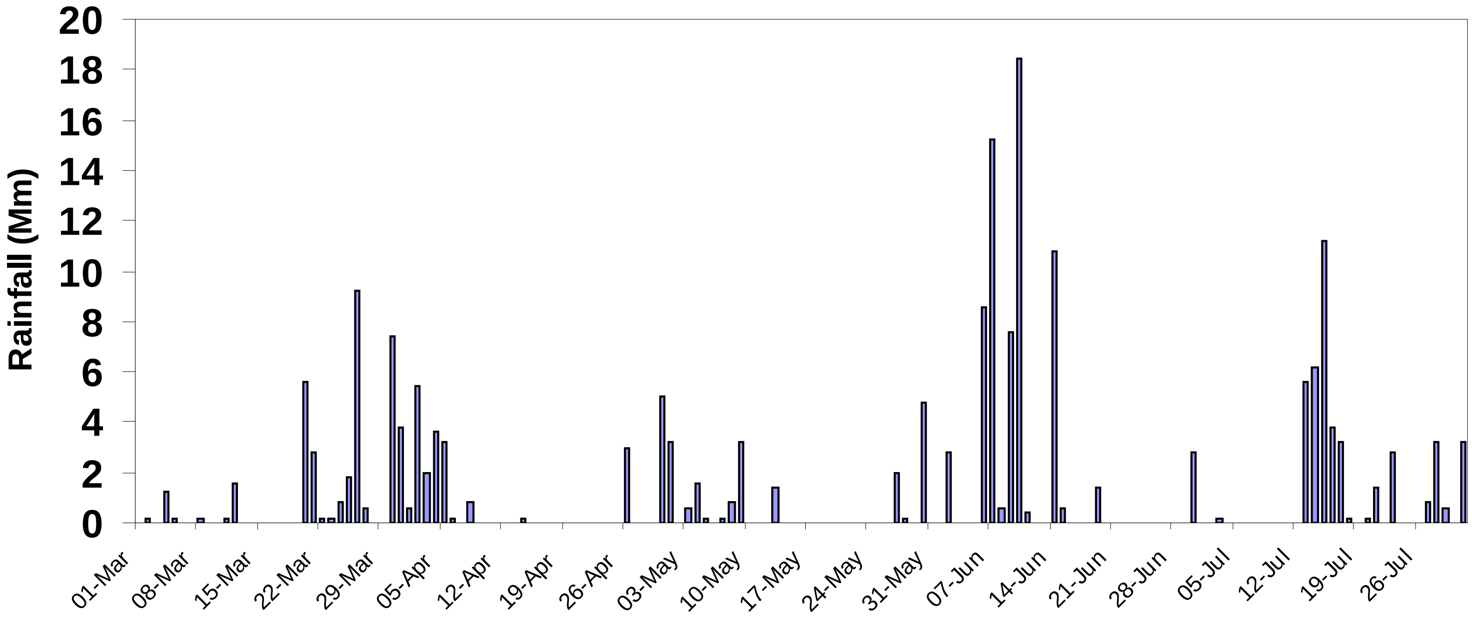
- **Combine grain yield, yield components**
- **DM & partitioning at GS31, GS61, harvest**
- **% stem WSC at GS61+10d**
- **Leaf senescence kinetics for L1, L2 and L3.**
- **Stomatal conductance/photosynthetic rate using Licor (unirrigated)**
- **Canopy temperature**
- **Water use ~ gravimetric analysis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



Leaf gas exchange

Canopy temp.

Sutton Bonington 2010 rainfall data

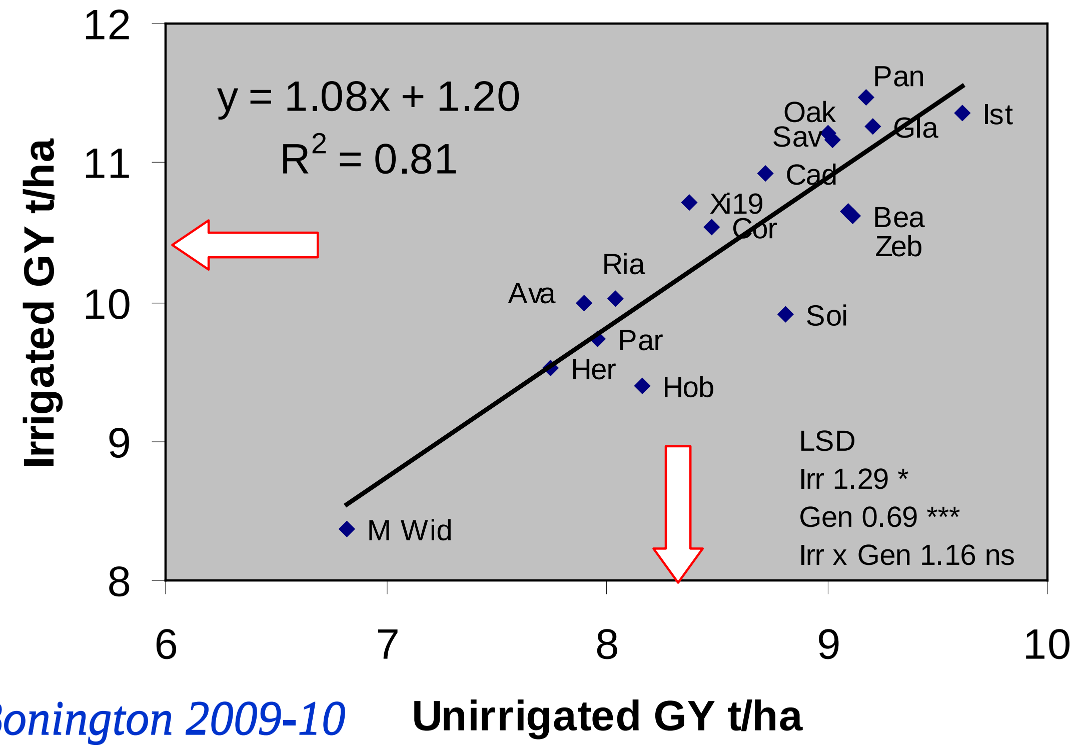


Rainfall (mm)		
	2010	LTM 75-09
Jan	33	54.1
Feb	41.6	43.4
Mar	36	45.7
Apr	24	44.4
May	18.2	45.6
Jun	69.2	58.7
Jul	42.6	49.8

Glasgow Irrigated vs Unirrigated 19 July

Grain yield responses to irrigation

Wheat Genetic Improvement Network



Sutton Bonington 2009-10

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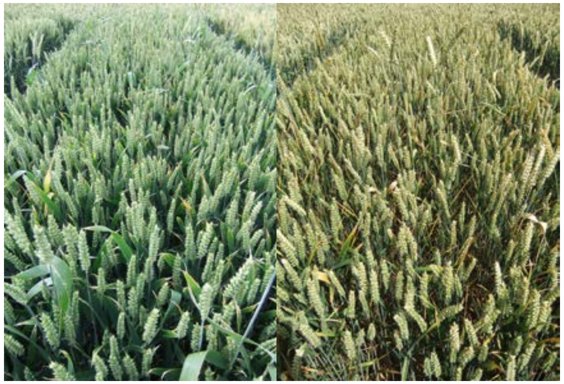
Glasgow Irrigated vs Unirrigated 19 July

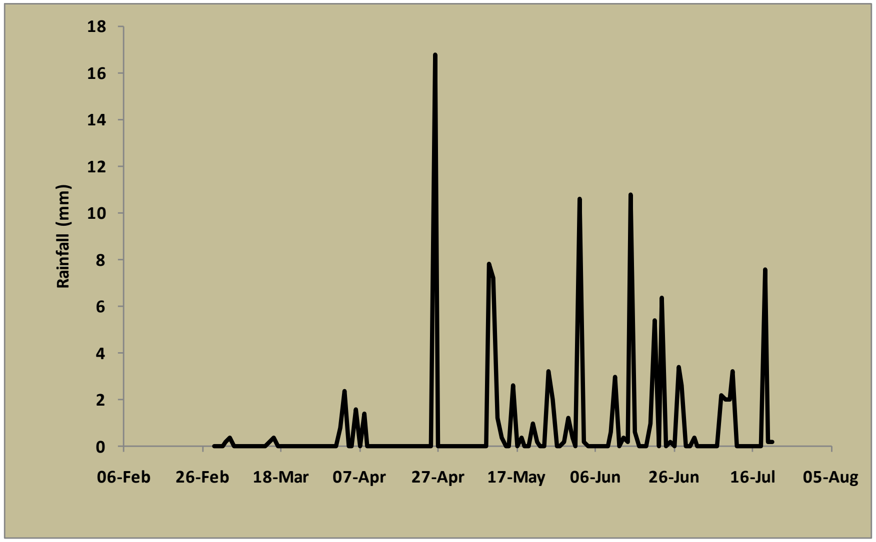
Drought effects 11 July 2011



Panorama

Cadenza

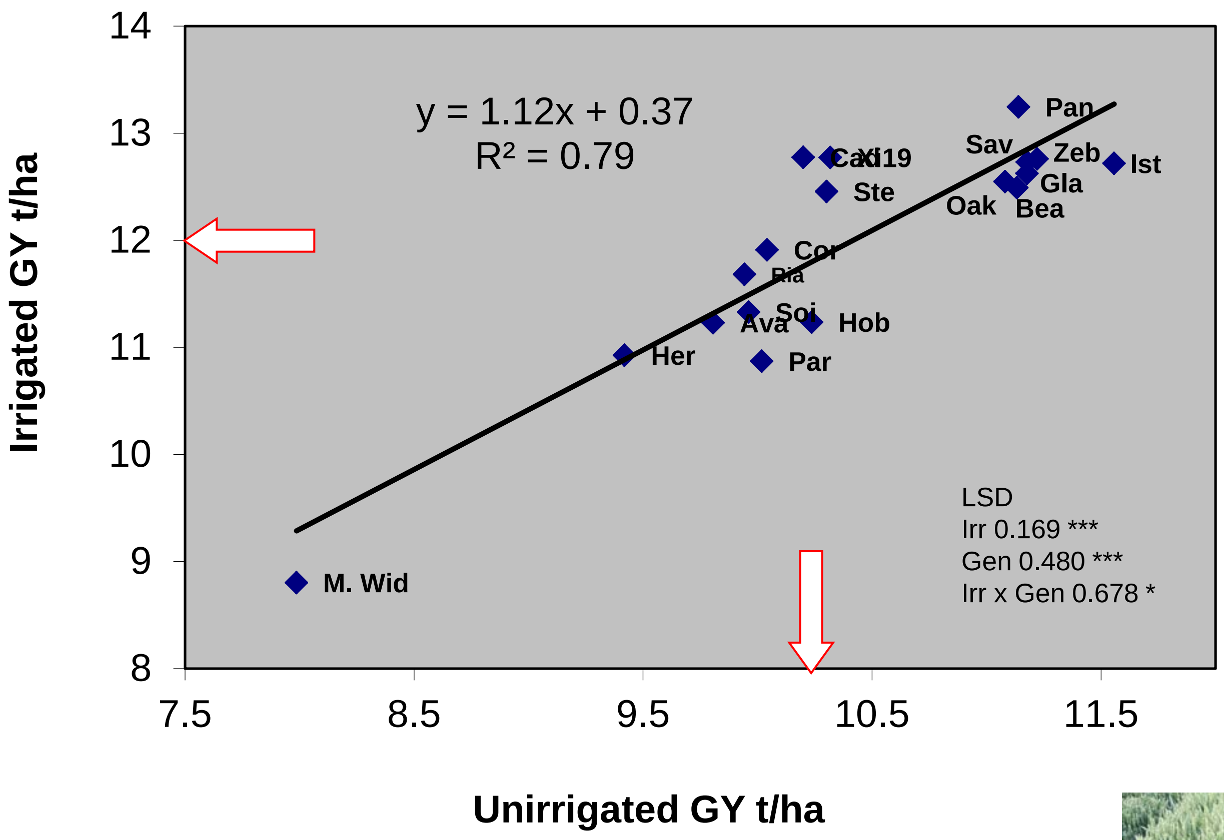
Istabraq



	Rainfal (mm) 2011	LTM 75-09
March	1.2	54.1
April	23	43.4
May	27.8	45.7
June	45.4	45.6
July	17.8	49.8

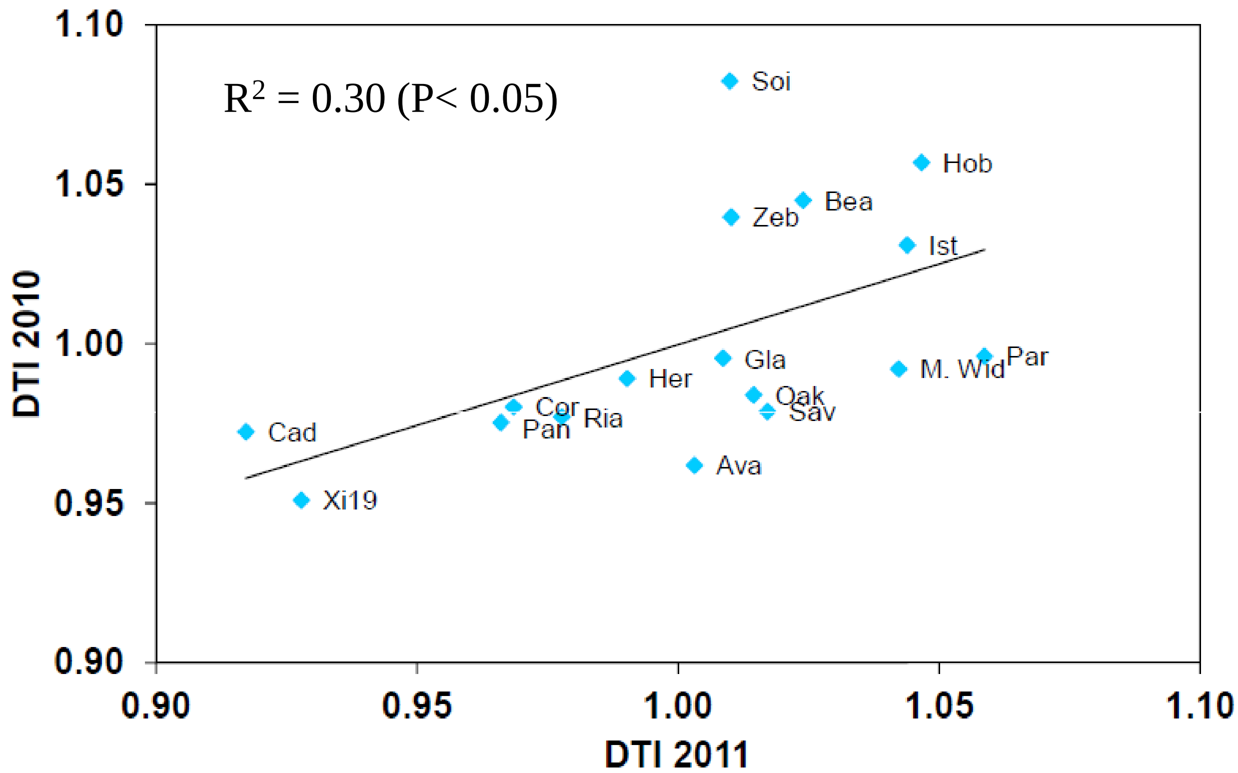
Wheat Genetic Improvement Network

Grain yield responses to irrigation



Sutton Bonington 2010-11

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



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.**

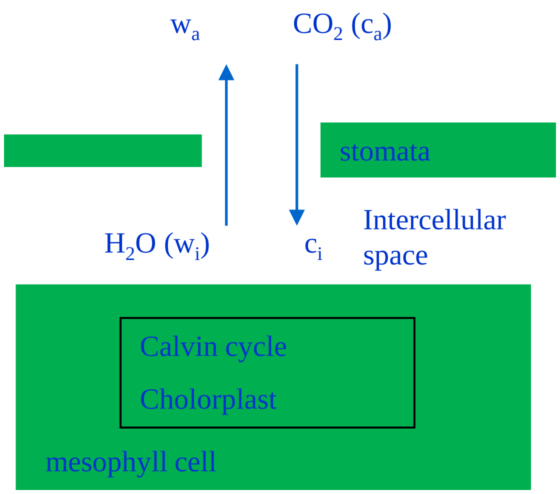
- **$^{13}C/^{12}C$ isotope ratio of fixed CO_2 can be used as an indicator of WUE**

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

Effects of leaf activty traits on WUE

- ***Stomatal conductance:***. Lower conductance ↓ ci hence ↑ WUE.

- ***N or Rubisco content per unit leaf area:*** Greater photosynthetic activity ↓ c_i , hence ↑ WUE.



The $^{13}C/^{12}C$ ratios (R) of leaves grains analysed using an elemental analyser (Carlo Erba 2100) interfaced to an isotope ratio mass spectrometer.

Results expressed as $\delta^{13}C$ values, using a secondary standard calibrated against Vienna Pee Dee Belemnite calcium carbonate (VPDB).

$\delta^{13}C = (R\text{sample} - R\text{standard}) - 1$

The C isotope discrimination (Δ 13C) of plant parts is then calculated as:

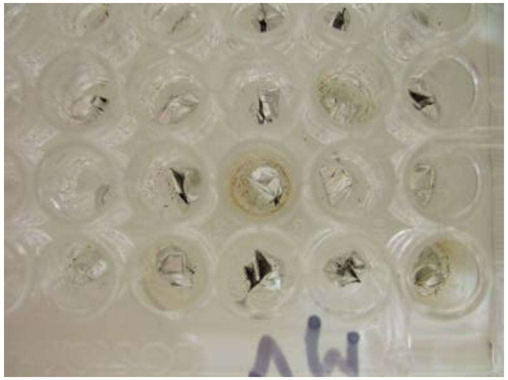
$\Delta 13C = (\delta^{13}Ca - \delta^{13}Cp) /[1 +(\delta^{13}Cp/1000)]$

where $\delta^{13}Ca$ and $\delta^{13}Cp$ refer to air and plant C isotope compositions, respectively. $\delta 13C$ of free atmospheric CO_2 taken as -8‰ (Farquhar et al., 1989).

Isotope analysis, sample submission: :Weighing and encapsulate of milled samples samples for 13C and O18 isotope analysis

Encapsulation of 2 mg sample

Submit samples to Mylnefield Isotope lab at JHI



Irrigated conditions

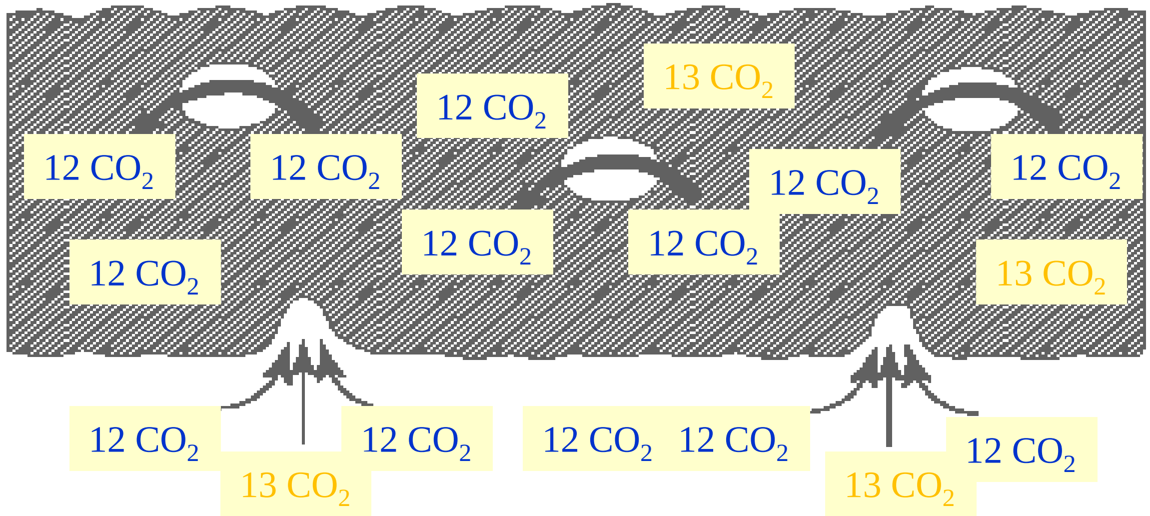
Stomata open (high stomatal conductance)

↓

High Ci

High Discrimination against $^{13}CO_2$ - - - - - → **Low WUE**

Stomata open (irrigated conditions): Discrimination in favour of $12CO_2$ isotope form at high internal CO_2 concentration.



Drought conditions

Stomata close (low stomatal conductance)

↓

Low Ci

Low Discrimination against $^{13}CO_2$ - - - - - → **High WUE**

Stomata closed (moisture stress): Discrimination less favourably to $12CO_2$ as internal CO_2 concentration falling.

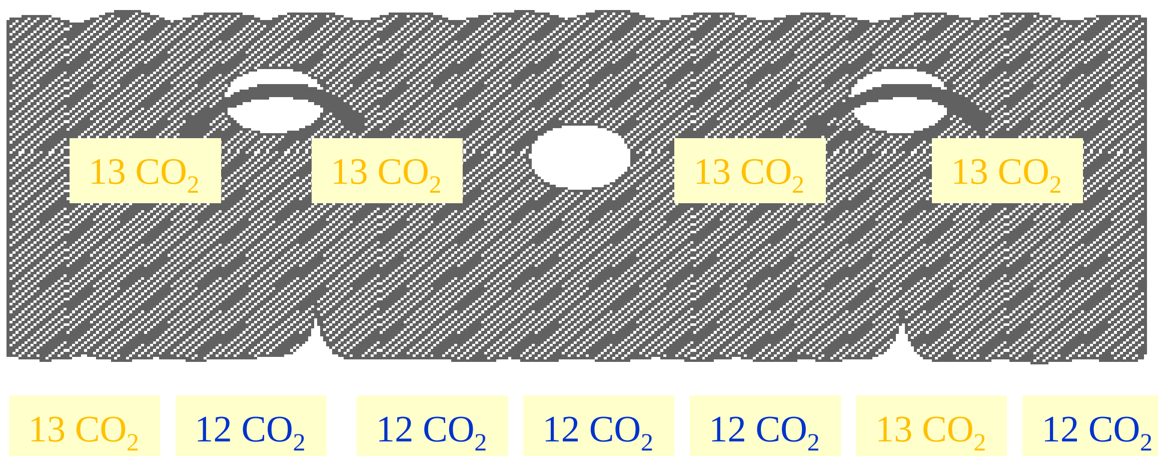
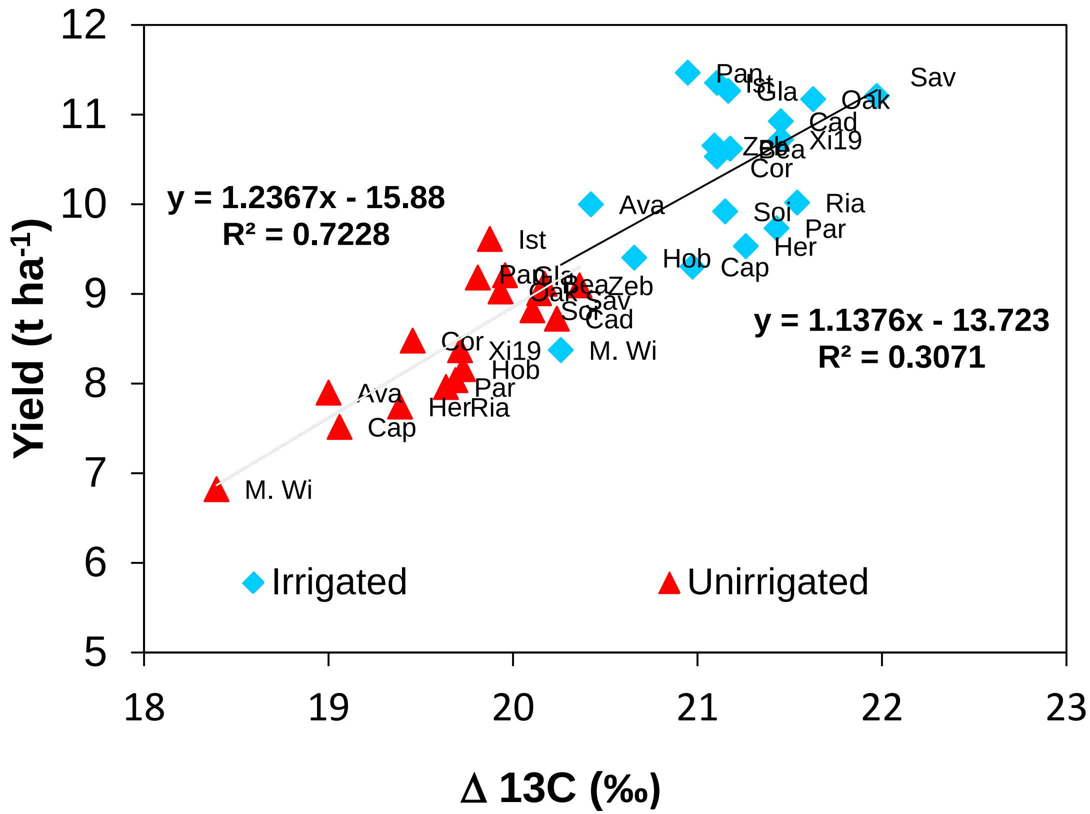


Diagram 1. Carbon isotope discrimination under irrigated and dry conditions.

Δ [13]C vs grain yield in 18 wheat cultivars



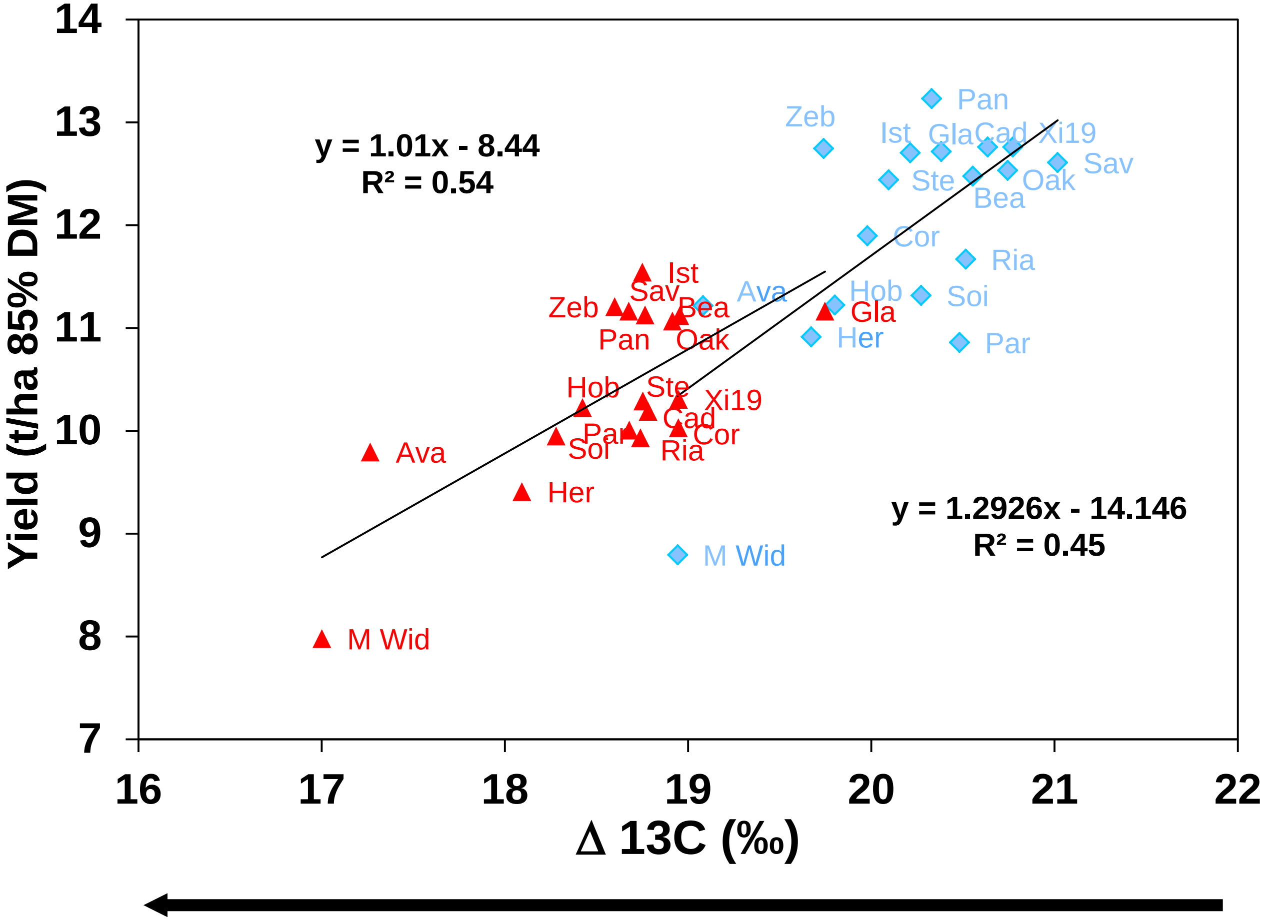
High WUE

Low WUE

Sutton Bonington 2009-10

Wheat Genetic Improvement Network

Δ ^{13}C vs grain yield in 18 wheat cultivars

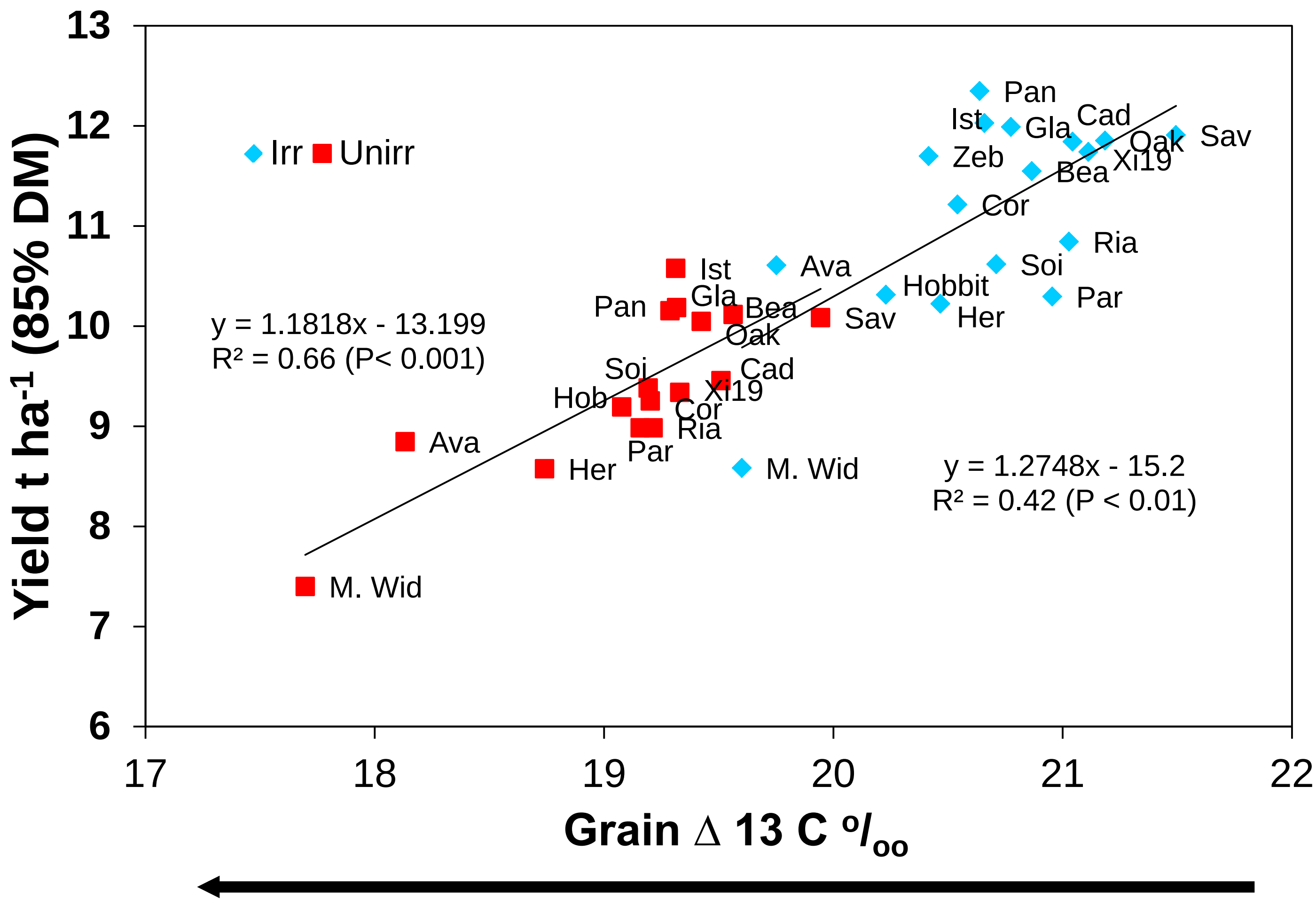


High WUE

Low WUE

Sutton Bonington 2010-11

Δ ^{13}C vs grain yield in 18 wheat cultivars

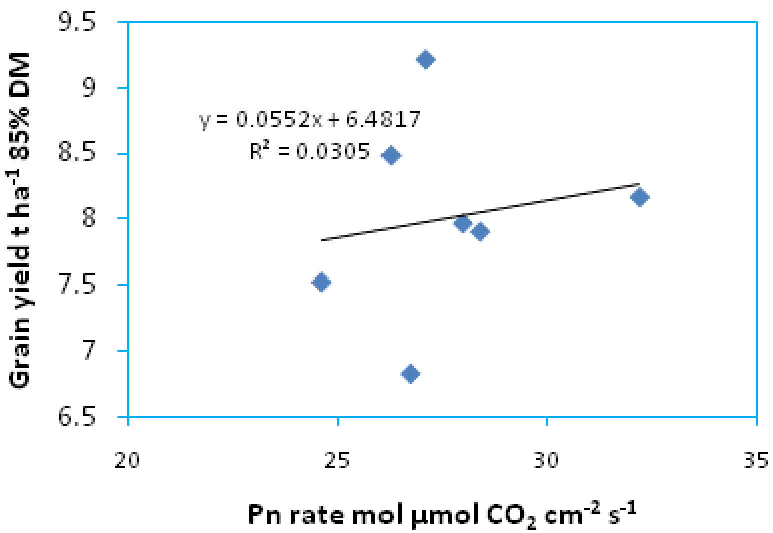


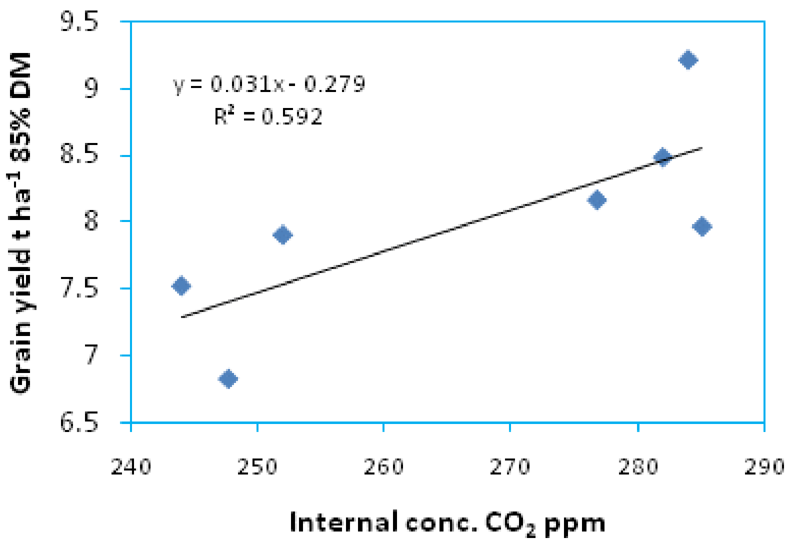
High WUE

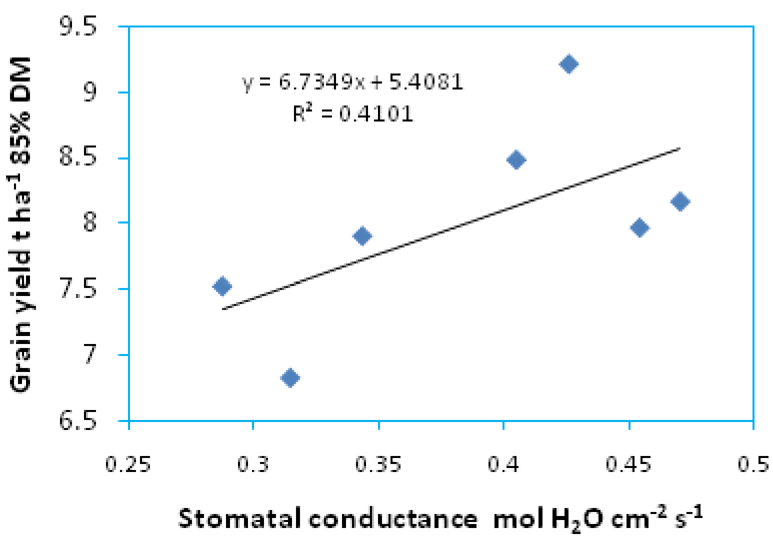
Low WUE

Sutton Bonington Mean 2009-10 & 2010-11

Relationship between leaf activity traits (24 June) and yield (unirrigated) 2010



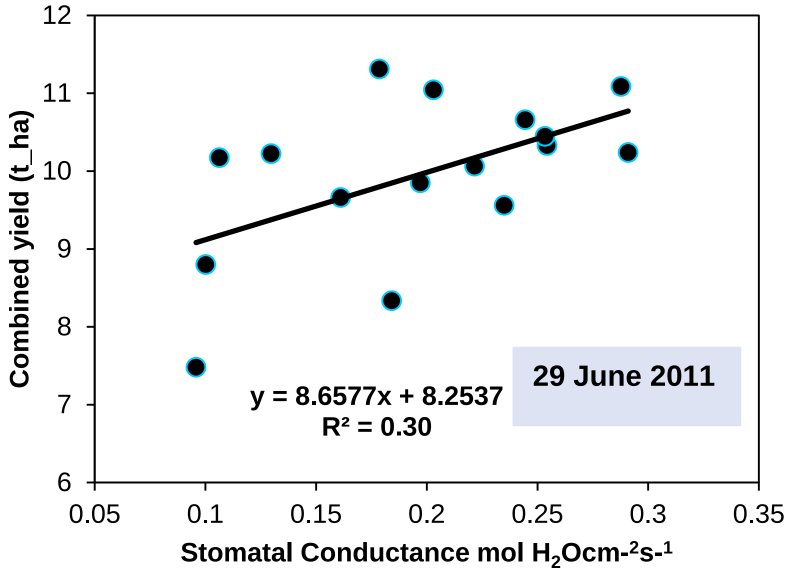


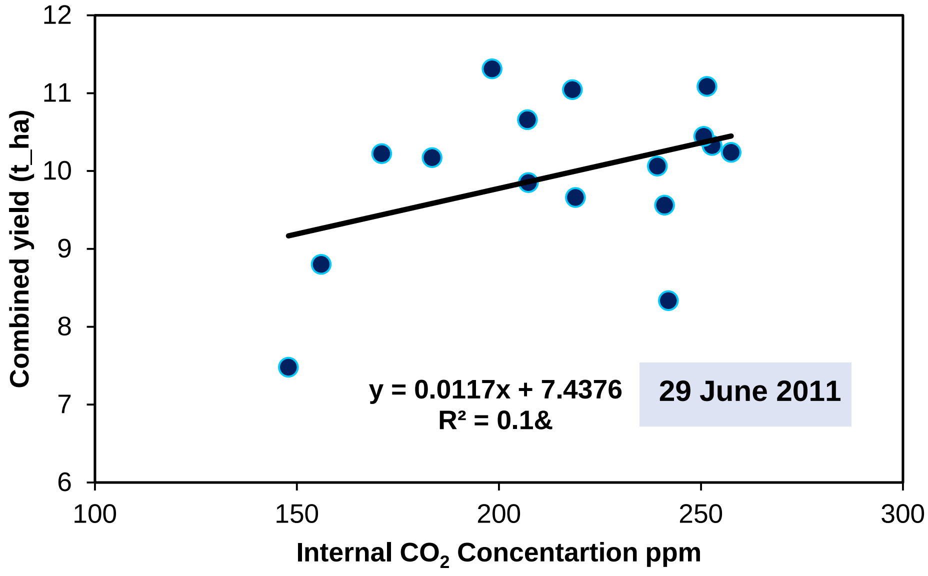


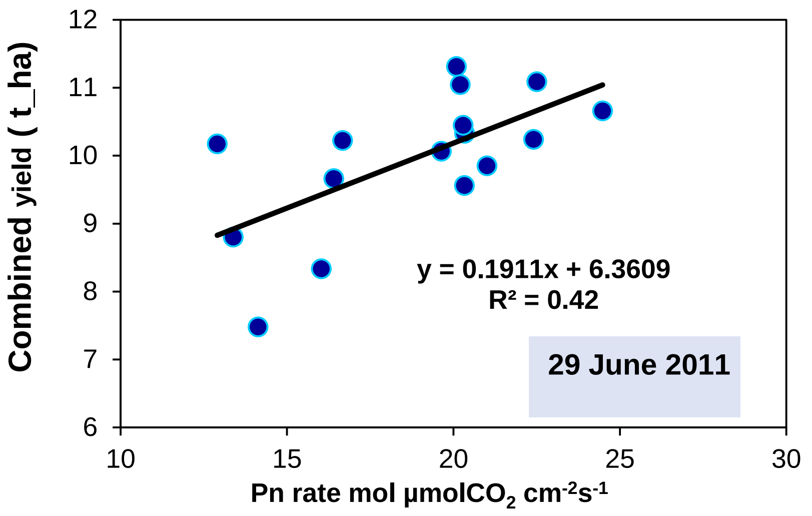
R^2 values versus grain yield

	02-Jun	24-Jun	28-Jun	13-Jul
Ps rate	0.22	0.03	0.26	0.00
Ci	0.18	0.59	0.20	0.36
Gs	0.31	0.41	0.25	0.37

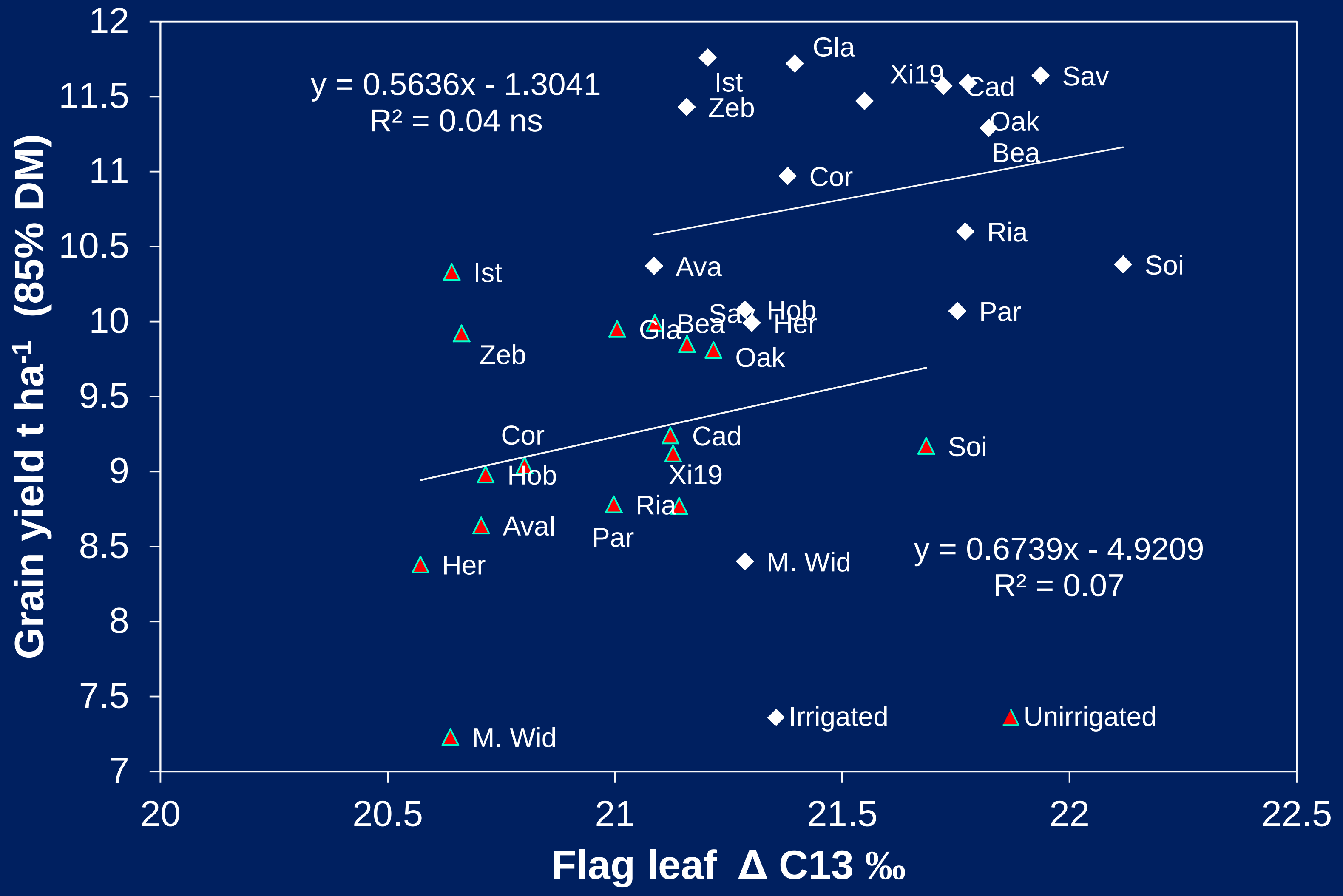
Relationship between leaf activity traits (29 June) and yield (unirrigated) 2011



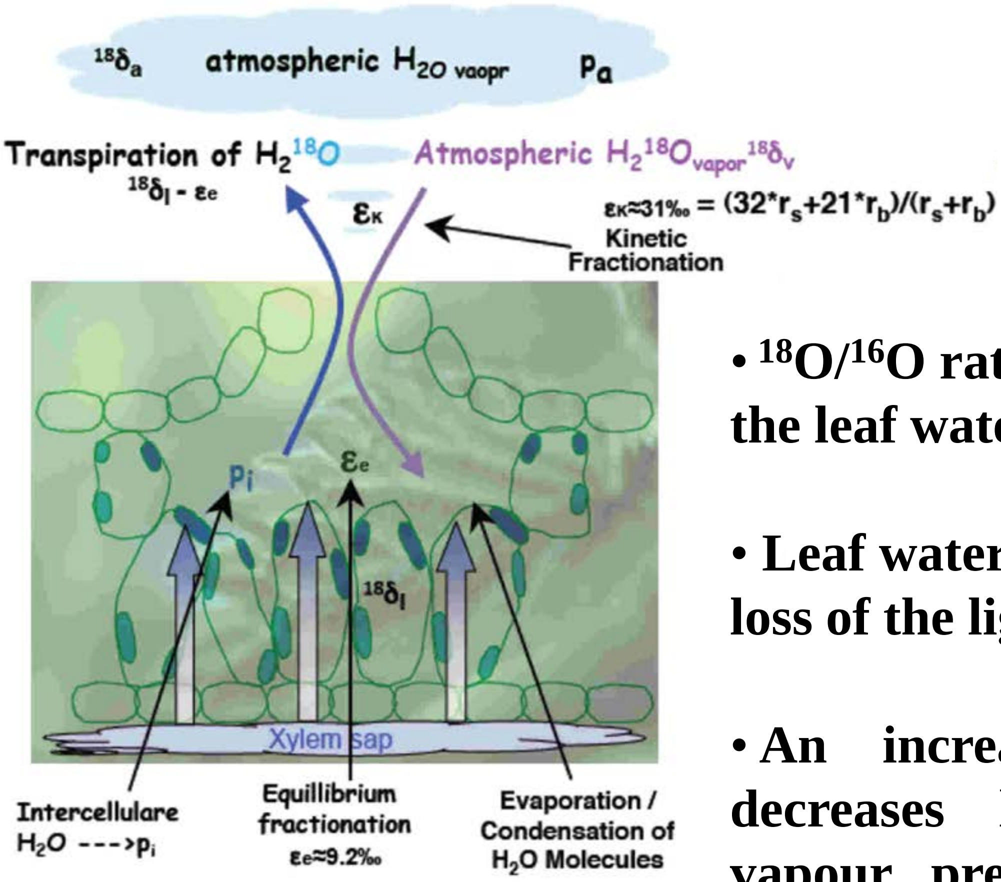




Relationship between flag leaf Δ^{13}C and grain yield in 18 wheat cultivars (mean 2010 and 2011)



Techniques: Oxygen isotope ratio ~ leaf transpiration



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

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

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

The 18O/16O ratios (R) of were determined by the CO_2/H_2O equilibration technique and using an isotope ratio mass spectrometer .

Results were expressed as δ18O values, using two secondary standards (IAEA 601 and IAEA 602) calibrated against to the Vienna Standard Mean Oceanic Water (VSMOW)

$$\delta 18O = (\delta R_{sample} / \delta R_{standard} - 1)$$

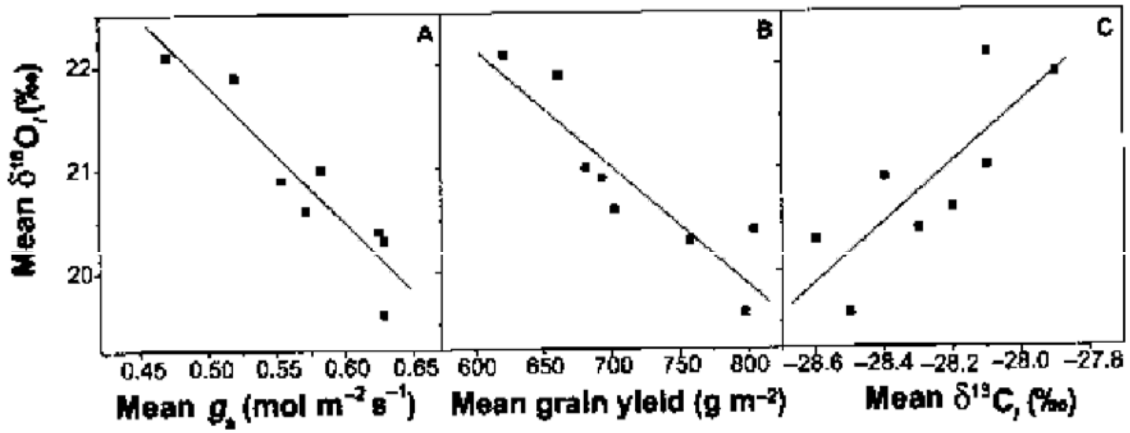
Then, the 18O enrichment in grains (Δ18O) was calculated as:

$$\Delta 18O = (\delta 18O_p - \delta 18O_w) / [1 + \delta 18O_w / 1000)]$$

where δ18Op and δ18Ow refer to the oxygen isotope compositions of plant sample and rain water, respectively (δ18O rain water was approx. 210.78 ‰).

Barbour et al. (2000) Aust. J. Plant Physiol., **27**, 625–637

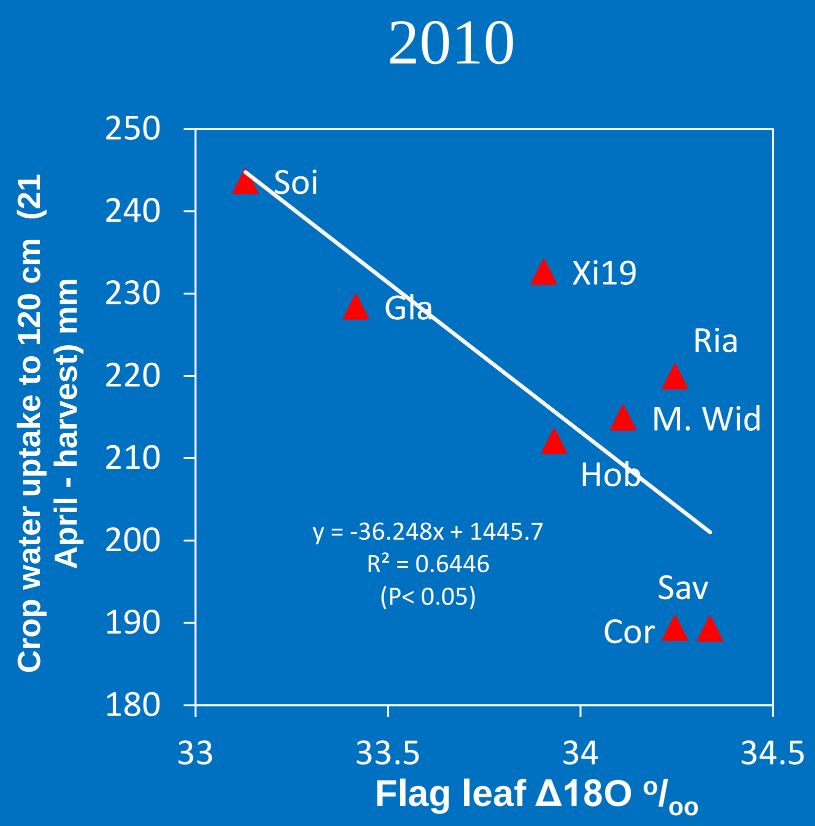
Oxygen isotope ratio of leaf and grain material correlates with stomatal conductance and grain yield in irrigated wheat

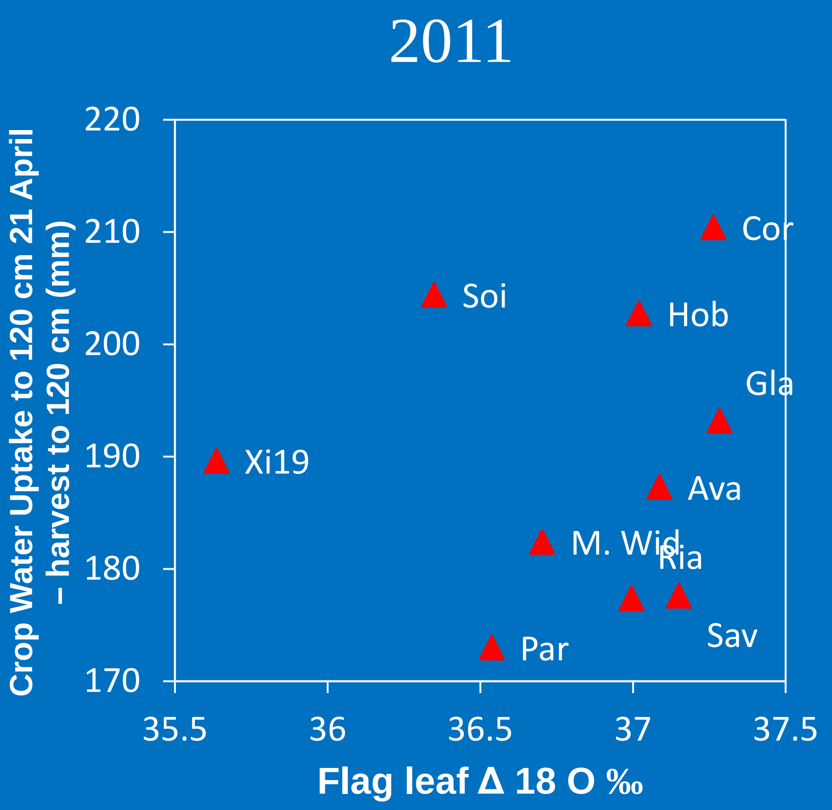


The relationship between the 3 year mean of cultivar $\delta^{18}O_{leaf}$ and corresponding means of stomatal conductance (gs) measured pre-anthesis, grain yield and δ 13C_{leaf} for eight CIMMYT spring wheat cvs

δ^{18}O is not thought to be strongly influenced by photosynthetic rate, so that combined measurement of both δ^{13}C and δ^{18}O should allow stomatal and photosynthetic effects on δ13C to be teased apart

Δ 18 O versus crop water uptake (gravimetric) 2010 unirrigated treatment

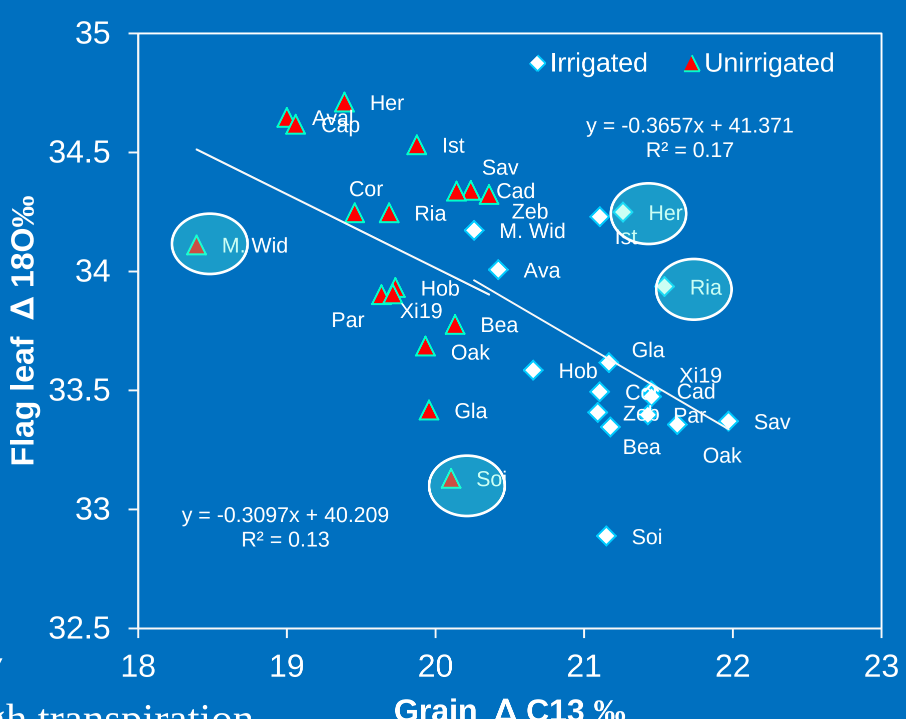




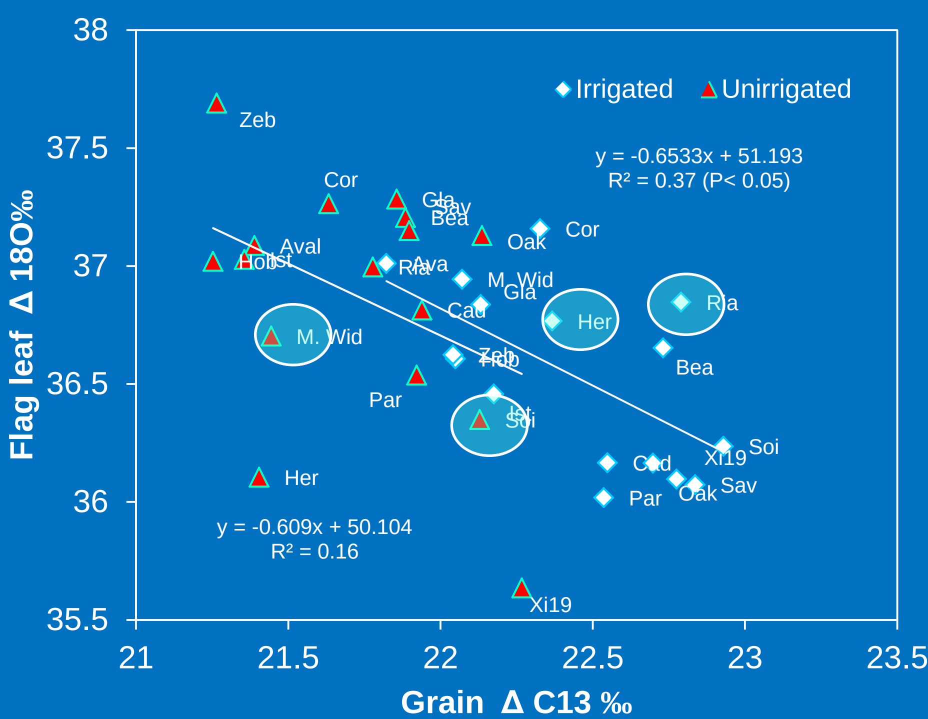
Relationship between Δ^{13}C and Δ^{18}O in 18 wheat cultivars

Low transpiration

2010



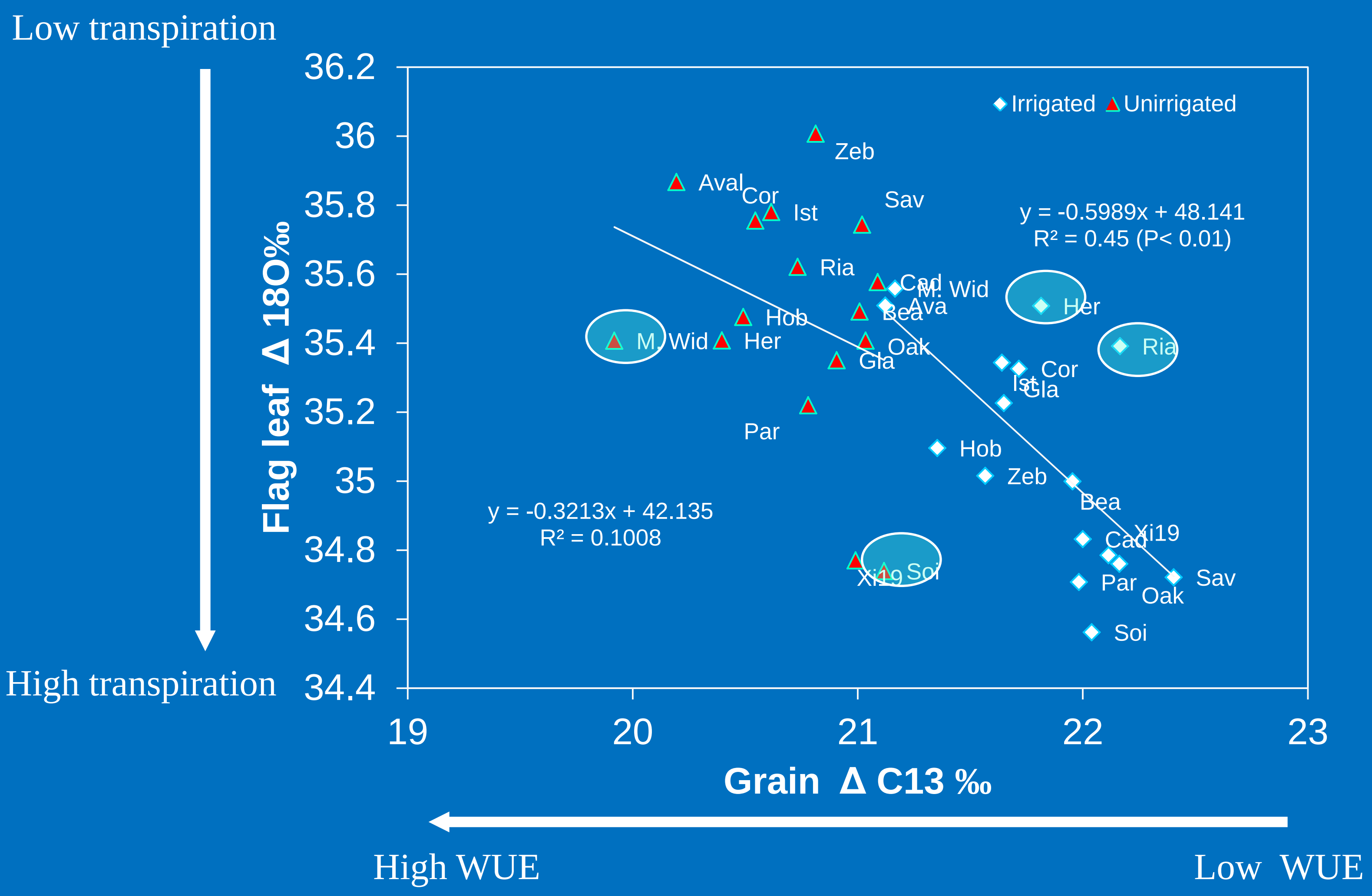
2011



High transpiration

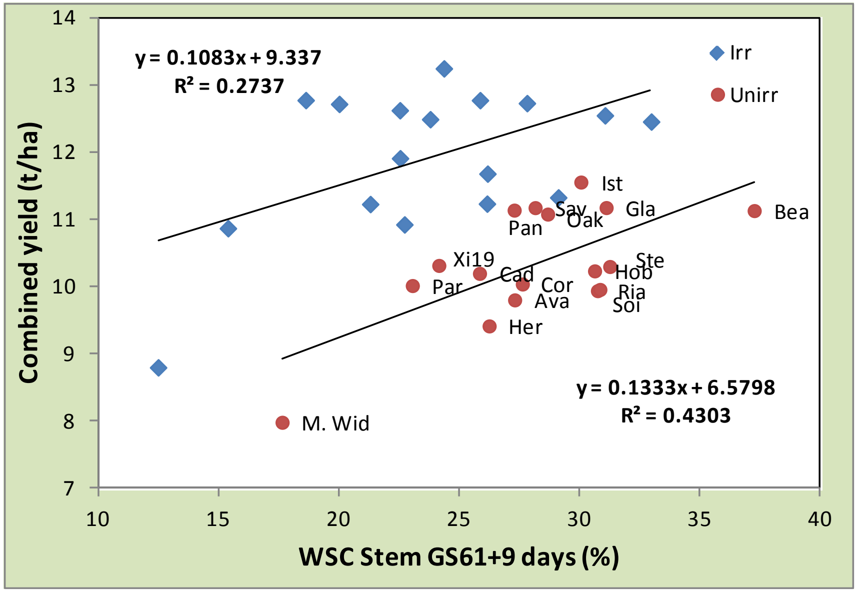
High WUE ← Low WUE

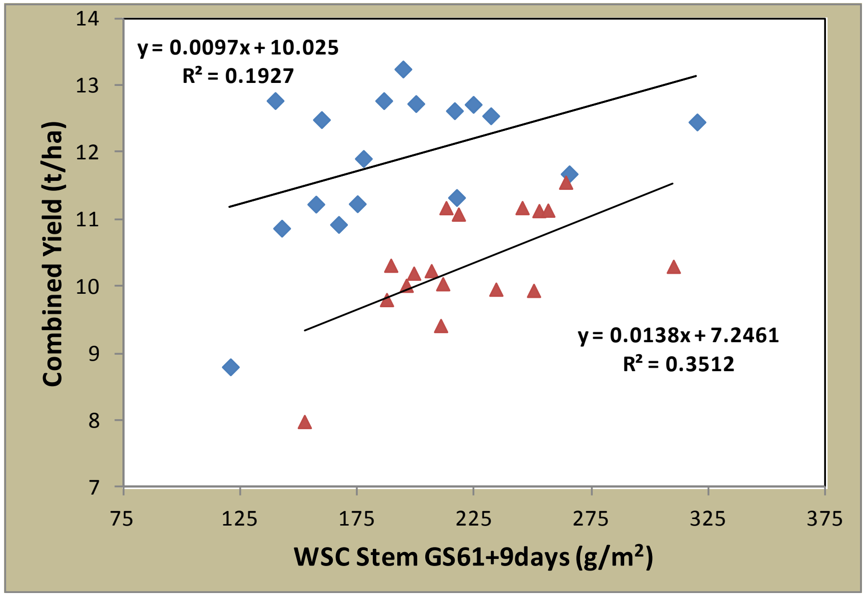
Relationship between Δ^{13}C and Δ^{18}O in 18 wheat cultivars (mean 2010 and 2011)



Other traits correlations:

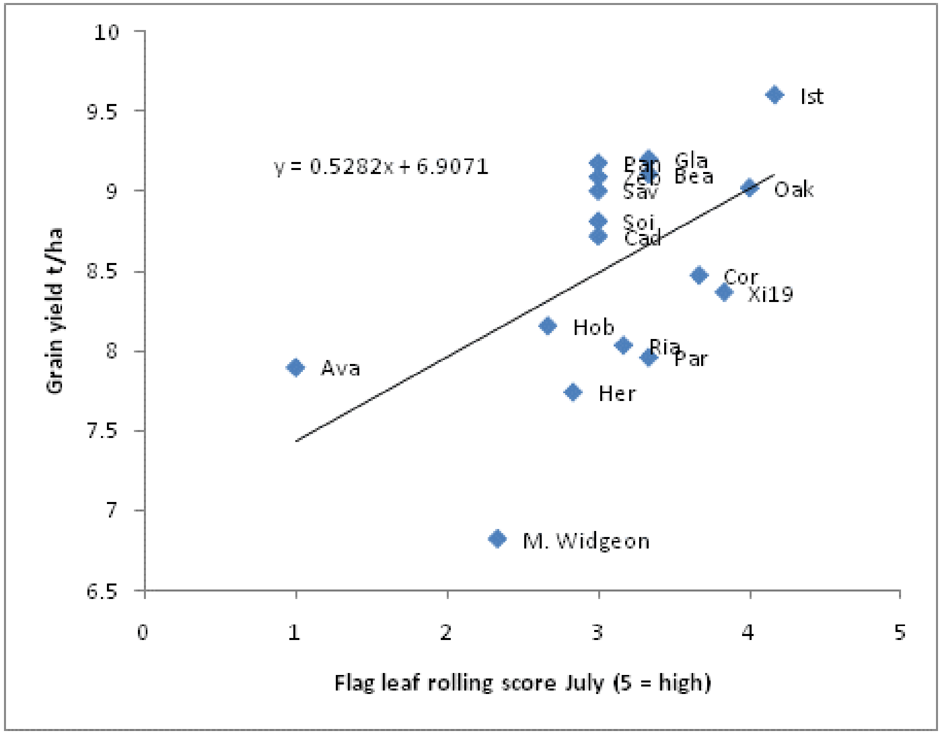
Grain yield versus stem WSC reserves





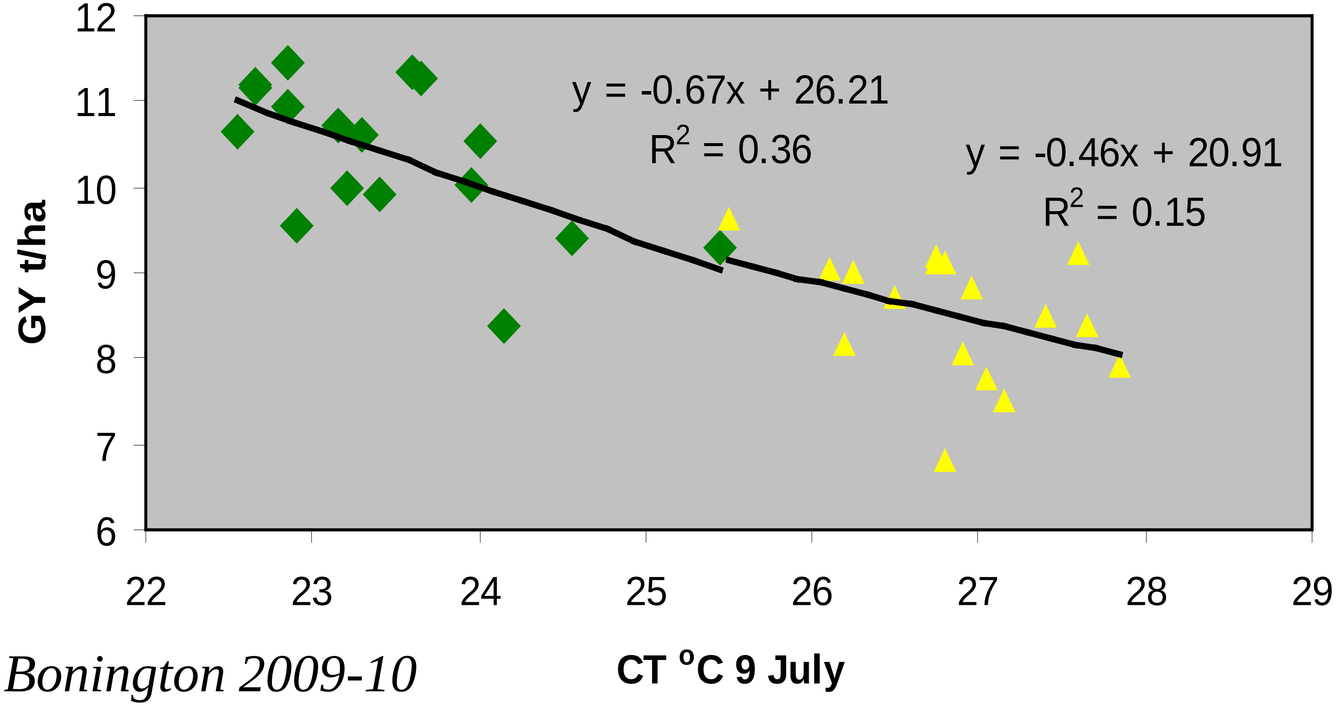
Sutton Bonington 2010-11

Flag leaf rolling score (July) Unirrigated trt



Mean 2010 & 2011

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

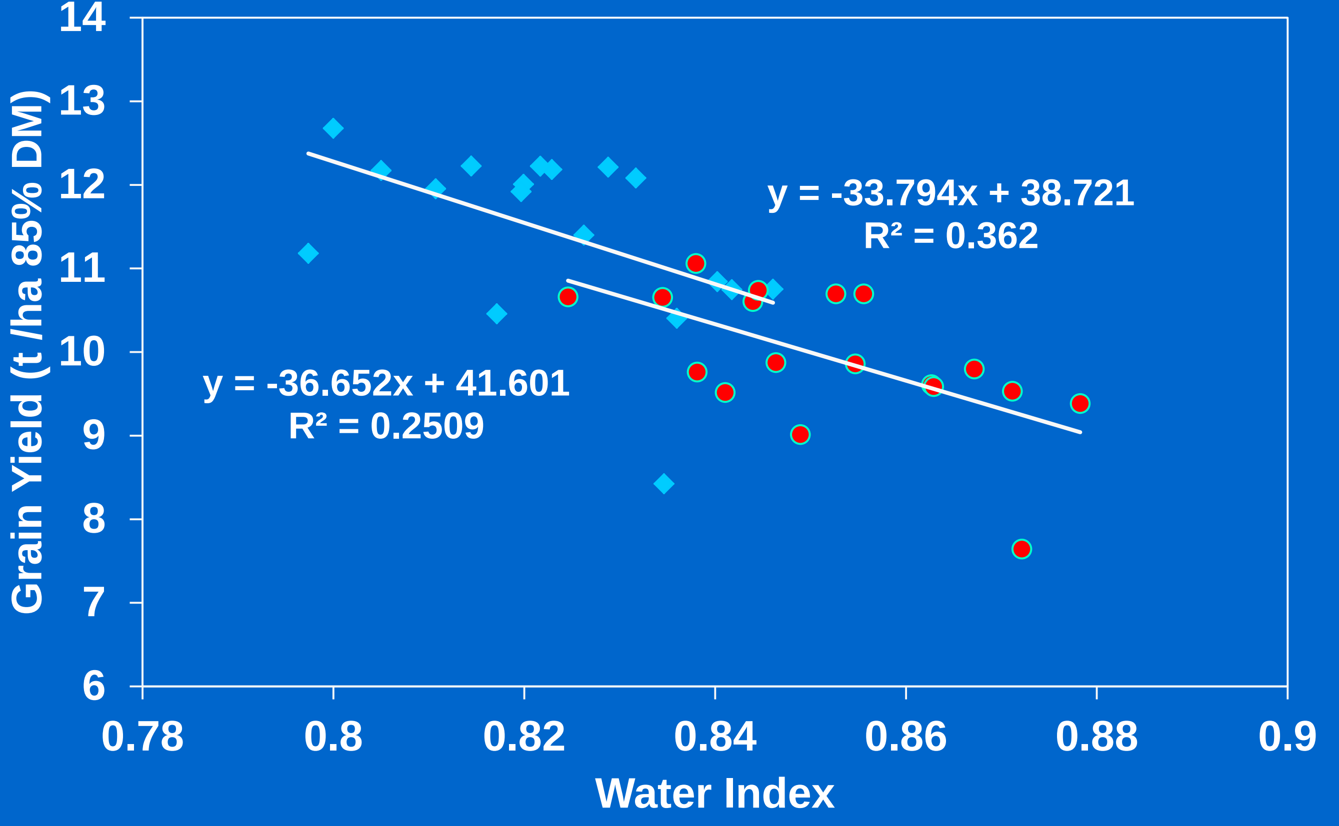


Sutton Bonington 2009-10

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

NIR – Water Index (R_{970}/R_{990}): 27 June 2011



Traits summary

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

Variety character	How it might work	Value
High Δ13C grain	Captures extra water	High
Low canopy T^oC/ deep roots	Captures extra water	High
High stem sugars	Buffers effects of post-flowering drought on grain filling.	Slight
Flag leaf ‘stay-green’/NIR_WI	Extends grain filling during late drought	High
Early flowering	Advances grain filling before the drought risk period.	Neutral
Awns	Use less water per unit growth.	Slight

DEFRA- LINK Project

Improving water use efficiency and drought tolerance in UK winter wheats

Table 1. Relationships between traits and yield or drought tolerance. Positive signs and minuses indicate positive and negative phenotypic correlations, respectively; blanks indicate a neutral effect.

	Drought tolerance index[7]	Irrigated yield	Droughted yield
Maintenance of green canopy[1]	+	+	
Stem dry mass at anthesis[2]	+	-	
Stem carbohydrate concentration[3]	+	+	
Carbon isotope discrimination ratio[4]	-	+	+
Water extraction from deep soil	+	-	
Stem height	+	-	
Flag leaf thickness	+	+	
Flag leaf area		-	
Flag Leaf rolling			+
Flag leaf photosynthetic efficiency[5]		+	
Waxiness[6]			+

[1]Maintenance of green canopy cover is the proportion of canopy cover at anthesis under irrigated conditions that was maintained under droughted conditions)

[2]Stem dry mass (or also the ratio of ear:stem dry matter) measured at anthesis

[3]Concentration of water-soluble carbohydrates (WSC) in stems sampled at anthesis

[4]Measured in flag leaves at anthesis or grain at maturity

[5]Measured using chlorophyll fluorescence techniques

[6]Appearance of waxy bloom on leaves and stems

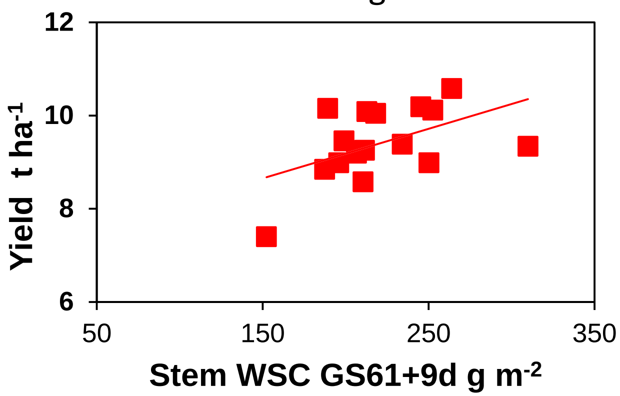
[7]The proportion of unstressed yield potential maintained under droughted conditions

Drought tolerant plant ideotype

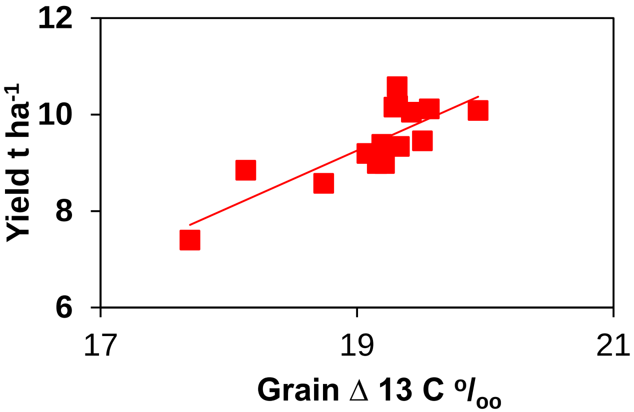
- **Multiple linear regression (P<0.001) accounted for 71% of the yield under drought and showed that:**

$$GY = -41.9 + 1.03\,x_1 + 0.08\,x_2 + 12.3\,x_3$$

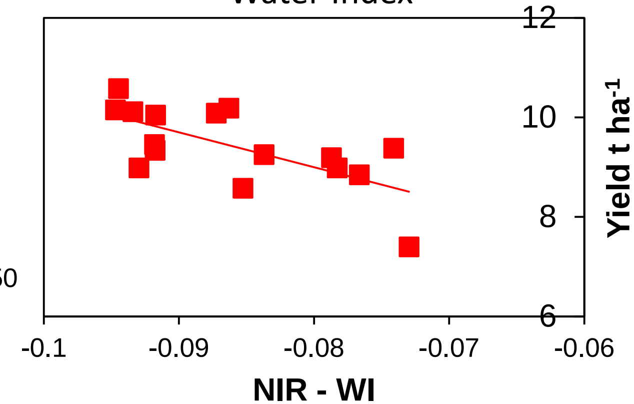
Grain yield increases with increasing stem WSC



GY increases with increasing Δ 13 C (↓WUE) :



GY increases with decreasing Water Index



WI = (R970-R900/)/(R970+R900)

Worldwide Literature

- Conflicting results obtained in various crops under different growing conditions on the association between Δ13C and yield - range from no relationship between Δ13C and yield to negative or positive relationships, depending on the crop and the environment.

- Deep or dense root system which would promote soil moisture capture and WU is correlated across genotypes with low WUE (Pinheiro et al., 2005; Kobata et al., 1996)

- Favorable genotypic plant water status under drought stress as reflected in measurements of canopy temperature is correlated with low WUE across genotypes (Araus et al., 1993; Frank et al., 1997; Read et al., 1991; Zong et al., 2008).

- Genotypic variation in WUE under limited water regimes is affected more by variation in the denominator (WU) rather than by variation in the nominator (biomass) (Blum, 2005).

- The widely cited case for dryland wheat grain yield improvement with selection for high WUE (low carbon isotope discrimination) in NSW Australia (Condon et al., 2002) can be explained by the fact that wheat is grown there mainly on stored soil moisture.

- Drought resistance was found to be associated with low WUE when analyzed by Δ13C under limited water supply (e.g.Araus et al., 2003; Morgan et al., 1993; Ngugi et al., 1994; Solomon and Labuschagne, 2004; Kumar et al., 2011).

- Water uptake (WU), water-use efficiency (WUE), and harvest index (HI) are drivers of yield.” Literature suggests WU is the main (not the exclusive) driver of yield under drought stress .

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 13C Δ correlated with grain yield under drought. Physiological basis ~ increased stomatal conductance, deeper roots?**
- **Measurement of stable isotopes in plant dry matter may a useful phenotypic tool for speeding up breeding**
  - **Grain ^{13}C Δ**
  - **Flag leaf Δ ^{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 2 (9.2 QTL Detection)

2010-11 and 2011-12 expts

• 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

- $^{13}C\ \Delta$ grain
- senescence kinetics
- canopy temperature
- stem WSC

Measurements on DH pop

- **Combine grain yield, yield components**
- **% stem WSC at GS61+10d (unirrigated)**
- **Leaf senescence kinetics for flag-leaf, L2 and L3.**
- **Canopy temperature**
- **grain Δ 13C (unirrigated)**
- **NDVI**

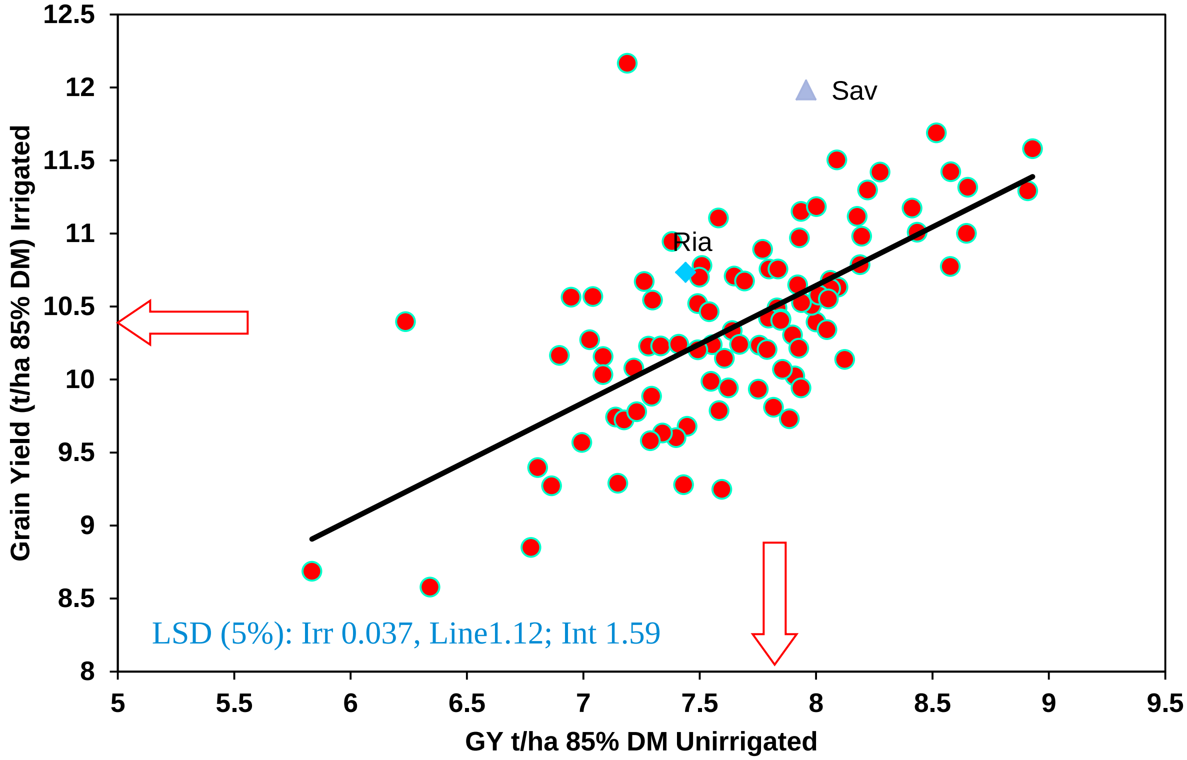
Drought effects 11 July 2011

L2

L39

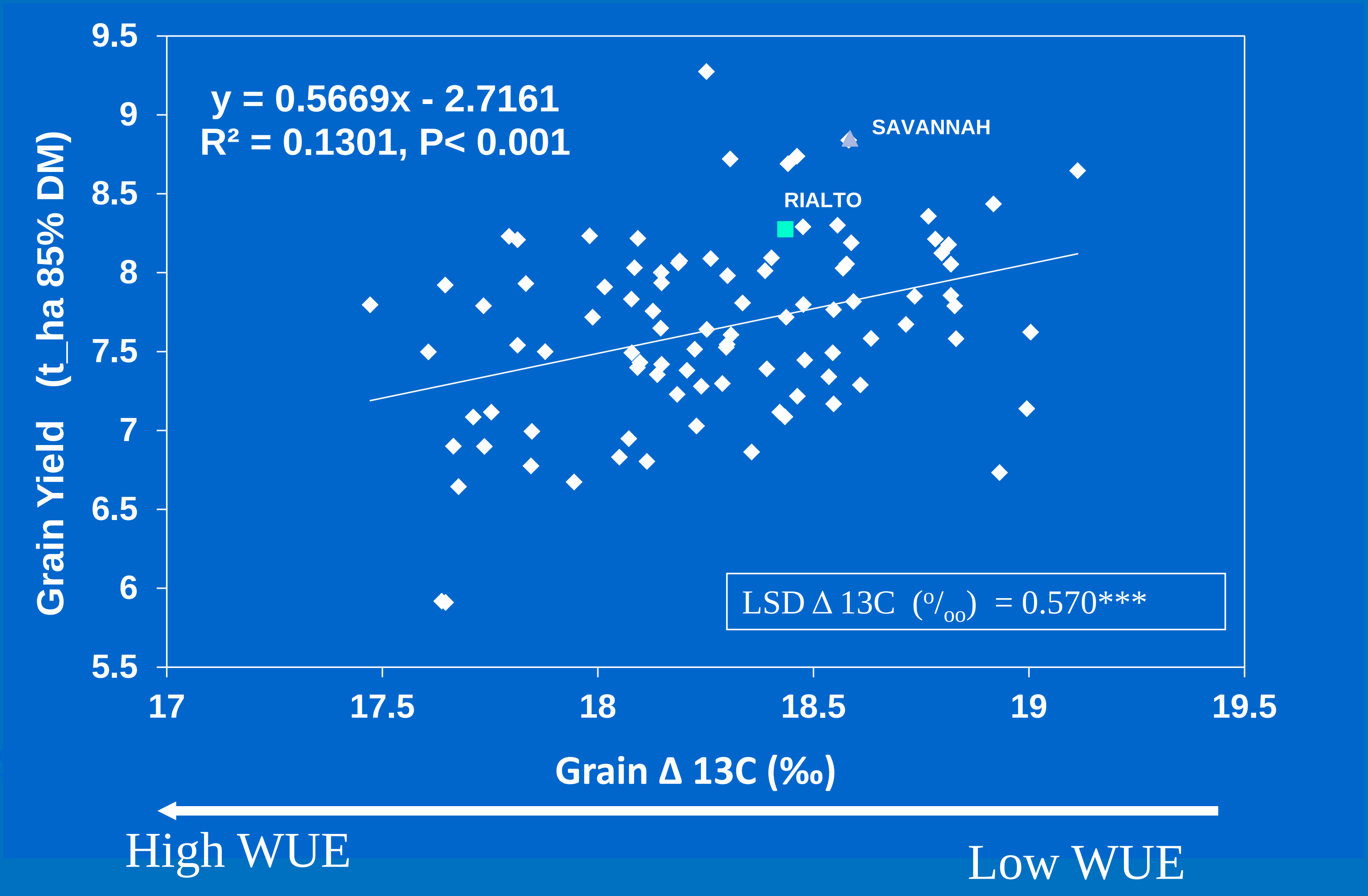
L47

Grain yield responses to irrigation



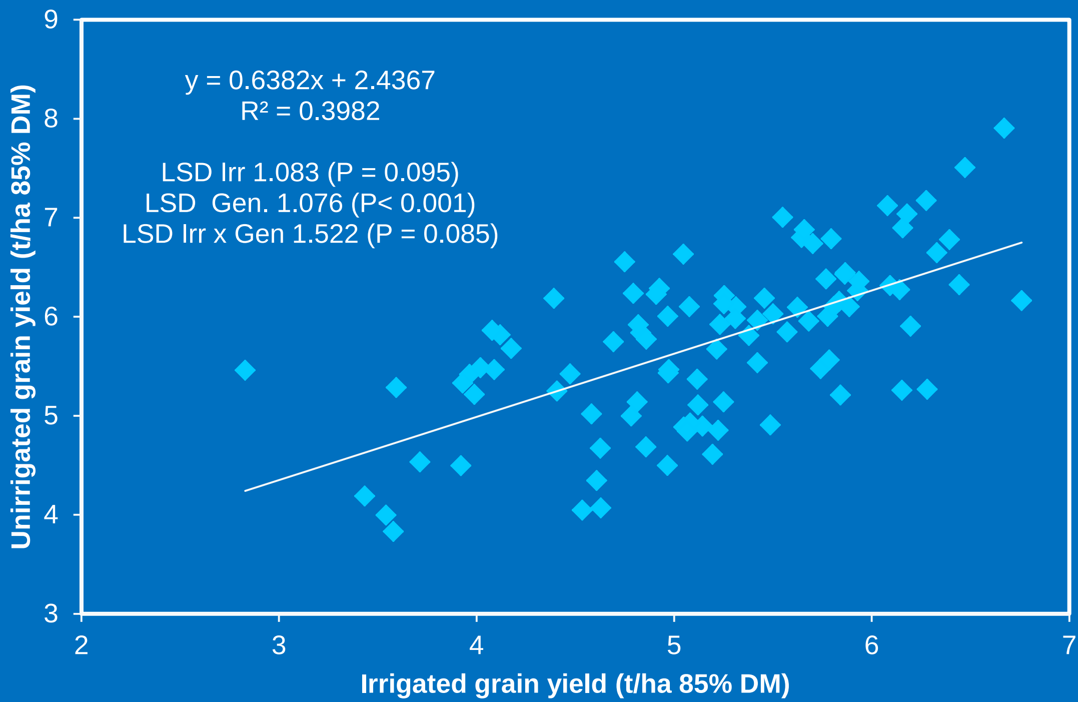
Sutton Bonington 2010-11

Δ ^{13}C vs grain yield: R x S DH (94 lines) 2010-11



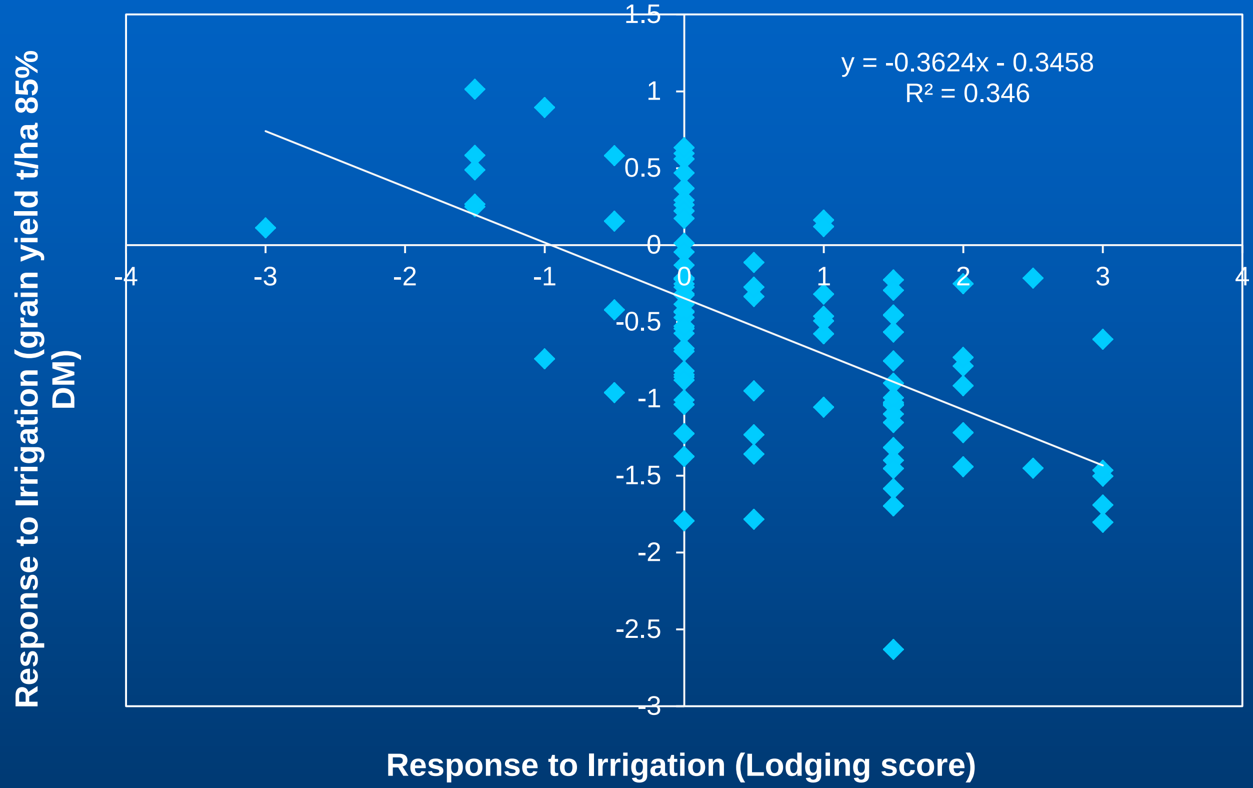
SB2010-11 Unirrigated

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

Rialto x Savannah DH exp 2011-12: Lodging vs grain yield



Reshm
Gaju

The University of Nottingham

Jayalath DeSilva *PhD student: Y.adgar Mahmood*

JOHN INNES CENTRE

Simon Griffiths
Simon Orford
Luzie Wingen

BRITISH WHEAT BREEDERS

defra
Department for Environment Food and Rural Affairs

Wheat Genetic Improvement Network

Reducing the risk of take-all root disease
Focus : The trait – Low take-all inoculum build-up

Vanessa McMillan
Richard Gutteridge
Kim Hammond-Kosack

Wheat Genetic Improvement Network

defra
Department for Environment Food and Rural Affairs

BBSRC bioscience for the future

ROTHAMSTED RESEARCH

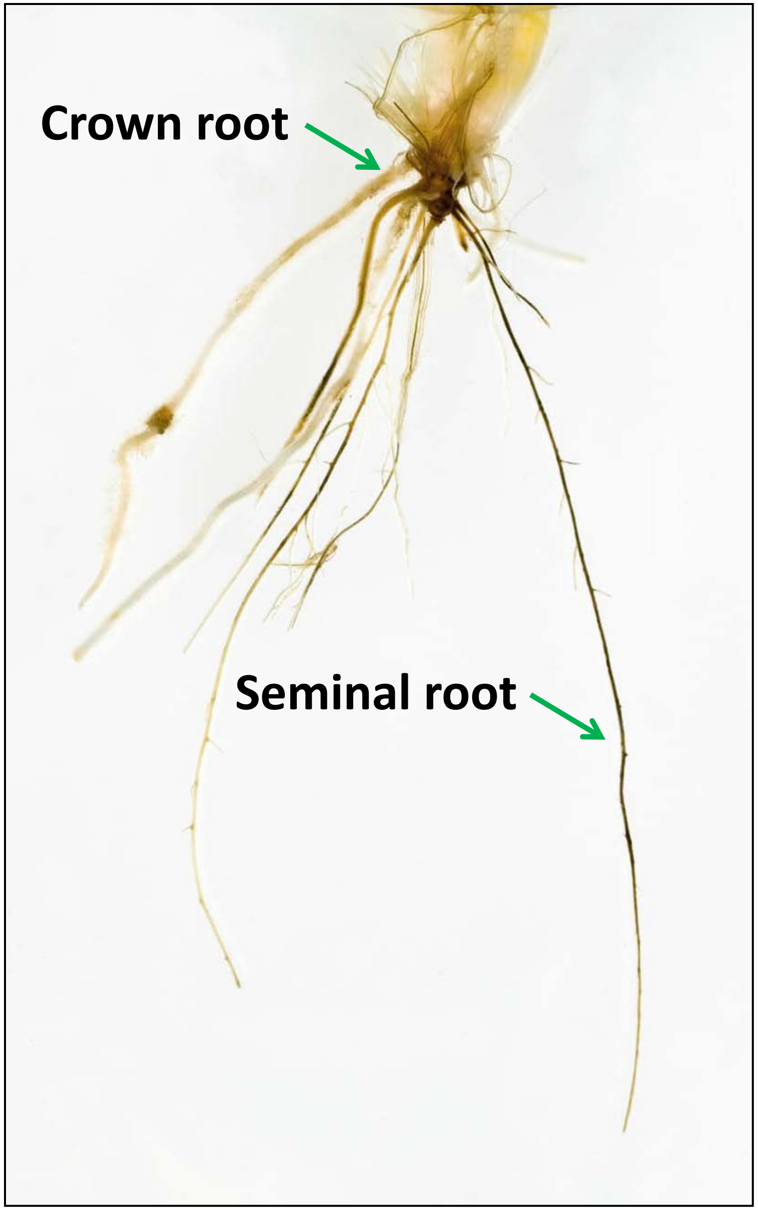
WGIN MM@JIC
6th November 2012

Take-all disease of wheat

• ***Gaeumannomyces graminis* var. *tritici* (*Ggt*)**

- ascomycete soil borne fungus

- related to rice blast fungus *Magnaporthe oryzae* (previously *M. grisea*)



***Ggt* infected wheat seedling**


A *Ggt* infected seminal root
Take-all lesion
Runner hypha

Take-all disease symptoms are usually only visible in 2nd and 3rd wheat crops

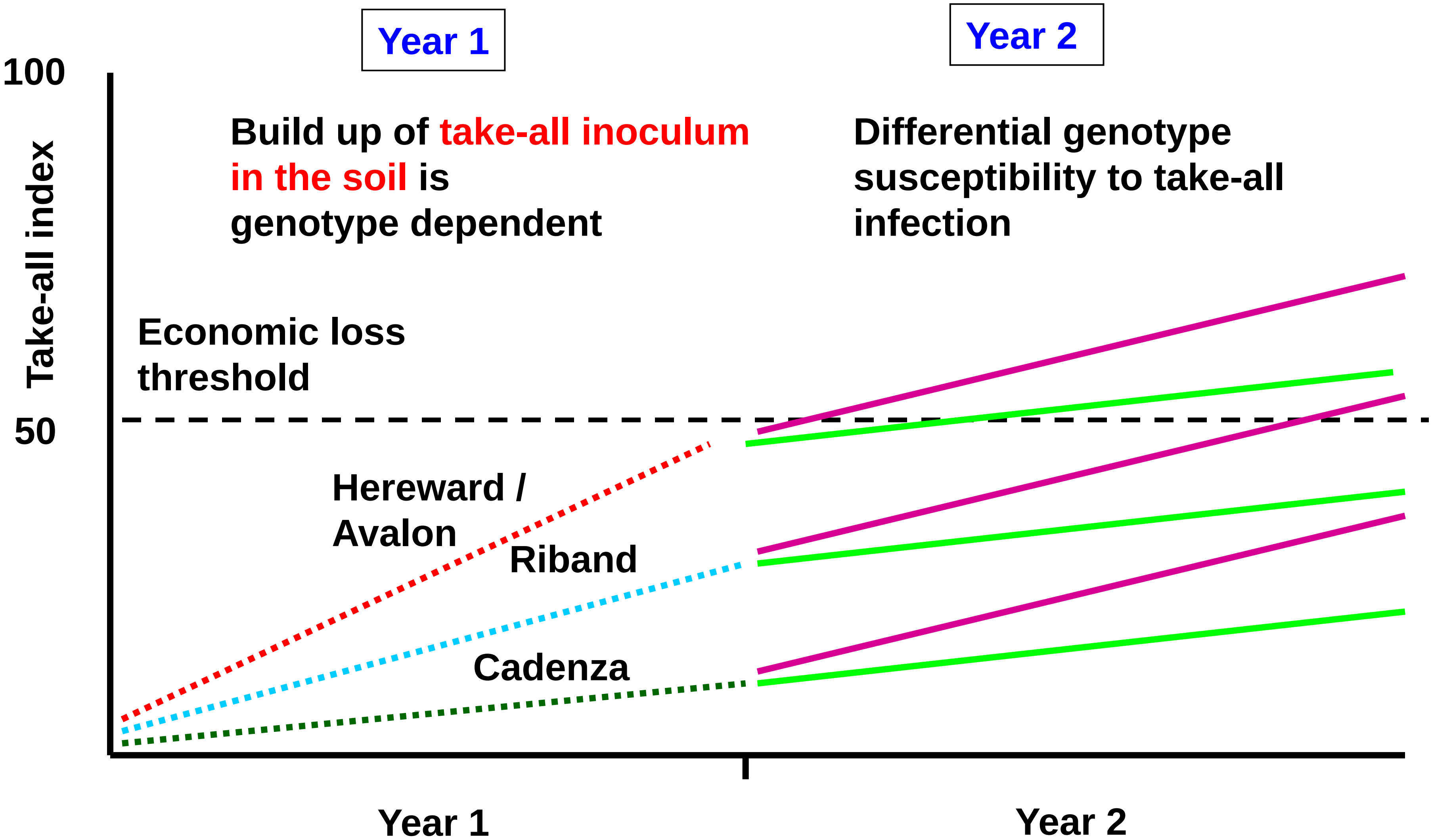
Typical take-all patch showing stunting and premature ripening of the crop

The WGIN Wheat Cultivar Rotation Trial

Overall objective: Explore the effect of sowing different sequences of cultivars on take-all disease pressure

Cultivar rotation trial – R/CS 688

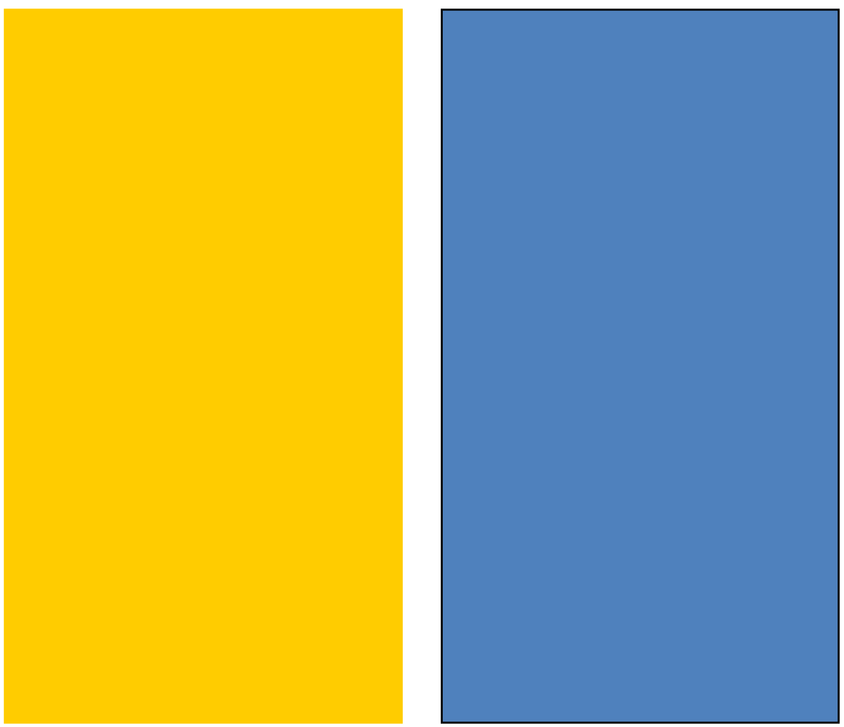
Overall objective: Explore the effect of sowing different sequences of cultivars on take-all disease pressure



Cultivar rotation trial – R/CS 688

Overall objective: Explore the effect of different cultivar sequences on take-all disease pressure

Step 1: Year 1 To create different take-all disease pressures in the field using the varieties Hereward (high inoculum build up) and Cadenza (low inoculum build up)

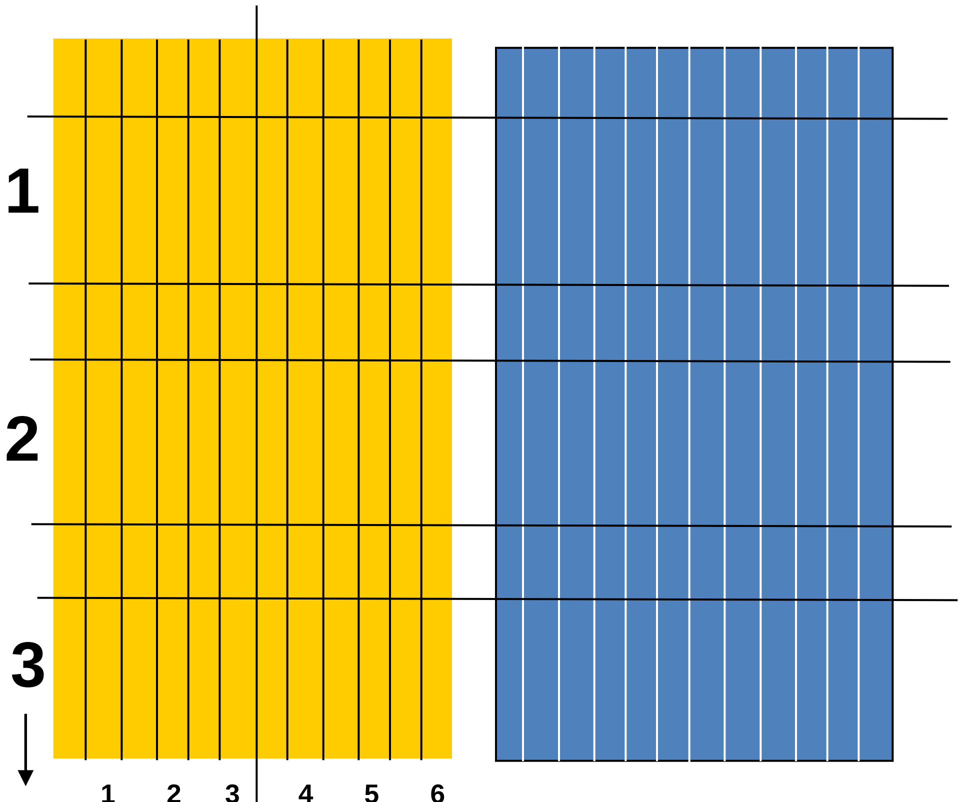


12m x 82m, of each variety
4 replicates of each
done in 2008 – 2009
Sown - 10th October 2008
Harvested – 16th August 2009
Great Knott III

Cultivar rotation trial – R/CS 688

Overall objective: Explore the effect of different cultivar sequences on take-all disease pressure

Step 2: Year 2 **Each of the 2009 large plots divided into eight 10m x 3m for the 2009 – 2010 field season**



14 m discard **(for tractor movement)**

10 m plot

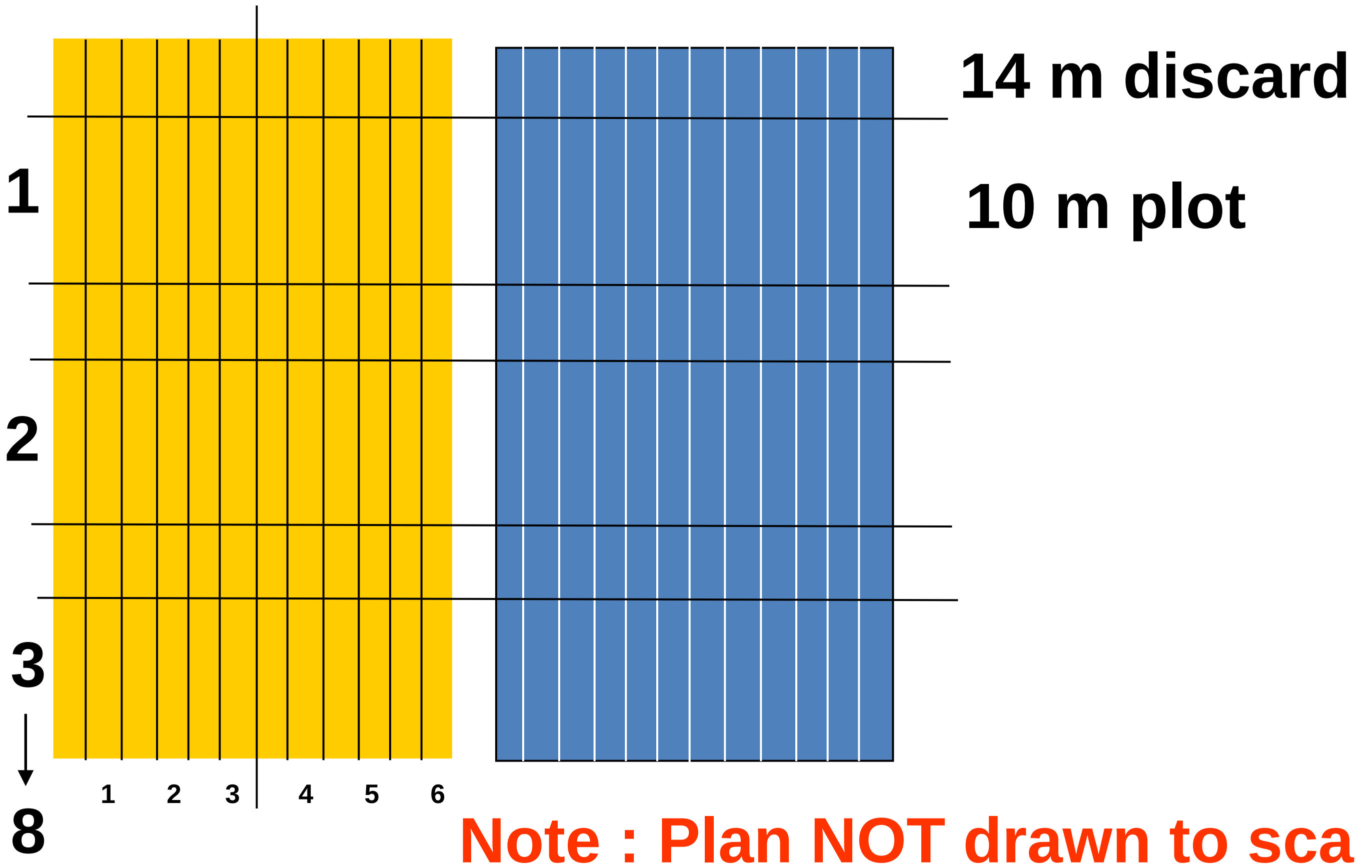
After 2009 harvest, five soil cores were taken from each of the designated 2010 plots
i.e. 64 plots x 5 = 320 cores, processed.

Plan NOT drawn to scale

Cultivar rotation trial – R/CS 688

Step 2: Year 2 Each of the 2009 large plots divided into eight 10m x 3m for the 2009 – 2010 field season

8 different wheat cultivars representing the NABIM groups 1 – 4 sown



Note : Plan NOT drawn to scale

The eight selected cultivars for the rotation trial

Variety	Group
Hereward	1
Gallant	1
Xi 19	1 (Cadenza pedigree)
Solstice	1
Cordiale	2
Einstein	2
Robigus	3
Duxford	4

Summary of the Rotation Trial No 1

Statistically significant differences (P<0.05) identified:

1. **Less take-all inoculum in the soil post – harvest from a Cadenza than a Hereward 1st wheat crop**
   - EXPERIMENTAL PLAN WORKED

2. **Less Take-all disease in the roots of the 2nd wheat crops following Cadenza than Hereward (June)**

% plants infected	**- 15% vis 36%**
Take-all index (0-100)	**- 8 vis 18**

BUT ONLY A TREND TOWARDS MORE GRAIN YIELD AFTER CADENZA

TRIAL was somewhat compromised due to the presence of moderate levels of *Phialophora graminicola* (= patchy *Ggt* distribution)

Rotation trial 2 (Year 1: 10/R/CS/706; Year 2: 11/R/CS/706)

Take-all infectivity of the soil after the first wheat source varieties Cadenza and Hereward, and take-all disease and yield data in the subsequent second wheat oversow. Great Knott I

	Year 1	Year 2				2011
	Soil bioassay after harvest of 1st wheat plots	Oversow Spring plant samples		Oversow Summer plant samples		Oversow Yields
Source variety	Logit % roots infected (BT[1] means)	Logit % plants with take-all (BT means)	Take-all roots per plant	Logit % plants with take-all (BT means)	TAI (0-100)	tonnes/ha
Cadenza	-1.87 (**1.8%**)	-1.55 (**3.8**)	**0.05**	-0.56 (**24.2%**)	**13.49**	**11.17**
Hereward	-1.72 (**2.6%**)	-1.37 (**5.5**)	**0.12**	-0.38 (**31.5%**)	**21.07**	**10.97**
d.f.	3	3	3	3	3	3
SED	0.173	0.039	0.018	0.104	2.345	0.059
F Probability	**0.450**	**0.021**	**0.039**	**0.181**	**0.048**	**0.043**
Grand mean	-1.79 (2.2)	-1.46 (4.7)	0.08	-0.467 (27.9)	17.28	11.07

0.2 tonnes / hectare more yield = 25-35% UK crop in 2nd or more wheat crops

485 - 582 K hectares = 97 to 116 K tonnes of grain (low take-all period)

Yield of the eight oversow 2nd wheat varieties

Harvest year
2011

RL
1st – 10.7t /ha
2nd - 9.0t / ha

NABIM group	Oversow variety	Yield tonnes / ha
	Grand mean	11.07
2	Einstein	9.91
1	Gallant	10.07
1	Solstice	10.30
2	Cordiale	10.30
1	Hereward	10.54
3	Robigus	11.96
1	Xi 19	12.03
4	Duxford	12.53
	d.f.	42
	SED	0.298
	F. probability	<0.001

Cad / Cad

Rotation trial 3 (Year 1: 11/R/CS/719; Year 2: 12/R/CS/719)

Take-all infectivity of the soil after the first wheat source varieties Cadenza and Hereward, and take-all disease and yield data in the subsequent second wheat oversow. Great Harpenden 2

	Year 1	Year 2 Spring	
	Soil bioassay after harvest of 1st wheat plots	Oversow Spring plant samples (Xi 19 & Hereward plots sampled)	
Source variety	Logit % roots infected (Back-transformed means)	Logit % plants with take-all (Back-transformed means)	Take-all roots per plant
Cadenza	-0.73 (**18.4%**)	0.56 (**75.5%**)	**2.18**
Hereward	-0.31 (**34.7%**)	1.82 (**97.9%**)	**4.29**
d.f.	3	3	3
SED	0.115	0.216	0.268
F Probability	**0.034**	**0.010**	**0.004**
Grand mean	-0.52 (26.6%)	1.19 (86.7%)	3.23

Rotation trial 3 (Year 1: 11/R/CS/719; Year 2: 12/R/CS/719)

Take-all infectivity of the soil after the first wheat source varieties Cadenza and Hereward, and take-all disease and yield data in the subsequent second wheat oversow. Great Harpenden 2

	Year 2 Summer				
	Oversow Summer measurements		Oversow Summer plant samples	Oversow Yield	
Source variety	Take-all patch score (% area)	Canopy height pre-harvest (cm)	TAI (0-100)	Grain yield (tonnes/ha)	Straw yield (tonnes/ha)
Cadenza	**49.4**	**63.55**	**73**	**8.60**	**5.57**
Hereward	**81.3**	**57.75**	**94**	**6.18**	**4.25**
d.f.	3	3		3	3
SED	3.72	0.818		0.338	0.167
F Probability	**0.003**	**0.006**		**0.006**	**0.004**
Grand mean	65.4	60.65		7.39	4.91

N.B. Summer plant samples still to be statistically analysed

Additional measurements : TGW and Hagbergs

Yield of the eight oversow 2nd wheat varieties 2012

No significant interaction between source variety and oversow variety: P = 0.753

Harvest year 2012

High take-all disease pressure

Nabim group	Variety	Yield (tonnes/ha)
3	Robigus	6.15
1	Hereward	6.16
2	Einstein	7.35
1	Xi 19	7.68
2	Cordiale	7.74
4	Duxford	7.80
1	Gallant	7.87
1	Solstice	8.39
	d.f.	42
	SED	0.445
	F. Probability	<.001

Yield of the eight oversow 2nd wheat varieties

		Yield (tonnes/ha)		
Nabim group	Oversow variety	2010	2011	2012
2	Cordiale	11.17	10.30	7.74
4	Duxford	11.06	12.53	7.80
2	Einstein	10.71	9.91	7.35
1	Gallant	9.93	10.07	7.87
1	Hereward	10.08	10.54	6.16
3	Robigus	10.85	11.96	6.15
1	Solstice	10.36	11.19	8.39
1	Xi 19	10.60	12.03	7.68
	d.f.	42	42	42
	SED	0.368	0.298	0.445
	F. Probability	0.013	<.001	<.001
	Grand Mean	10.60	11.07	7.39

The remaining WGIN Cultivar Rotation trial

Rotation trial 4 (Year 1: 12/R/CS/725; Year 2: 13/R/CS/725)

Take-all infectivity of the soil after the first wheat source varieties Cadenza and Hereward, and take-all disease and yield data in the subsequent second wheat oversow. Drapers

Soil cores taken after harvest in August 2012, still to be processed, expected high take-all inoculum build-up year.

Year 2 (2012-2013) 7 cultivars the same

plan to replace Xi19 with Cadenza

Cadenza – Cadenza

Hereward – Hereward

Data Summary : Cultivar rotation trials

Bold values - significant

2nd Harvest Year	Parameter measured	Cadenza (1st wheat)	Hereward (1st wheat)	F probability	Yield dif
2010	1st wheat % inf roots	**11.10%**	**20.10%**	**0.027**	
	2nd wheat % inf plants	**15.40%**	**35.80%**	**0.033**	
	2nd wheat TAI	**8.3**	**18.5**	**0.4**	
	2nd wheat yield (t/ha)	10.85	10.38	0.19*	0.47 t/ha
2011	1st wheat % inf roots	1.80%	2.60%	0.45	
	2nd wheat % inf plants	24.20%	31.50%	0.181	
	2nd wheat TAI	**13.49**	**21.07**	**0.048**	
	2nd wheat yield (t/ha)	**11.17**	**10.97**	**0.043**	**0.2 t/ha**
2012	1st wheat % inf roots	**18.40%**	**34.70%**	**0.034**	
	2nd wheat % inf plants	**75.50%**	**97.80%**	**0.01**	
	2nd wheat TAI	73	94	in stats	
	2nd wheat yield (t/ha)	**8.6**	**6.18**	**0.006**	**2.42 t/ha**
	2nd wheat straw (t/ha)	**5.57**	**4.25**	**0.004**	**1.32 t/ha**

*** Phialophora**

Summary : Cultivar rotation trials

Using 1st wheat genetics to improve 2nd wheat crop yield performance

0.2 t /ha (good growing season – 2011)
2.42 t /ha (difficult growing season – 2012)

- **Less take-all disease in a 2nd wheat crop when Cadenza is grown as the 1st wheat (n = 8 cultivars, 2nd wheats)**

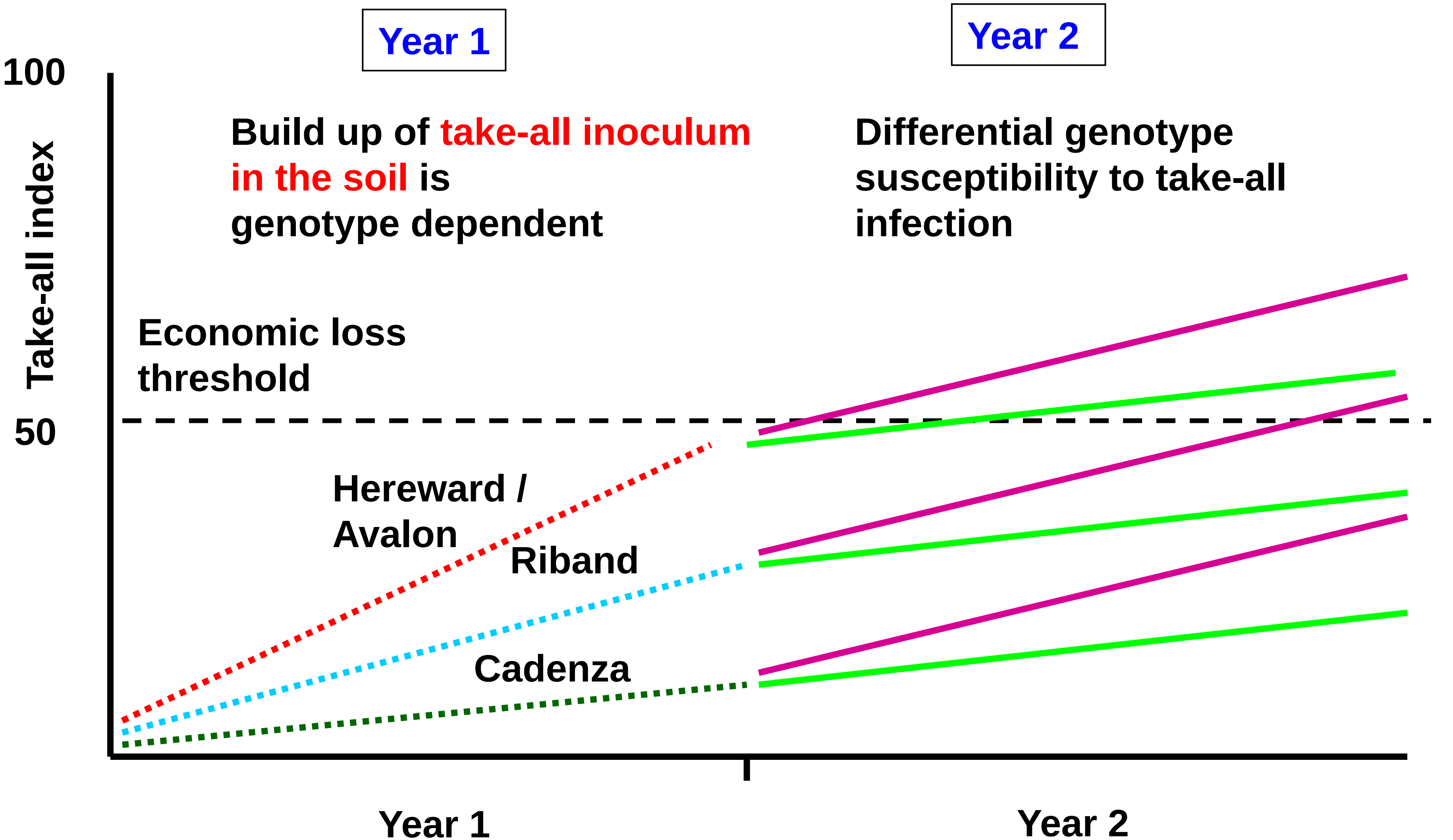
2nd wheat cultivar independent effect (3 years data)

- **Fewer plants infected and less disease/plant root system**

- **Grain yield advantage in the 2nd wheat crop**

Cultivar rotation trial

Overall objective: Explore the effect of sowing different sequences of cultivars on take-all disease pressure



Earlier field cropping history

Rotation trial 1: 09-10/R/CS/688

Great Knott III

2008 Winter oats

2007 Winter wheat/Spring beans/Winter beans

2006 Winter wheat/ Peas

Rotation trial 2: 10-11/R/CS/706

Great Knott I

2009 Winter rape

2008 Winter wheat

2007 Winter oats

2006 Winter wheat

Rotation trial 3: 11-12/R/CS/719

Great Harpenden 2

2010 Winter beans

2009 Winter barley

2008 Winter wheat

2007 Spring beans

2006 Winter wheat

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Rotation trial 1 (Year 1: 09/R/CS/688; Year 2: 10/R/CS/688)

Take-all infectivity of the soil after the **first wheat source varieties Cadenza and Hereward**, and take-all disease and yield data in the subsequent **second wheat oversow (means of 8 cultivars)**. **Great Knott III**

	Year 1	Year 2[4]				
	Soil bioassay after harvest of 1st wheat plots[2]	Oversow Spring plant samples		Oversow Summer plant samples		Oversow Yields
Source variety[1]	Logit % roots infected (BT[3] means)	Logit % plants with take-all (BT means)	Take-all roots per plant	Logit % plants with take-all (BT means)	TAI (0-100)	tonnes/ha
Cadenza	-1.01 (11.1%)	-1.21 (7.7)	0.20	-0.83 (15.4)	8.3	10.82
Hereward	-0.67 (20.1%)	-0.90 (13.9)	0.35	-0.28 (35.8)	18.5	10.38
d.f.	3	3	3	3	3	3
SED	0.084	0.167	0.068	0.148	2.910	0.261
F Probability	0.027	0.158	0.118	0.033	0.040	0.190
Grand mean	-0.84	-1.06 (10.8)	0.27	-0.557 (25.6)	13.4	10.60

[1] No significant interactions between the 2 first wheat source varieties and the 8 second wheat oversow varieties

[2] Moderate levels of *Phialophora graminicola* on soil core bioassay plants across the trial site

[3] BT, back-transformed

[4] Seed spill on plots 48 and 64 during sowing of the second wheat varieties, samples not taken from these plots.

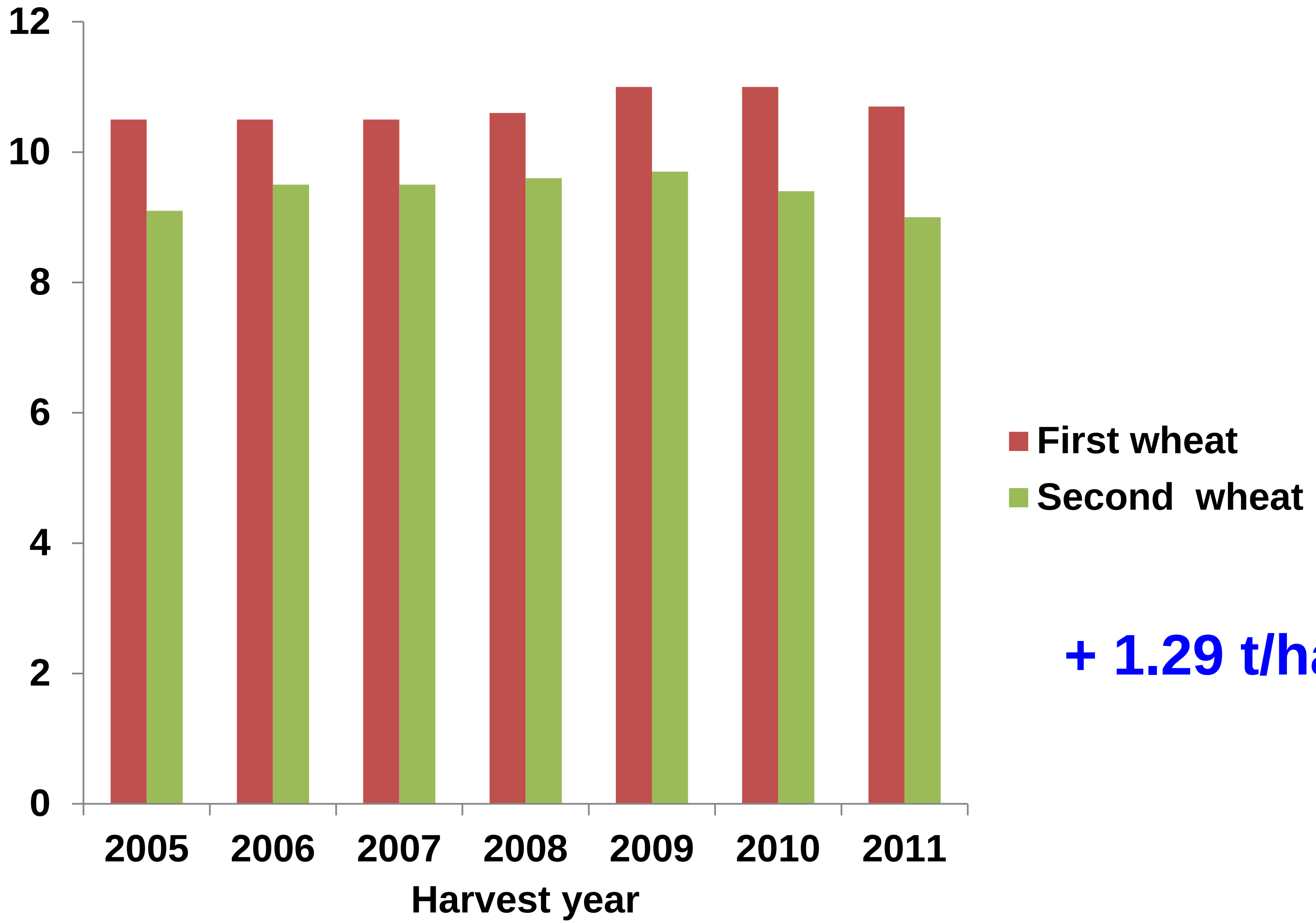
Yield of the eight oversow 2nd wheat varieties

Harvest Year 2010

RL
1st - 11.0t / ha
2nd – 9.4t / ha

NABIM group	Oversow variety	Yield tonnes / ha
	Grand mean	10.60
1	Gallant	9.93
1	Hereward	10.08
1	Solstice	10.36
1	Xi 19	10.60
2	Einstein	10.71
3	Robigus	10.85
4	Duxford	11.06
2	Cordiale	11.17
	d.f.	42
	SED	0.368
	F. probability	0.013

Seven years of Recommended List data



+ 1.29 t/ha

GRAIN YIELD (t/ha)	2005	2006	2007	2008	2009	2010	2011
First wheat	10.5	10.5	10.5	10.6	11	11	10.7
Second wheat	9.1	9.5	9.5	9.6	9.7	9.4	9