Rothamsted Research
where knowledge grows

Nutrient use efficiency in wheat
What are the challenges?

Malcolm J. Hawkesford

Crop Science Workshop, May, 2014

BBSRC 20 Years of Pioneering Great British Bioscience

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Outline: some NUE challenges?

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- Yield and NUE
  - Link between yields and NUE
  - Genetic variation and scope for improvement
- Inverse relationship of grain protein and yield
- Quality: micronutrients
- Some opportunities
  - Exploiting more diverse germplasm diversity
  - Improved high throughput phenotyping





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Goal: food security via sustainable increases in yields

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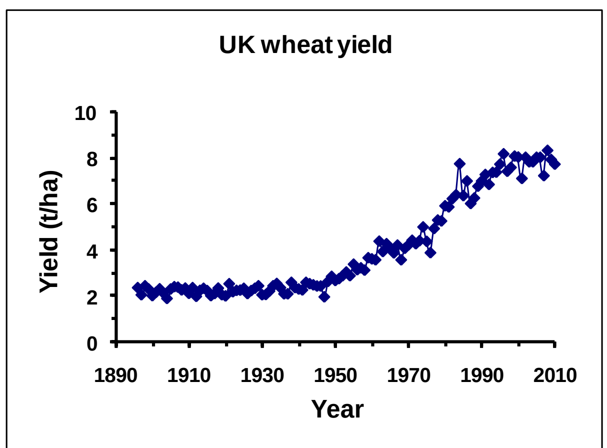
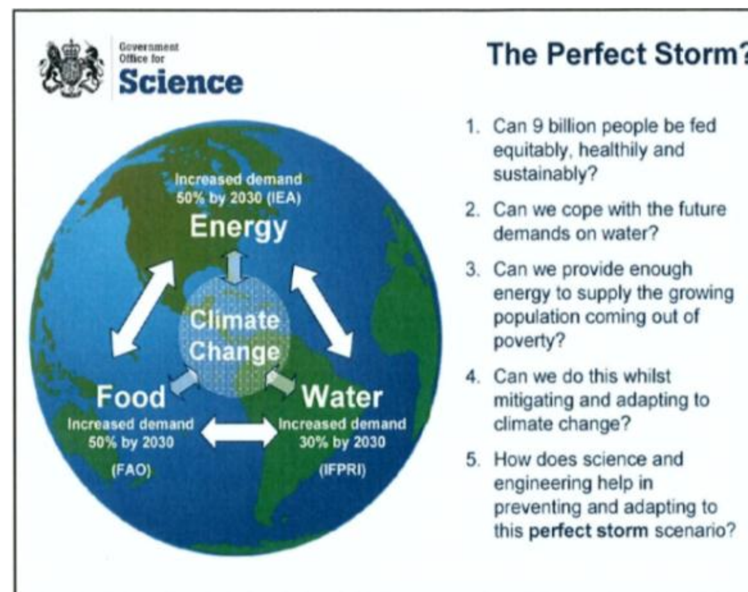
- Double production by 2050
- Population increase
- Climate change
- Land pressure
- Water availability
- Cost/availability of fertiliser
- Plateauing yields





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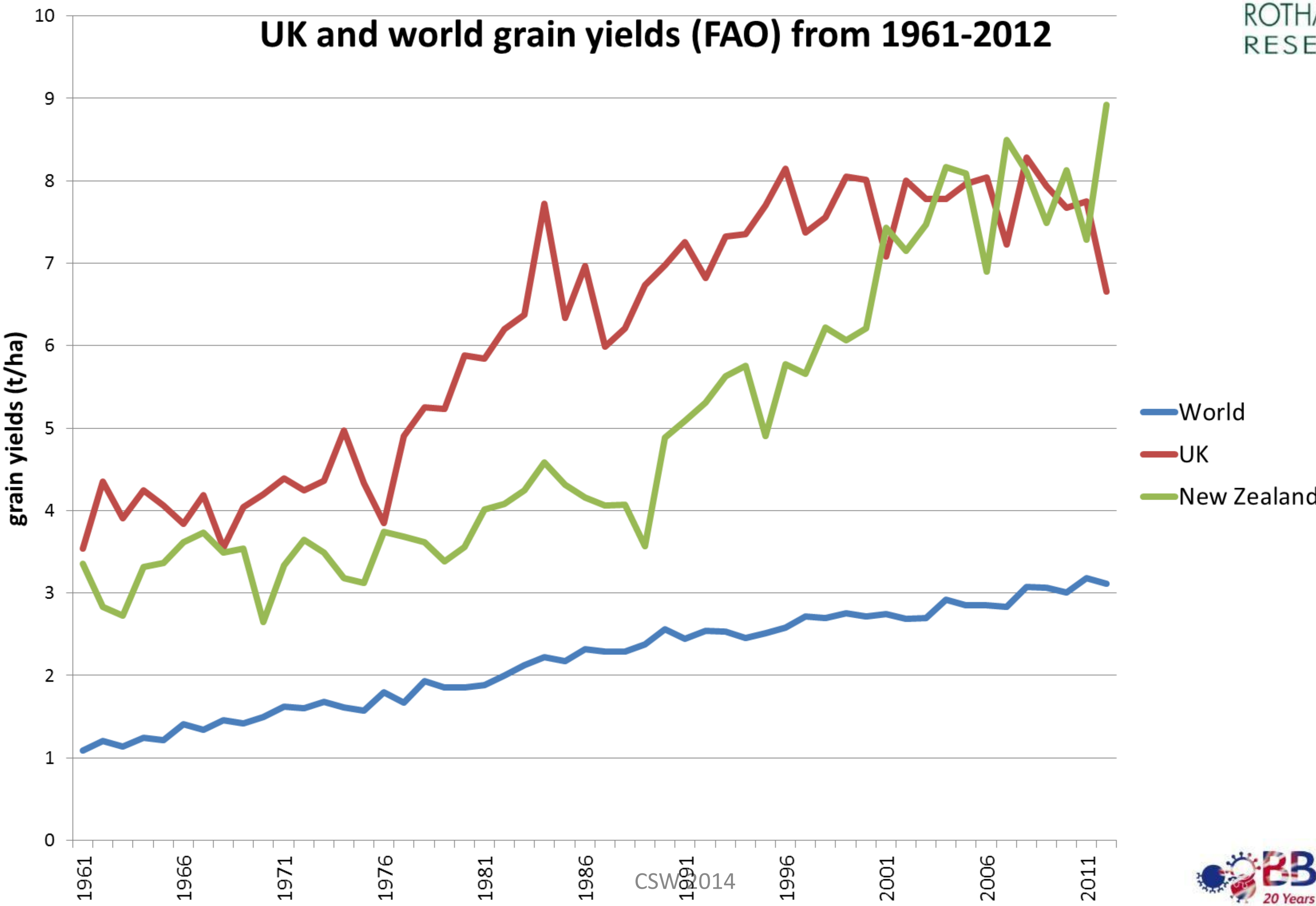
Trends in wheat yields (farm gate)



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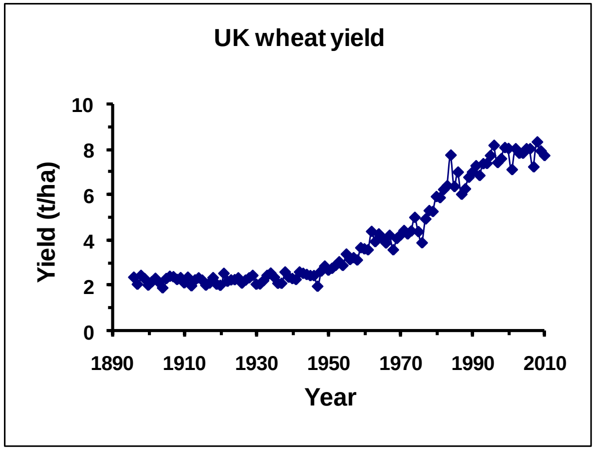
First green revolution

- Norman E. Borlaug
  - Dwarfing genes
  - More nitrogen
- Some issues
- Next green revolution?
  - Roots
  - Primary production



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Why do we need NUE?

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Food security
Increase yields and avoid plateauing
Challenging environments and climate

Financial costs
Farmers
Fertilizer producers
Millers, bakers
Distribution

INPUTS:
FERTILIZER &
WATER

efficiency

YIELD
&
QUALITY

Sustainability
Carbon footprint
Limited resources (P)
Organic production

Environmental costs
Pollution
Land use
Carbon footprint
Government/legislation
Public concerns

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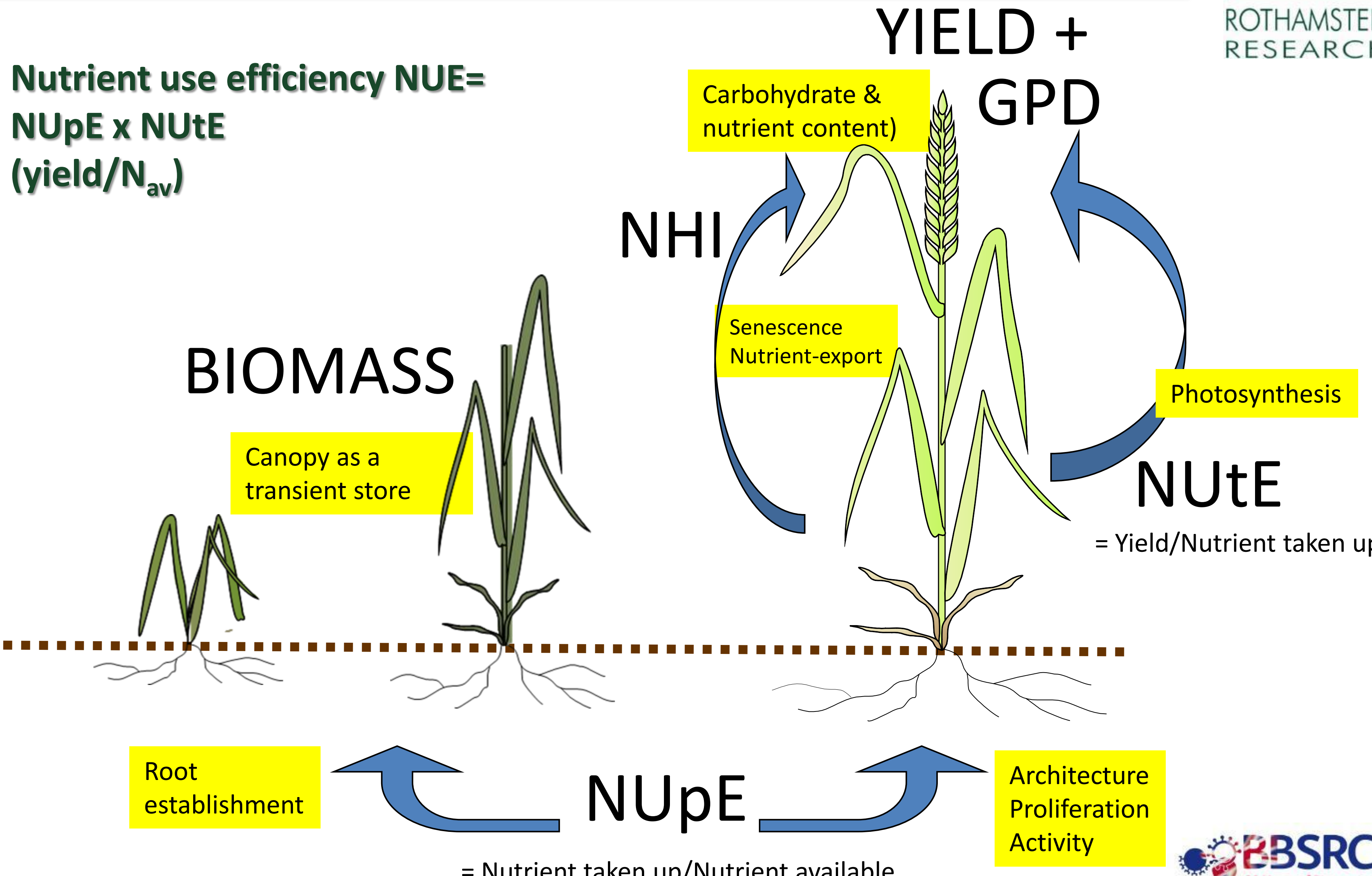
Target traits

Nutrient use efficiency NUE= NUpE x NUtE (yield/N_{av})



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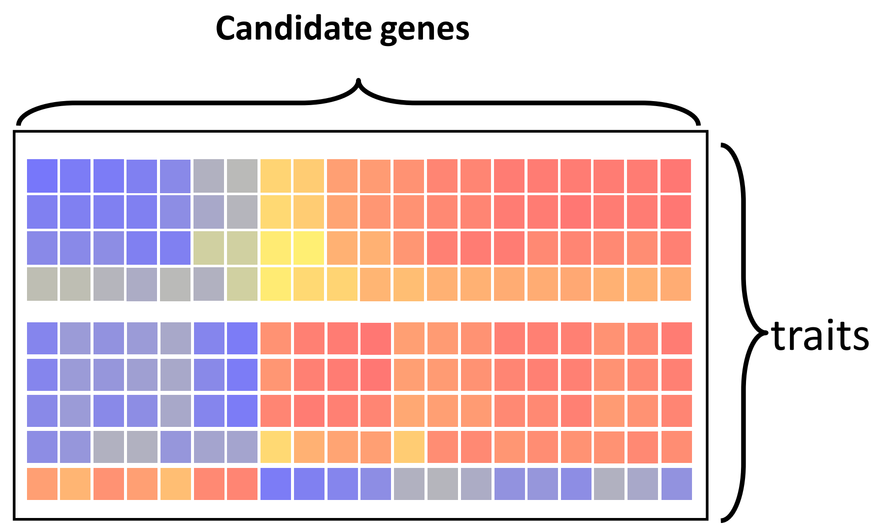
Key approach: genes correlating to NUE traits

- Trait de-convolution and prioritization
- Assessment of variation
  - Provision of data for breeding
  - Aid new gene discovery
- Identification of genes/markers
  - Transcriptomics
  - Correlation with traits
  - Mapping populations
- Breeding or biotechnology



NUE and diversity

Why are diversity studies needed?

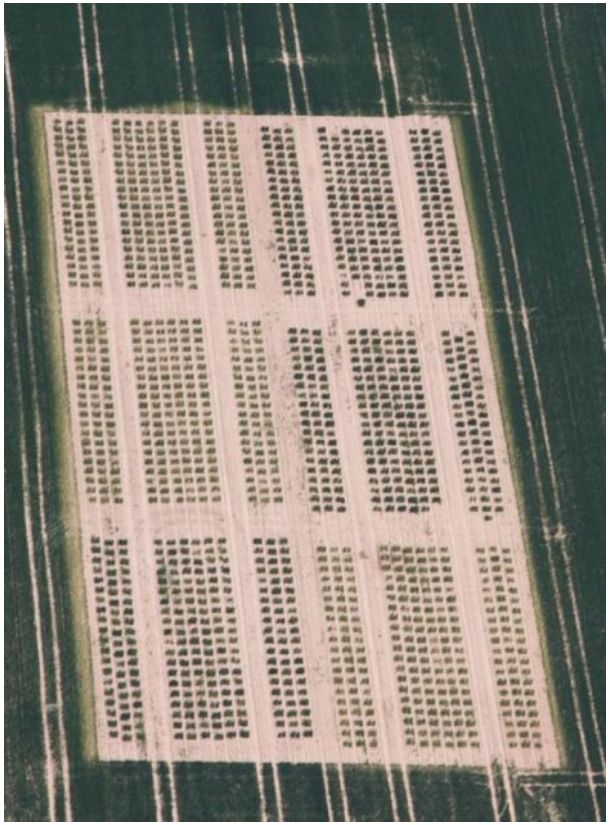
- Assess current extent of variation (**WGIN**)
- Wider screening may be necessary if not enough variation in current germplasm
- Bottlenecks, recent and ancient
- Harness 'lost' genes and alleles, a particular problem for some sustainability traits
- Modern selection under high inputs

What are the problems?

- Finding the right germplasm
- Genetics and Phenotyping
- Metrics when comparing very different materials

WISP

- http://www.wheatisp.org/
- **Watkins, Gediflux, SHW and modern cultivars**
- **Derived mapping populations**



WGIN: Wheat Genetic Improvement Network




defra
Department for Environment Food and Rural Affairs

Wheat Genetic Improvement Network

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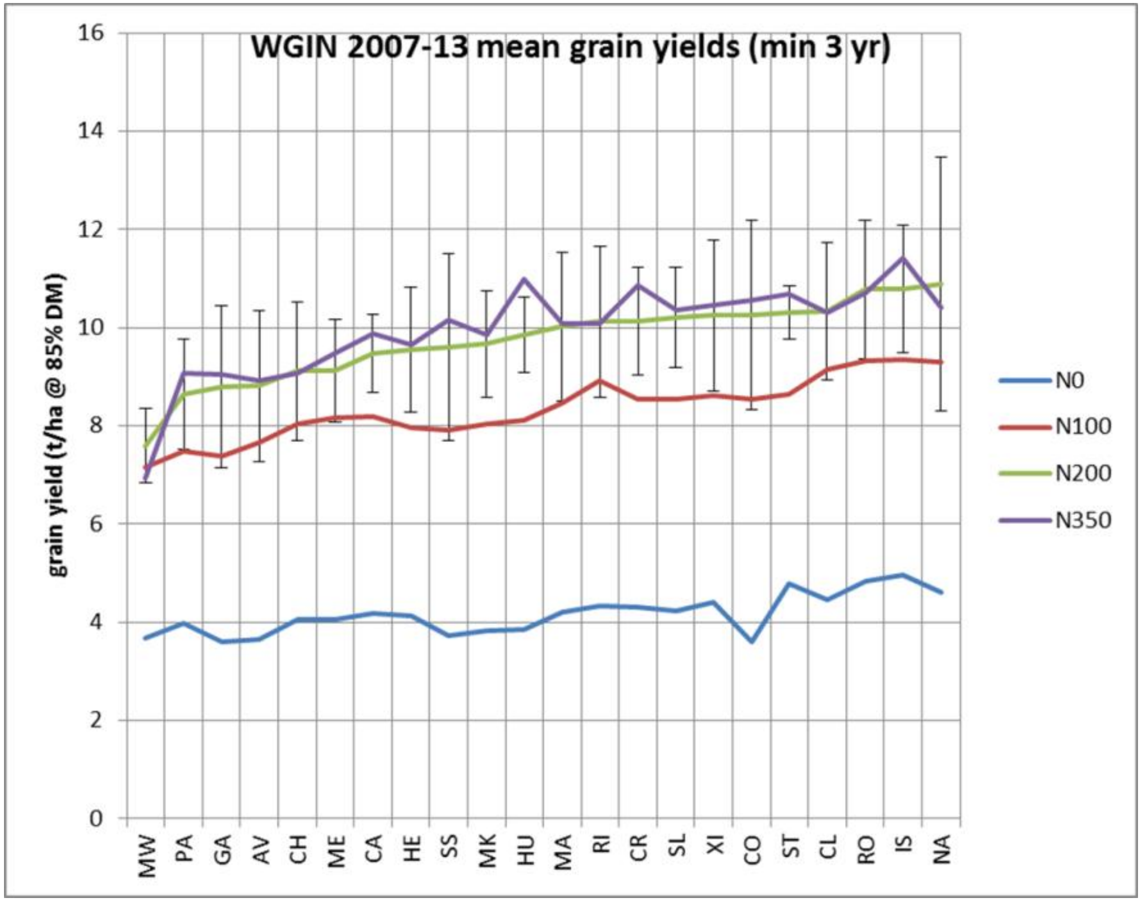
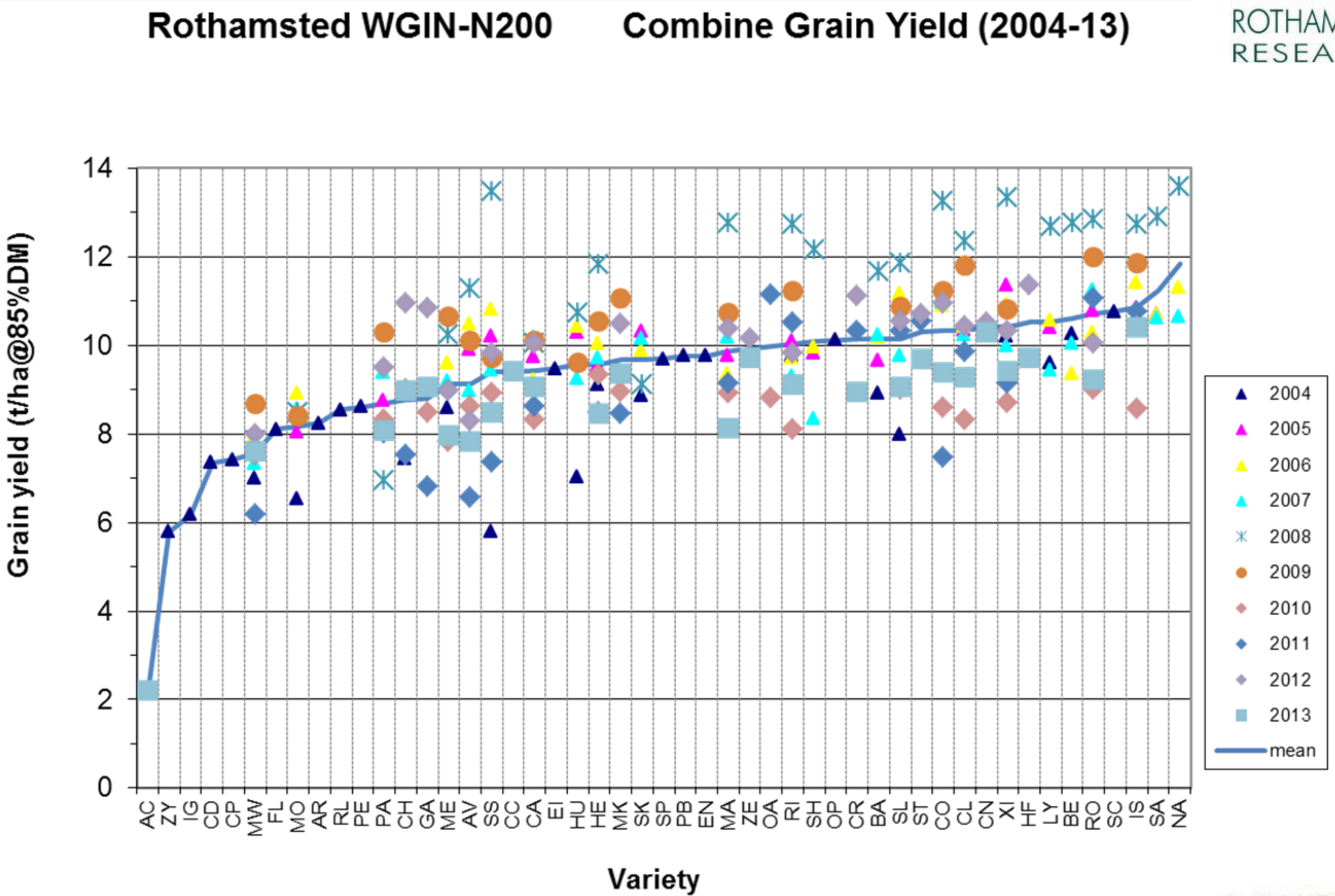
WGIN: The Nitrogen-Diversity trial

- 2004-13
- 51 varieties
- 14 in at least 9 years
- All 4 groups
- 4 N levels in all except 2 years
- Grain and straw, yield and %N
- Archived fresh grain
- Archived dry milled grain and straw
- Many spin-off projects



WGIN – yield stability



N-supply impacts on yields and quality

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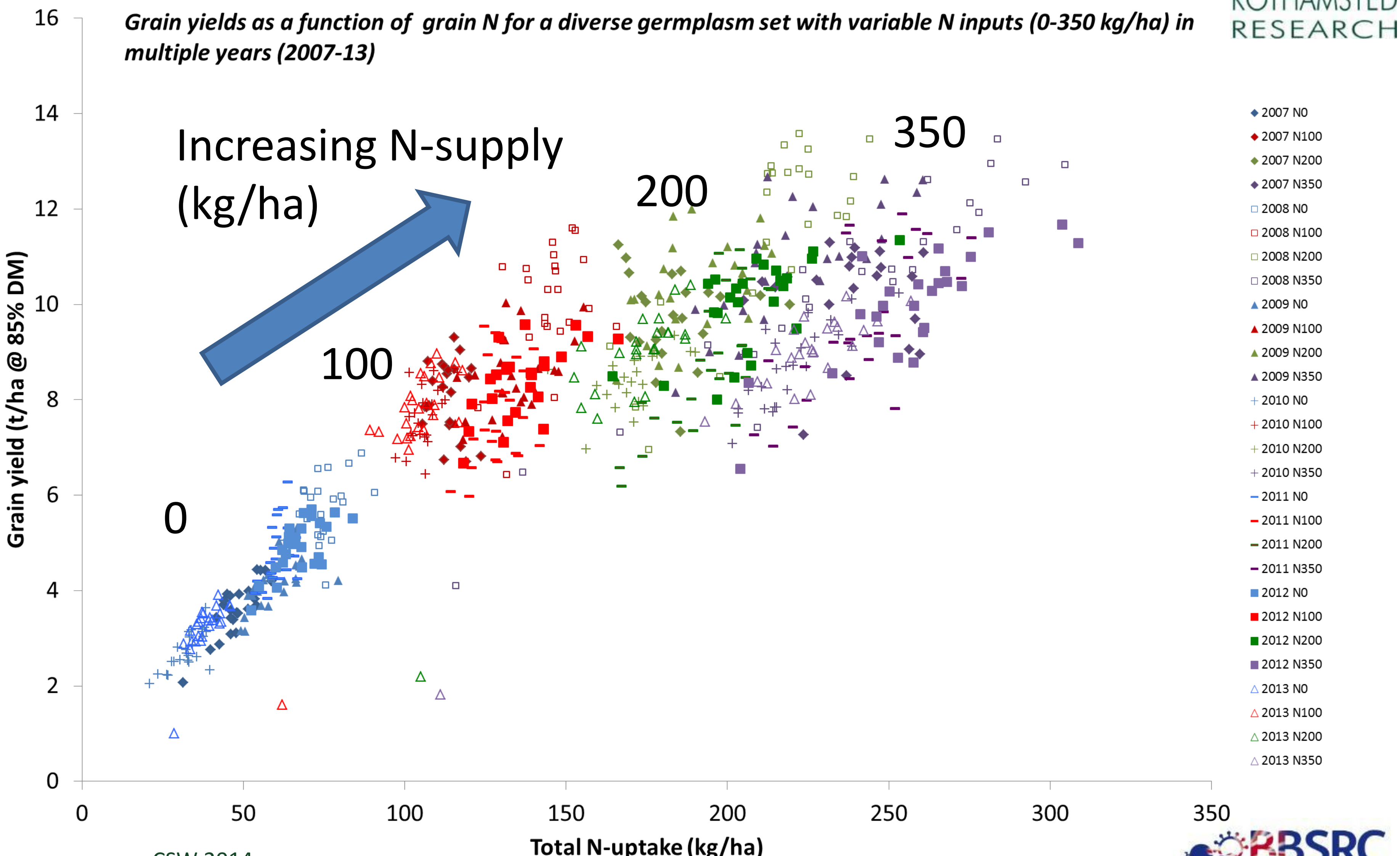

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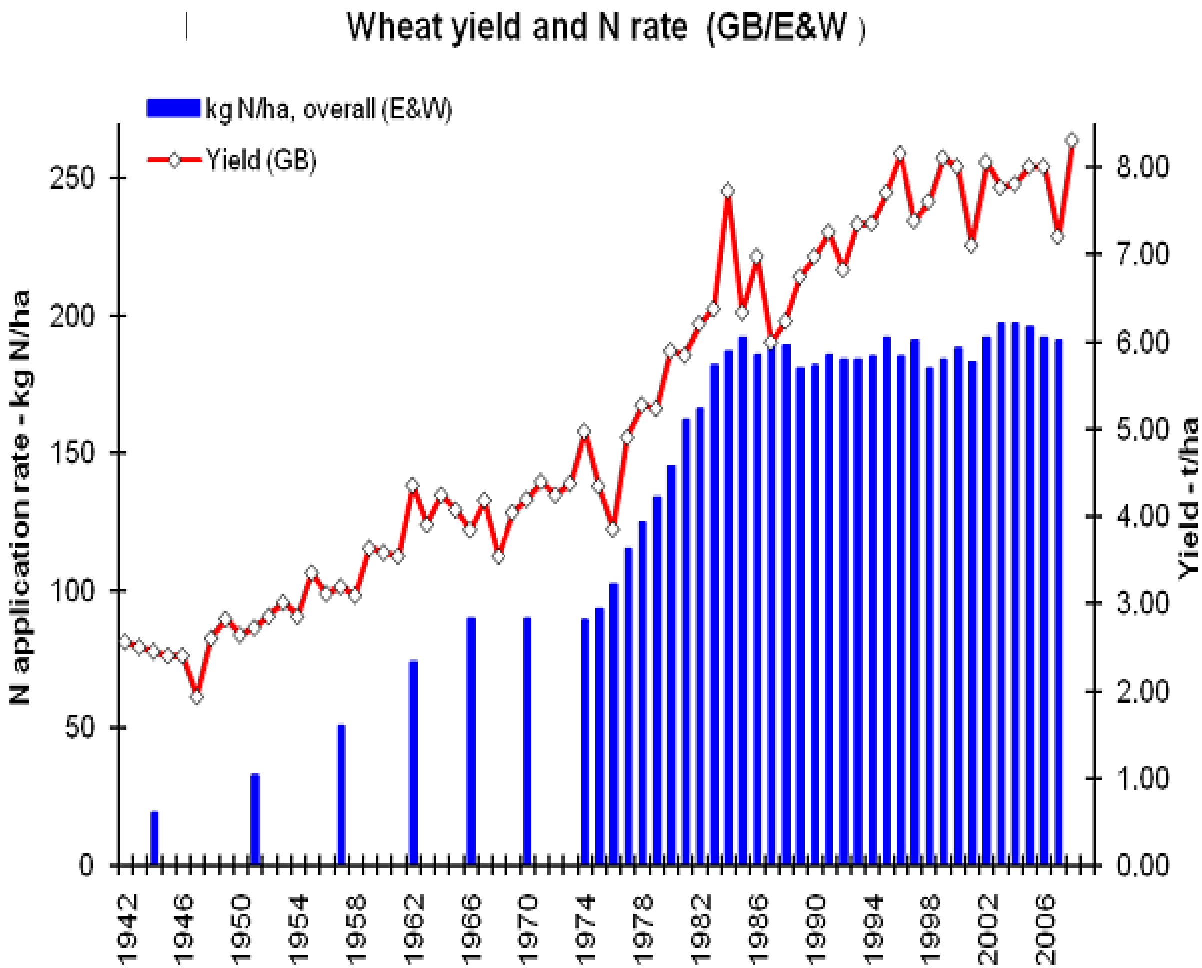
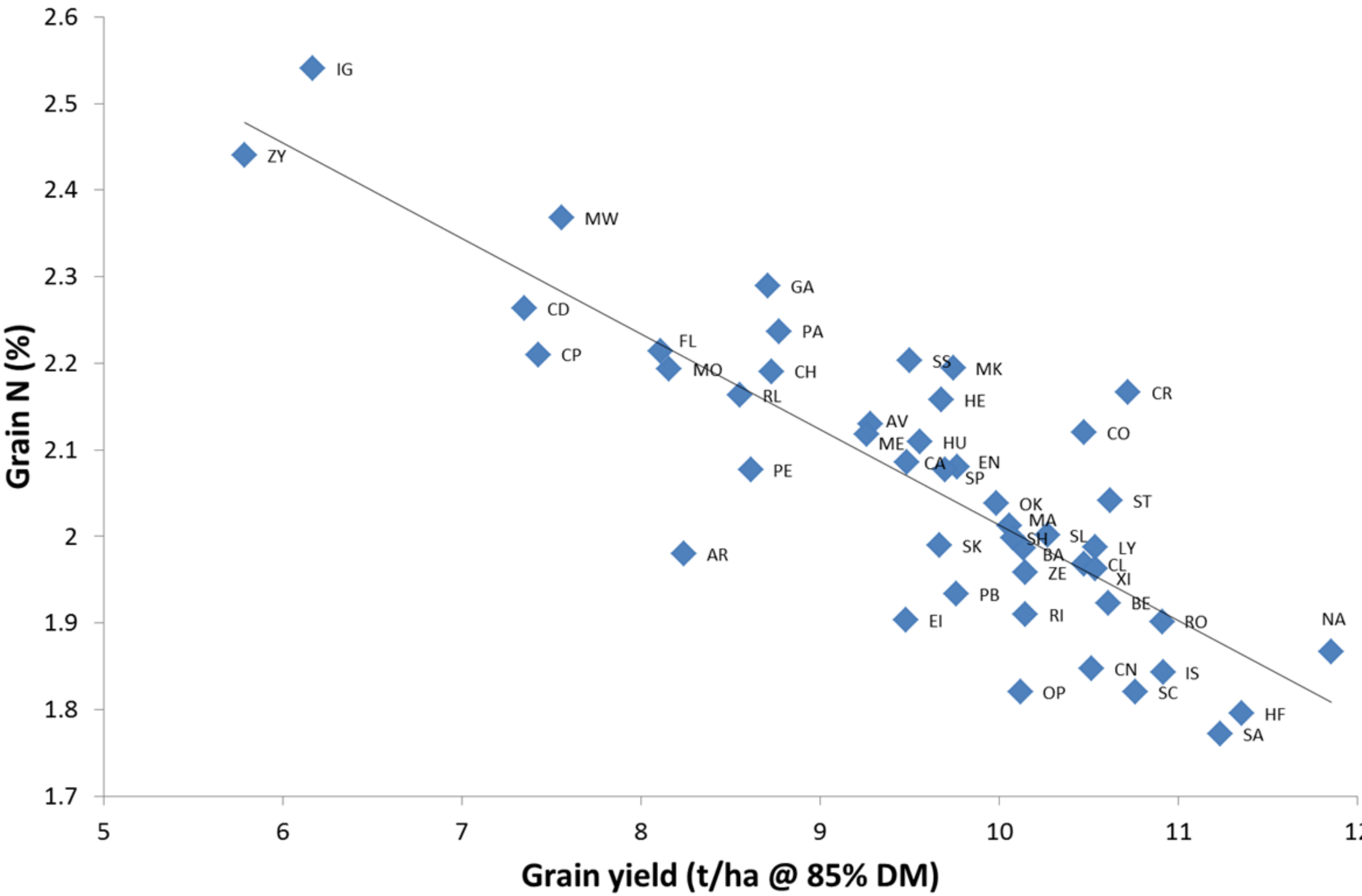
N fertiliser use trends in the UK



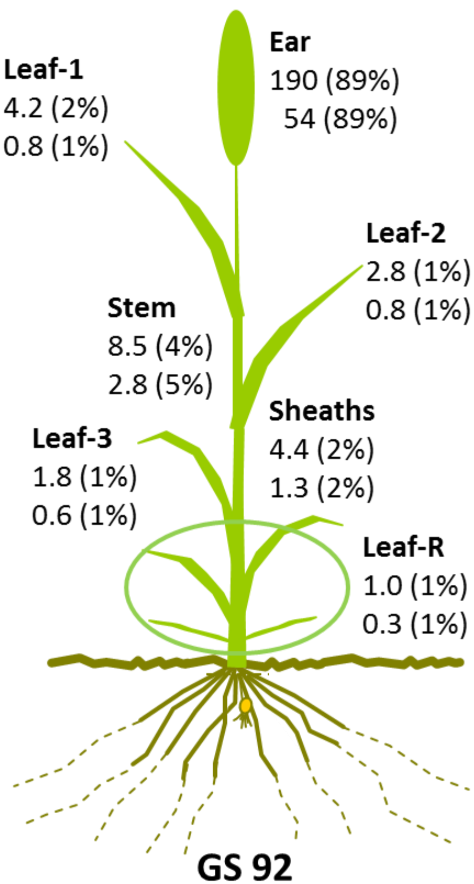
Hawkesford (2014) J Cereal Sci

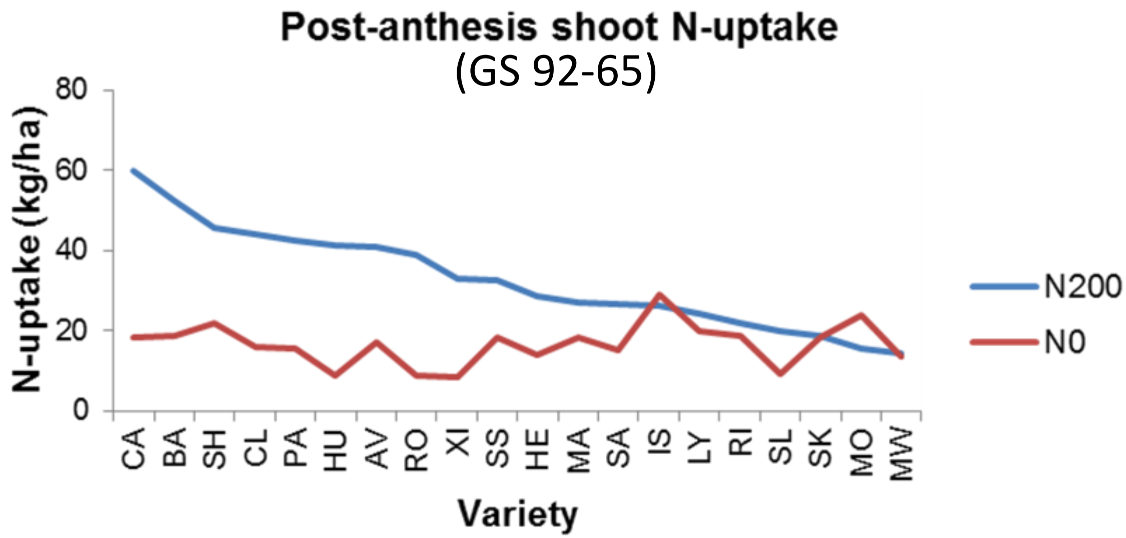
Grain protein deviation



Post anthesis N uptake

Shoot total
N200 - 213 kg/ha (100%)
N0 - 61 kg/ha (100%)



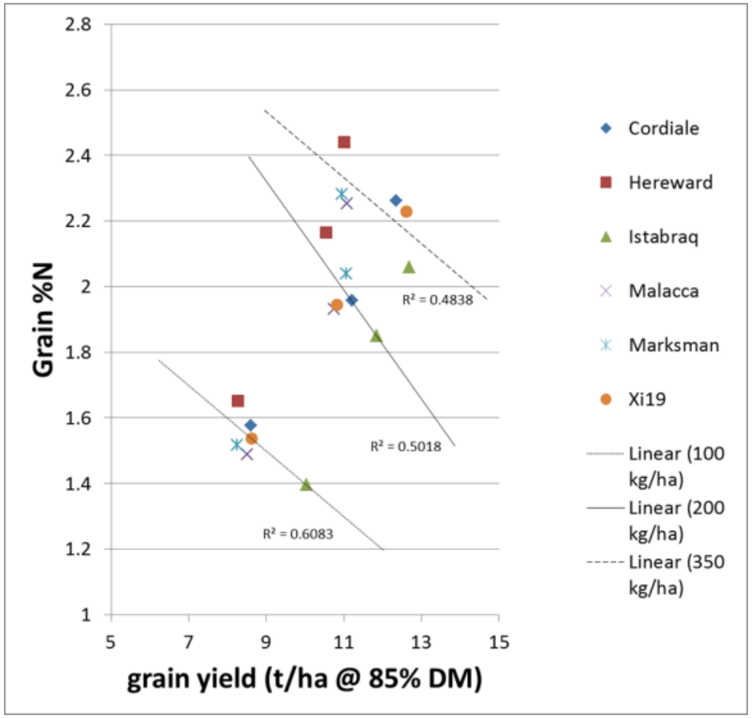


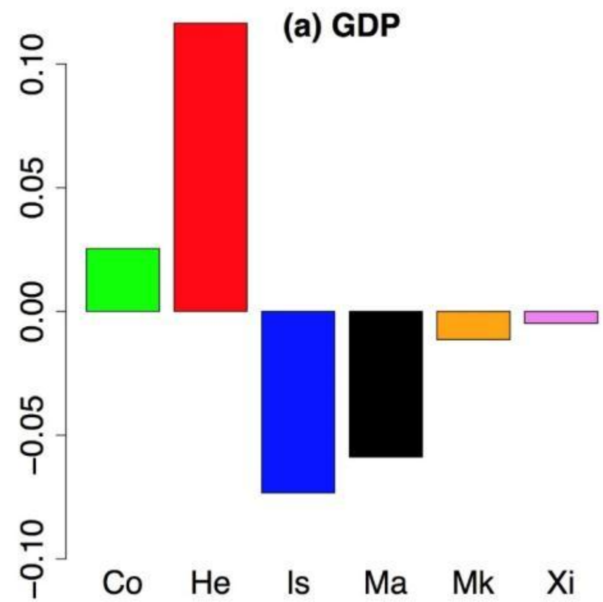
Field Crops Research xxx (2013) xxx–xxx
Contents lists available at ScienceDirect
Field Crops Research
journal homepage: www.elsevier.com/locate/fcr
ELSEVIER

Genotypic variation in the uptake, partitioning and remobilisation of nitrogen during grain-filling in wheat☆

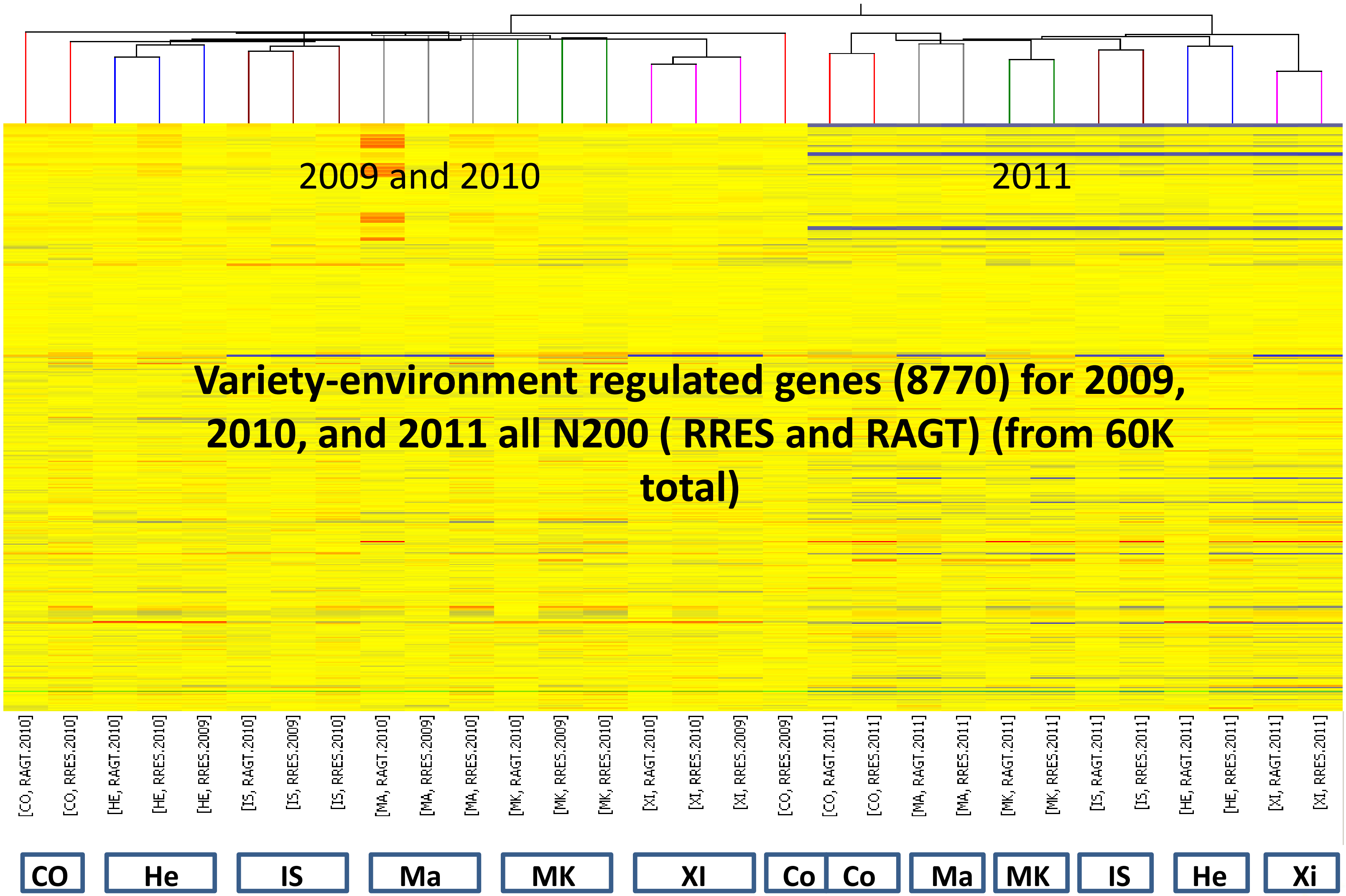
Peter B. Barraclough*, Rafael Lopez-Bellido[1], Malcolm J. Hawkesford
Plant Biology and Crop Science Department, Rothamsted Research, West Common, Harpenden, Hertfordshire AL5 2JQ, UK

Normalising datasets



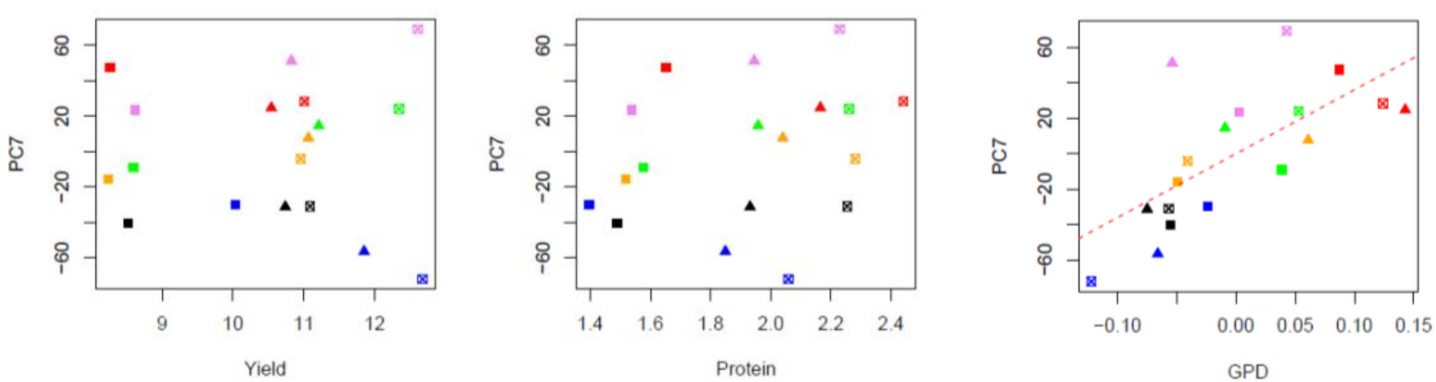


Transcriptomics

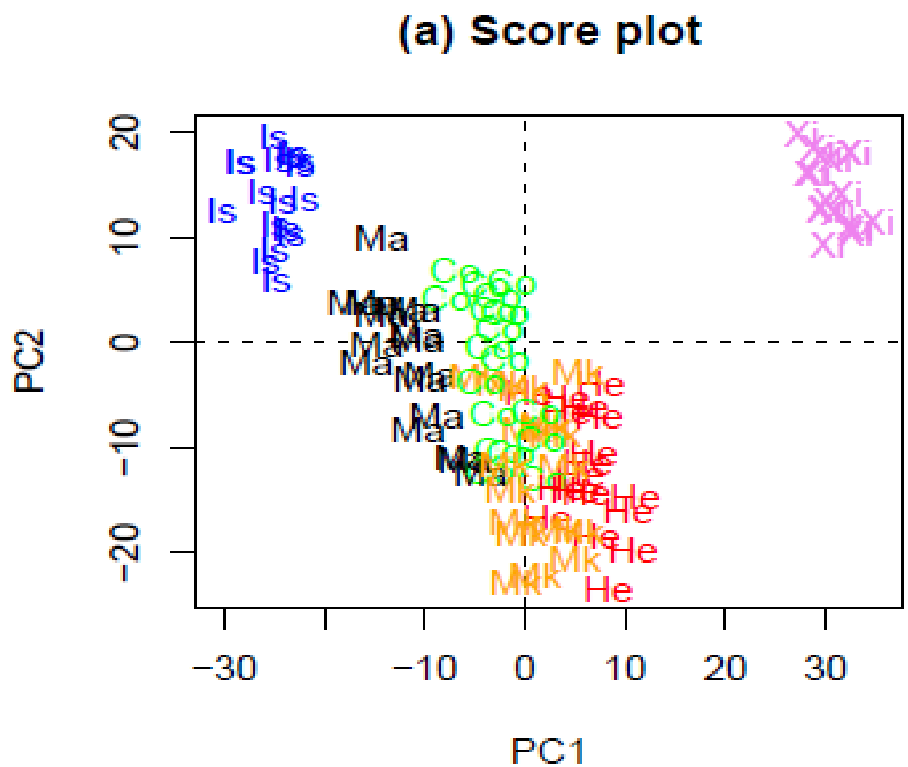


ANOVA – correlating the Affymetrix gene expression PC analysis to trait data for 2009

	Yield	Protein	Yield corr N	Protein corr N	Protein corr N & Y
Mean PC1	0.078	**0.031**	0.740	0.519	0.581
Mean PC2	**0.065**	0.991	**0.053**	**0.005**	**0.043**
Mean PC3	0.152	0.460	**0.008**	**0.006**	0.129
Mean PC4	0.736	0.682	0.139	0.911	0.421
Mean PC5	0.362	**0.037**	0.000	0.015	0.643
Mean PC6	0.357	0.195	0.823	0.572	0.415
Mean PC7	0.853	**0.063**	0.199	**0.000**	**0.000**
Mean PC8	0.071	0.034	0.431	0.636	0.285
Mean PC9	0.314	0.446	0.080	0.067	0.297
Mean PC10	**0.000**	**0.000**	0.447	0.088	**0.010**

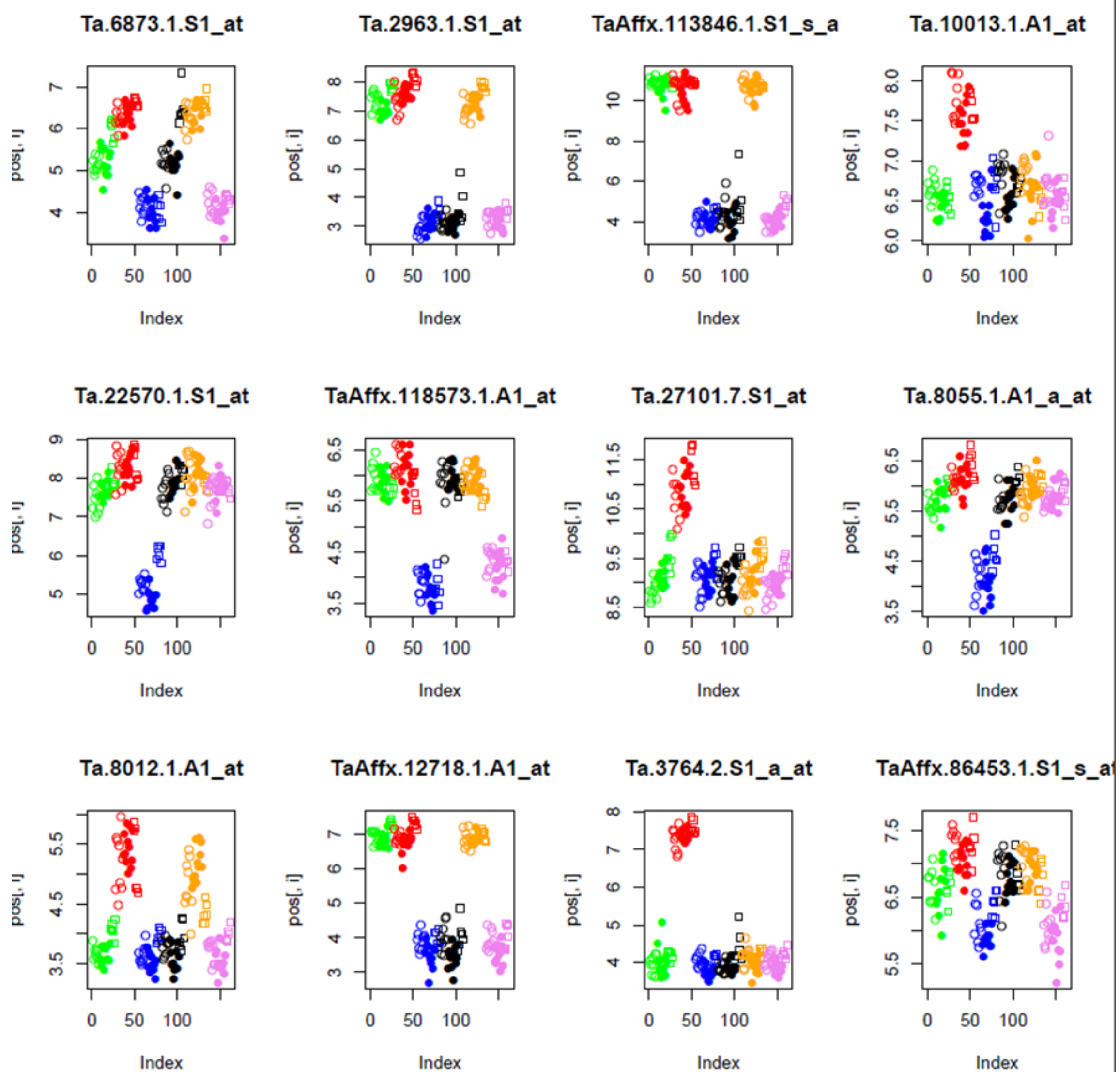


PCA of the selected GPD genes



Partial Least Squares regression to further refine these list **resulting in 537 key genes defining differences in GPD between the varieties**

Validation of genes positively related to GPD



No varieties are perfect!

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Variety Performance at 200 kg-N/ha (2004-08)

Variety	Code	Nabim	Years	Yield	%N	Uptake	Utilisation
Avalon	AV	1	5	orange	orange	pink	yellow
Flanders	FL	1	1	green	pink	yellow	green
Hereward	HE	1	5	yellow	orange	pink	yellow
Hurley	HU	1	5	yellow	orange	orange	yellow
Malacca	MA	1	5	orange	yellow	yellow	orange
Mercia	ME	1	4	yellow	orange	yellow	yellow
Maris Widgeon	MW	1	5	green	pink	green	green
Shamrock	SH	1	4	yellow	yellow	orange	orange
Solstice	SL	1	5	orange	yellow	yellow	pink
Spark	SP	1	1	orange	orange	orange	yellow
Xi 19	XI	1	5	pink	green	orange	pink
Cadenza	CA	2	5	yellow	orange	pink	orange
Cordiale	CO	2	3	pink	orange	pink	orange
Einstein	EI	2	1	yellow	green	green	orange
Lynx	LY	2	5	pink	yellow	pink	orange
Rialto	RL	2	1	yellow	pink	yellow	green
Scorpion	SC	2	1	pink	green	orange	pink
Soissons	SS	2	5	yellow	pink	orange	green
Beaver	BE	3	4	orange	yellow	yellow	orange
Claire	CL	3	4	pink	yellow	pink	pink
Riband	RI	3	5	orange	green	yellow	pink
Robigus	RO	3	4	pink	green	pink	pink
Istabraq	IS	4	4	pink	green	orange	pink
Napier	NA	4	3	pink	yellow	pink	orange
Savannah	SA	4	4	pink	green	orange	pink
Paragon (spring)	PA	1	5	yellow	pink	orange	yellow
Chablis (spring)	CH	2	1	green	green	green	pink
Arche	AR	F	1	green	yellow	green	yellow
Batis	BA	G	5	orange	yellow	pink	yellow
Caphorn	CP	F	1	green	pink	green	green
Cappelle Desprez	CD	F	1	green	pink	green	green
Enorm	EN	G	1	orange	orange	pink	yellow
Isengrain	IG	F	1	green	pink	green	green
Monopol	MO	G	5	green	pink	yellow	green
Opus	OP	G	1	pink	green	green	pink
PBis	PB	G	1	orange	yellow	yellow	orange
Petrus	PE	G	1	yellow	orange	yellow	yellow
Sokrates	SK	G	5	orange	orange	yellow	orange
Zyta	ZY	P	1	green	pink	green	green

Upper-Q (pink)
Inter-Q (orange)
Inter-Q (yellow)
Lower-Q (green)

Summary of variety performance (quartile rankings) based on 2004-07 WGIN datasets

EJA (2010) 33, 1-11

Europ. J. Agronomy 33 (2010) 1–11

Contents lists available at ScienceDirect

European Journal of Agronomy

journal homepage: www.elsevier.com/locate/eja

ELSEVIER

Nitrogen efficiency of wheat: Genotypic and environmental variation and prospects for improvement

Peter B. Barraclough[a,*], Jonathan R. Howarth[a], Janina Jones[a], Rafael Lopez-Bellido[b], Saroj Parmar[a], Caroline E. Shepherd[a], Malcolm J. Hawkesford[a]

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Donor germplasm

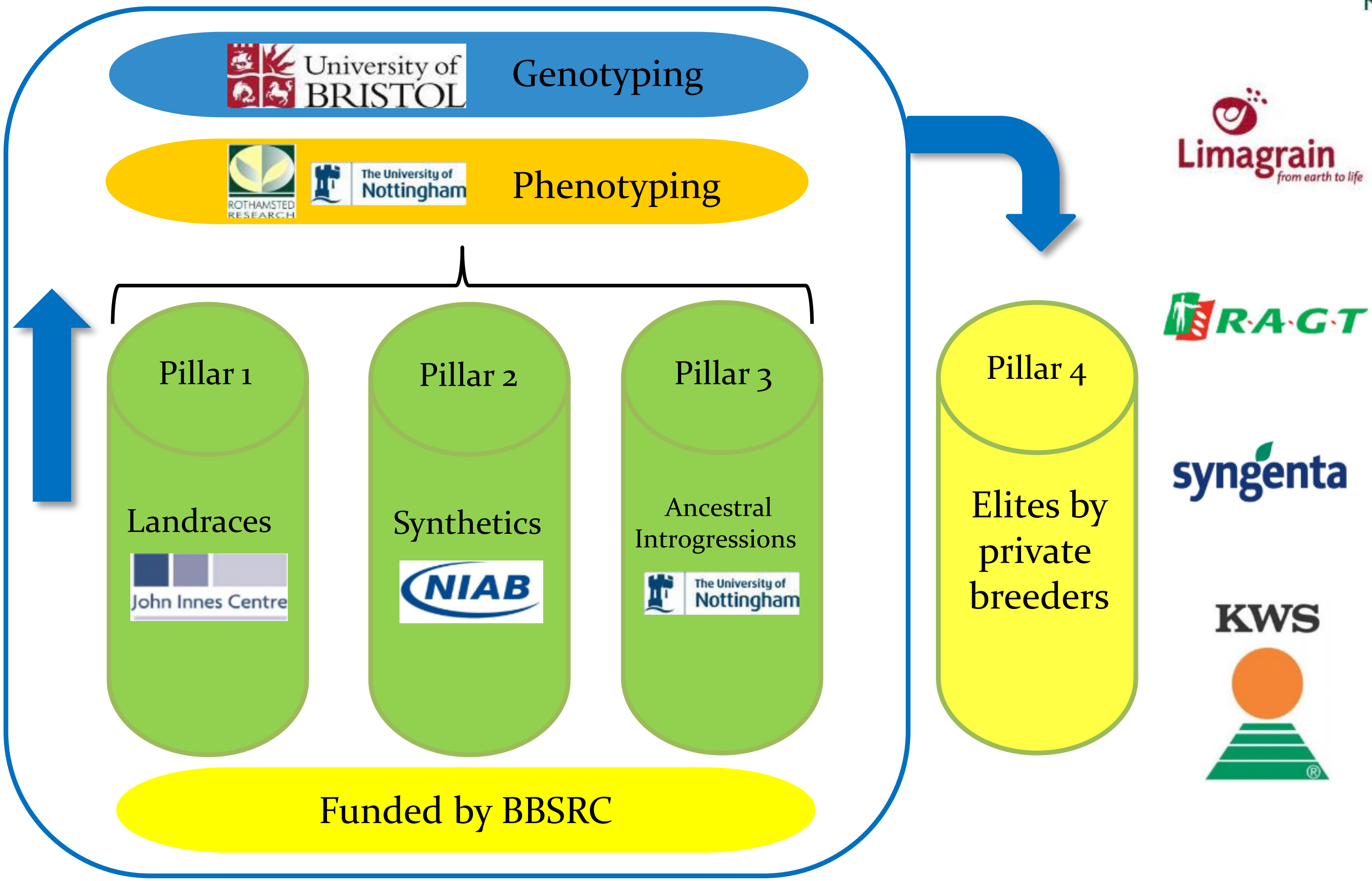
Mapping populations

NILS

New synthetics

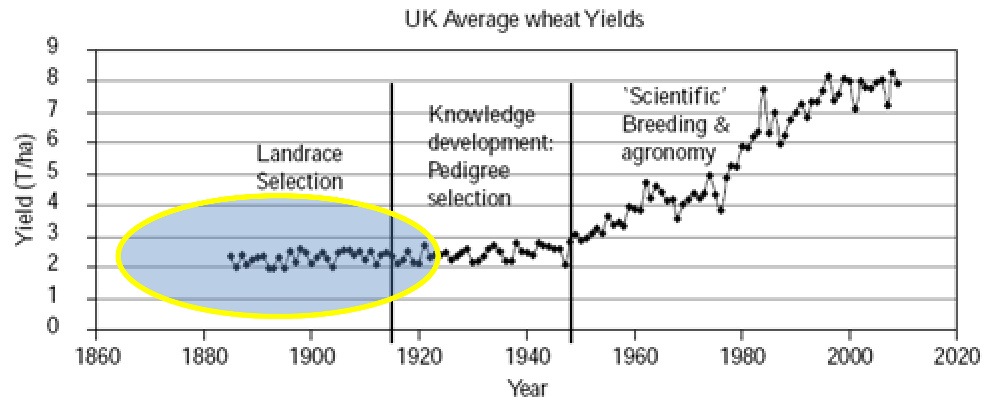
Introgressions

WISP (Wheat Improvement Strategic Program)



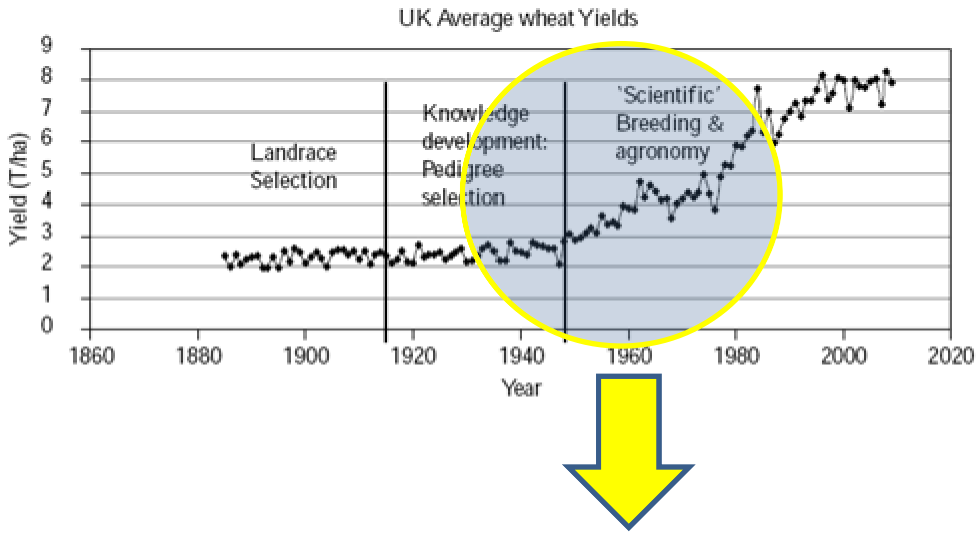
Watkins diversity

- A E Watkins, University of Cambridge
- 1920's and 30's
- Board of Trade
- Farmers, markets and researchers
- Several thousand but now 13
- 34 countries
- Held at JIC, duplicated in Australia
- Core genetic collection, c 120, plus other germplasm (Gediflux, synthetics) trialled at Rothamsted and Nottingham



(graphics and map courtesy of S Griffiths & S. Orford, JIC)

Gediflux is designed to capture Western European winter wheat diversity since 1940



Country	Varieties	Years of release	examples
Austria	40	40-90	Tassilo (50s) Hubertos (90s)
Belgium	24	50-90	Norda (60s) Escorial (80s)
Germany	18	80-90	Calif (80s) Pegassos (90s)
E Germany	30	40-80	Mahndorf (50s) Kanzler (80s)
W Germany	19	50-90	Muck (50s) Borenos (90s)
Denmark	5	80-90	Anja (80s) Pepital (90s)
France	34	40-90	Vague d'epis (40s) Isengrain (90s)
UK	66	40-90	Holdfast (40s) Equinox (90s)
Netherlands	19	40-80	Lovink (40s) Nautica (80s)
Sweden	26	25-90	Jarl (20s) Meridien (90s)
UK NL	229		

- Step changes
  - PBI
  - Rht1
  - 1BL.1RS
  - HMW glutenins
  - Claire, Robigus .....
- During each 'step change'
- What was being left behind?
- We can find out by looking into the 510 Gediflux varieties

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(slide from S. Griffiths, JIC)

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Grain yields – response to N inputs

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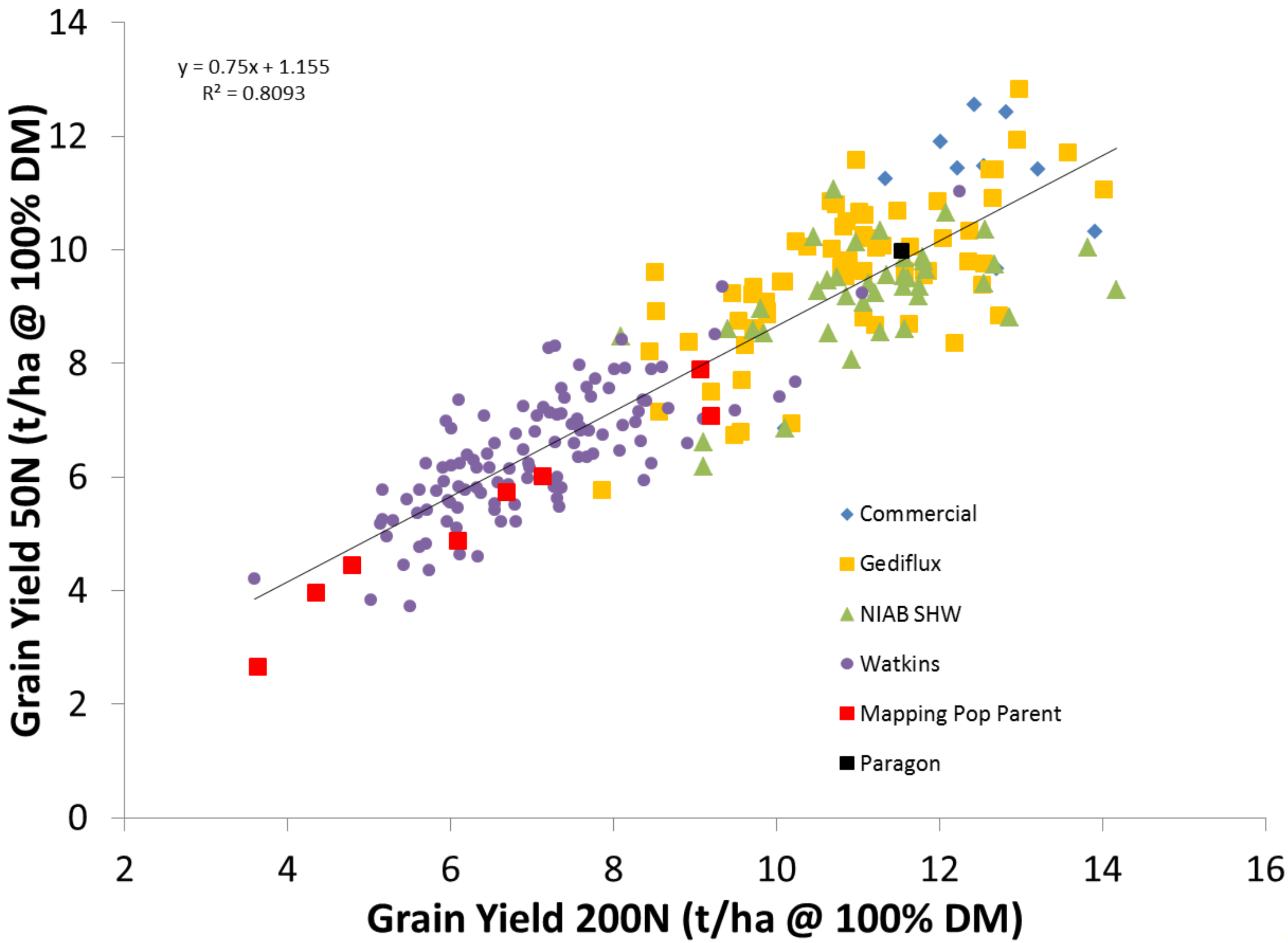

Rothamsted 2012

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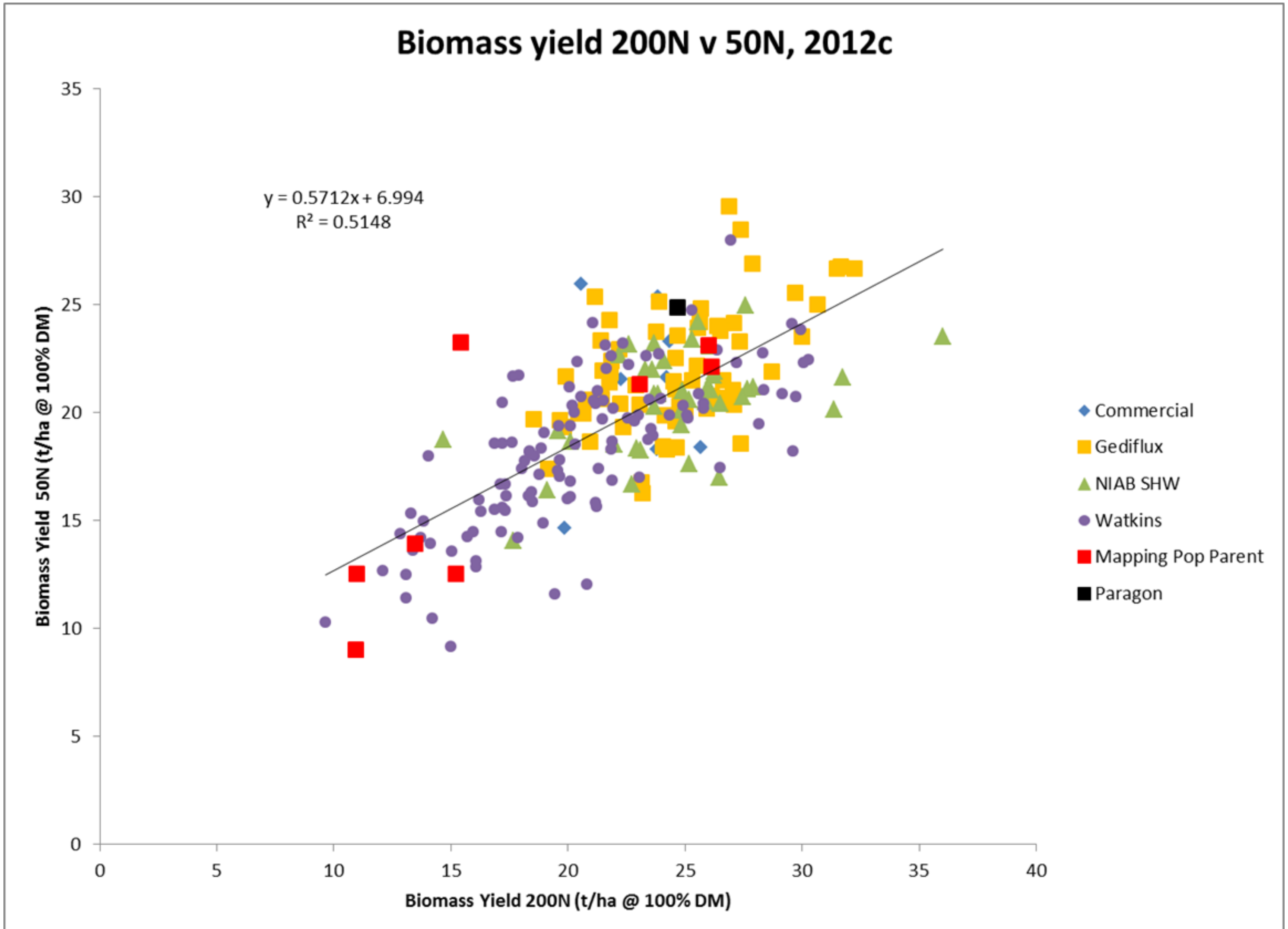
N-response: 2012 biomass



N-uptakes, 3 year mean at RRes

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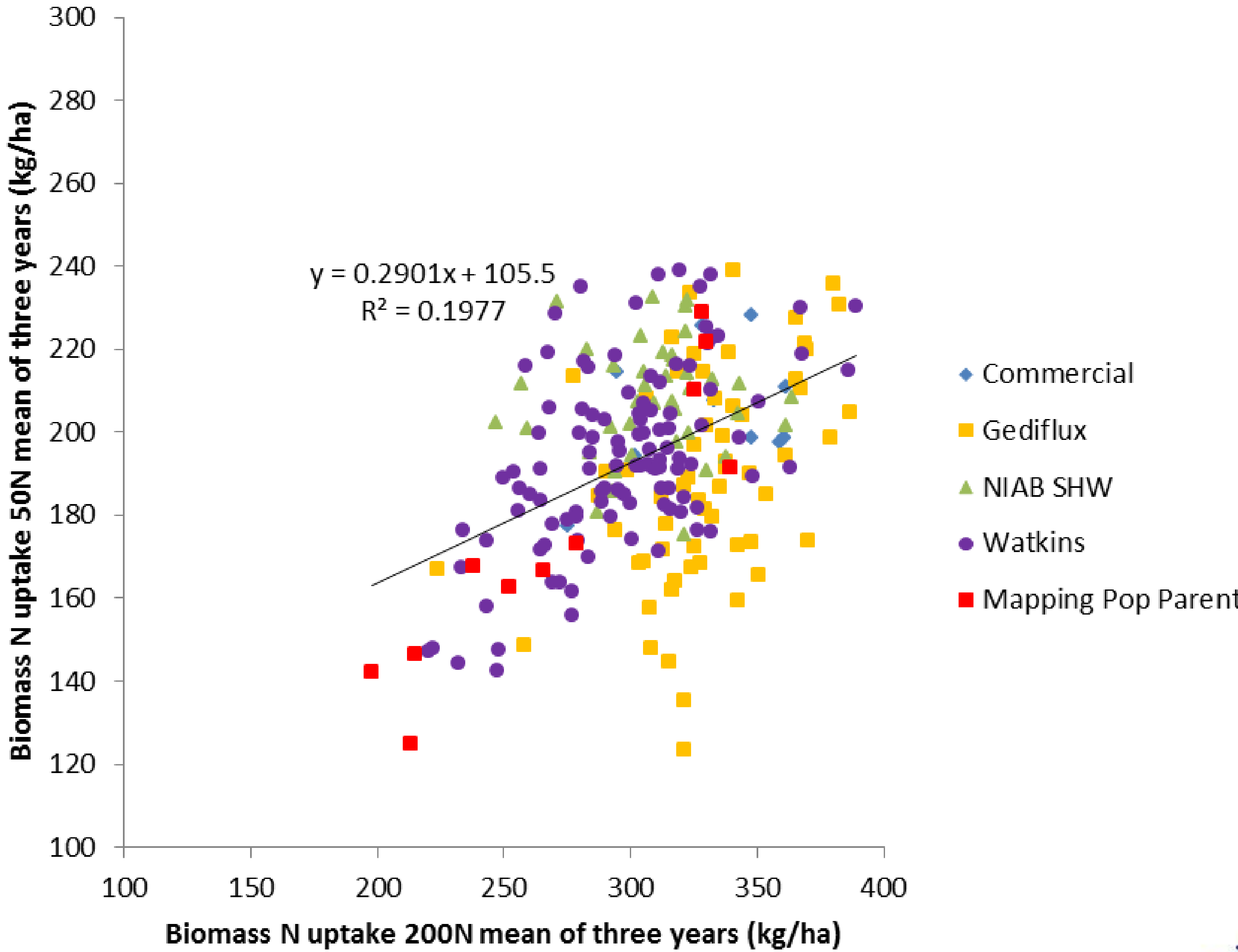

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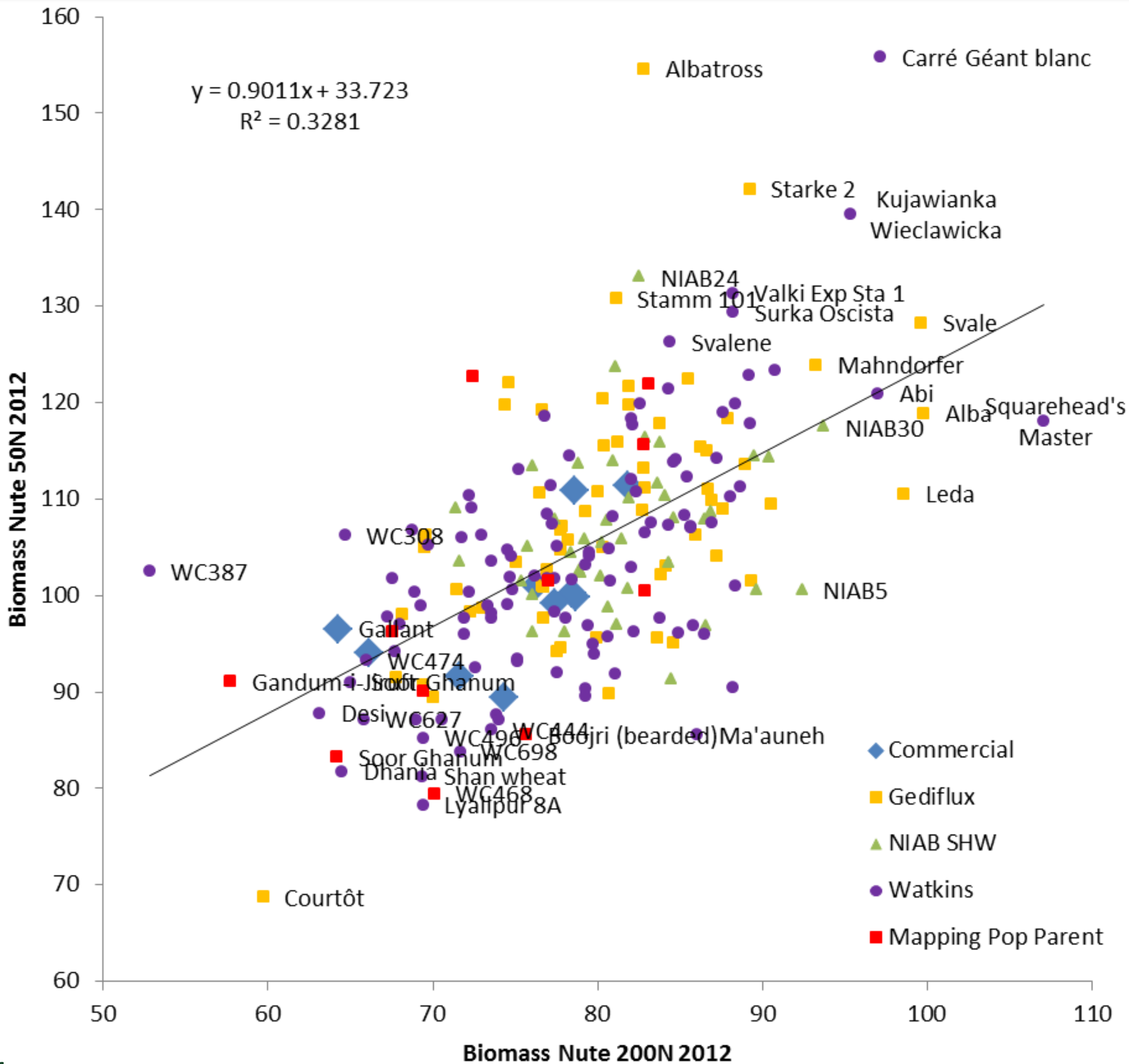
Biomass NUtE, 2012



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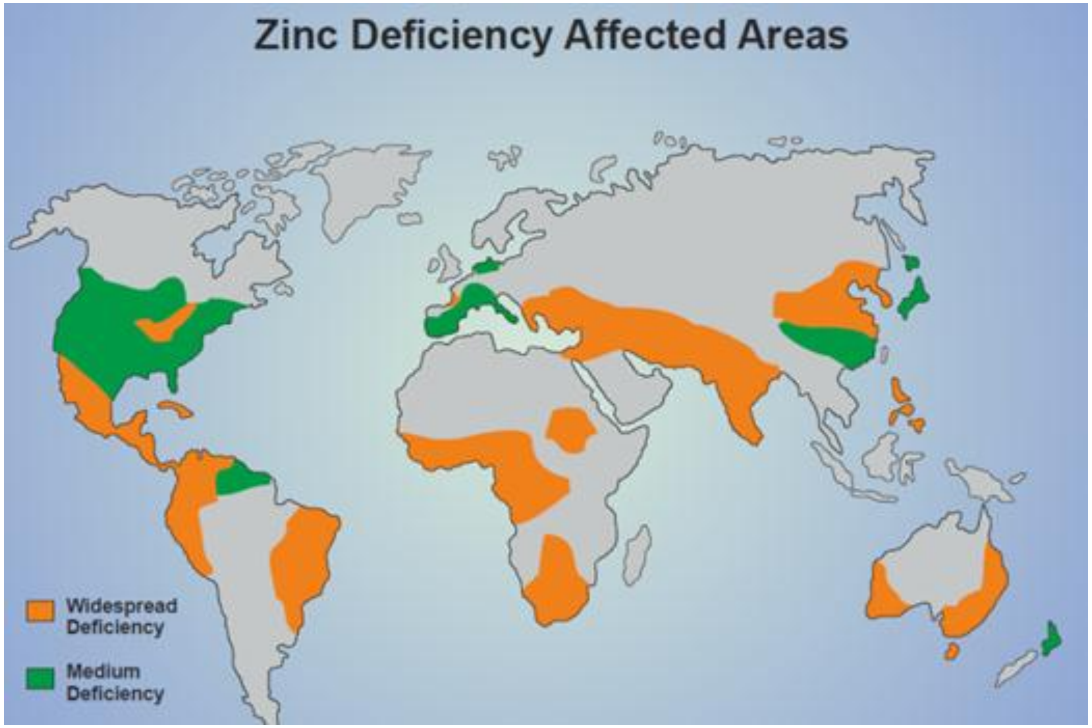
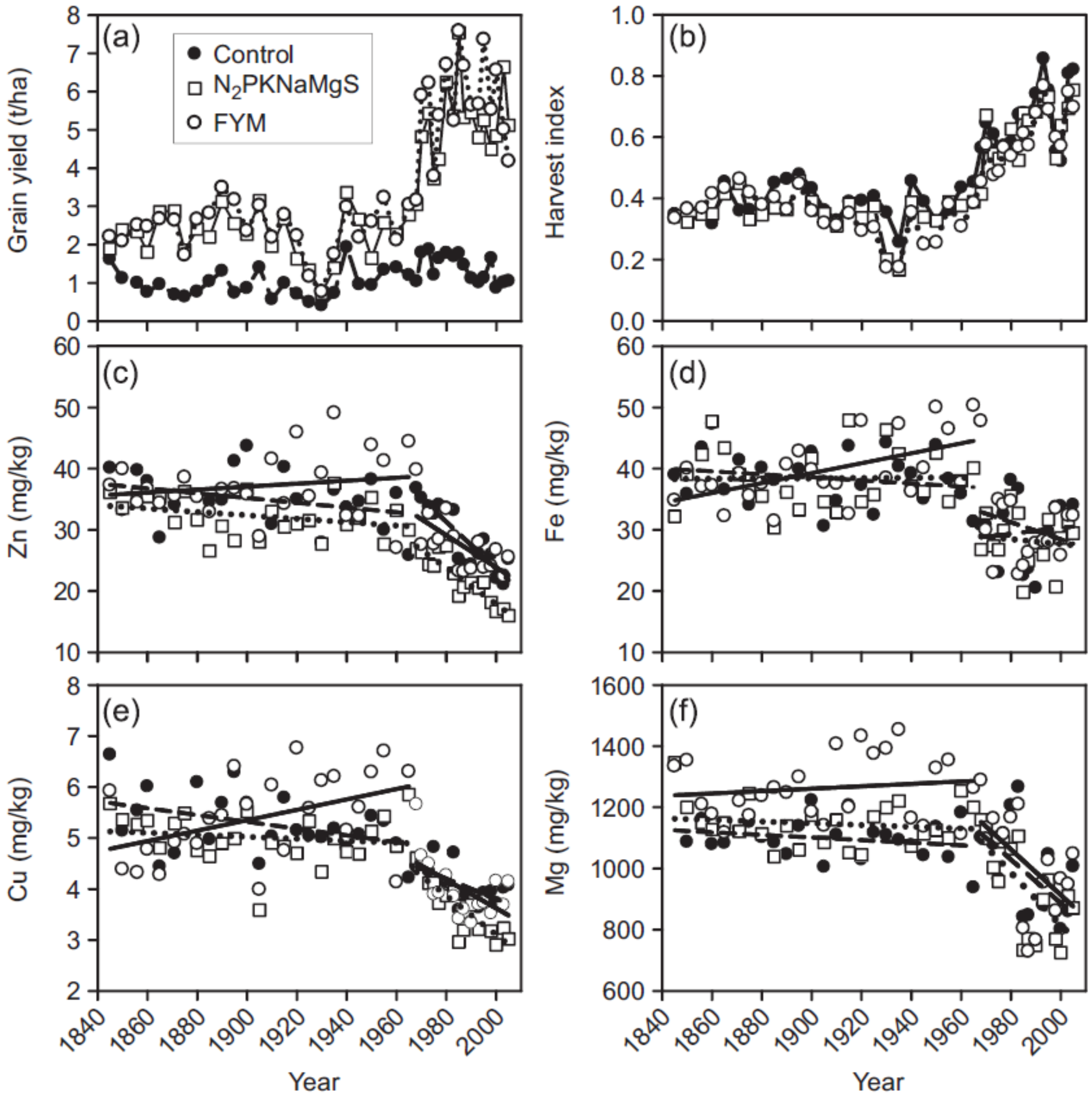
Micronutrients: zinc

- Cereals are low in bioavailable essential micronutrients such as zinc
- Zinc deficiency affects 30% of the world's population
- Reduced zinc grain content also reduces yield
- What plant breeding strategies are there to overcome this?



Decreasing mineral content of wheat



Fan et al (2008) J trace Elements in Medicine &Biology; 22, 315-24.

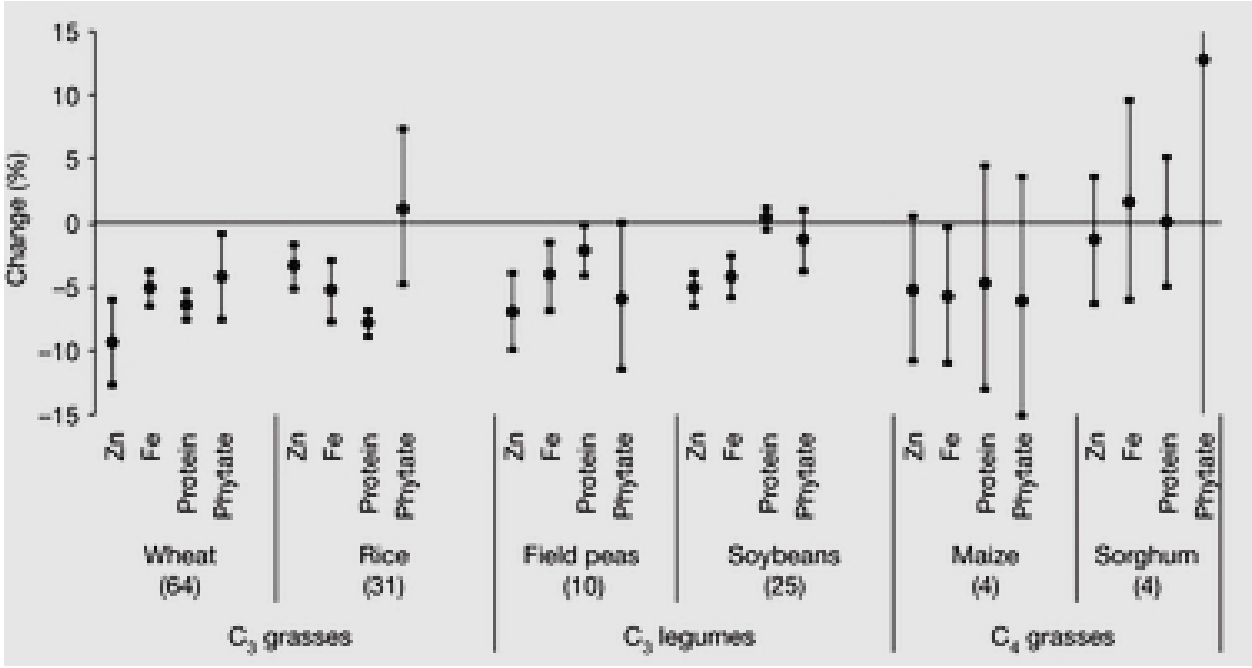
Elevated CO_2 impacts on micronutrients

LETTER

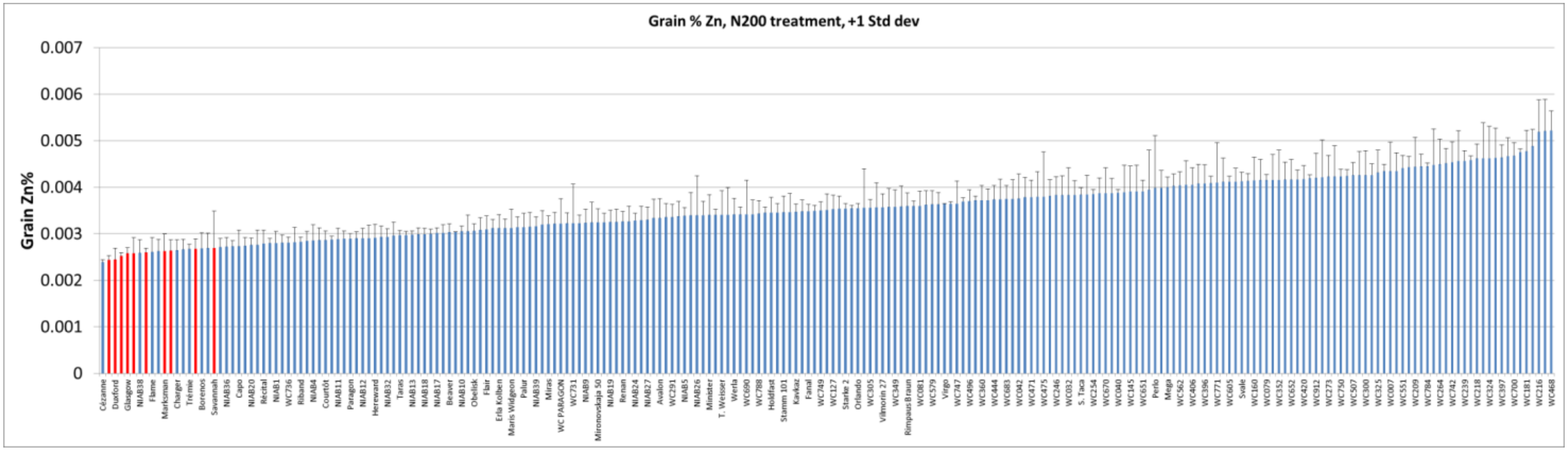
doi:10.1038/nature13179

Increasing CO_2 threatens human nutrition

Samuel S. Myers[1,2], Antonella Zanobetti[1], Itai Kloog[3], Peter Huybers[4], Andrew D. B. Leakey[5], Arnold J. Bloom[6], Eli Carlisle[6], Lee H. Dietterich[7], Glenn Fitzgerald[8], Toshihiro Hasegawa[9], N. Michele Holbrook[10], Randall L. Nelson[11], Michael J. Ottman[12], Victor Raboy[13], Hidemitsu Sakai[9], Karla A. Sartor[14], Joel Schwartz[1], Saman Seneweera[15], Michael Tausz[16] & Yasuhiro Usui[9]



Grain Zn concentrations in WISP germplasm



24-52 mg/kg

Red = modern cultivars
2012 Rothamsted
High N

Total Zn uptake in biomass

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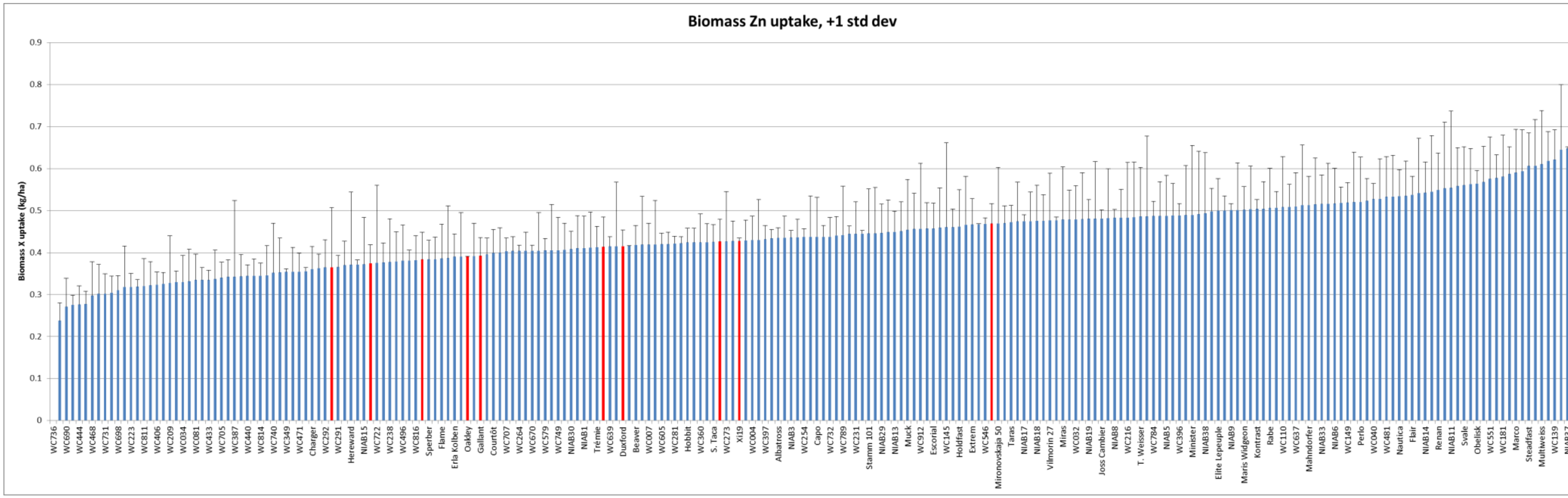

Range = 0.24-0.55 kg/ha
Red = modern cultivars
2012 Rothamsted

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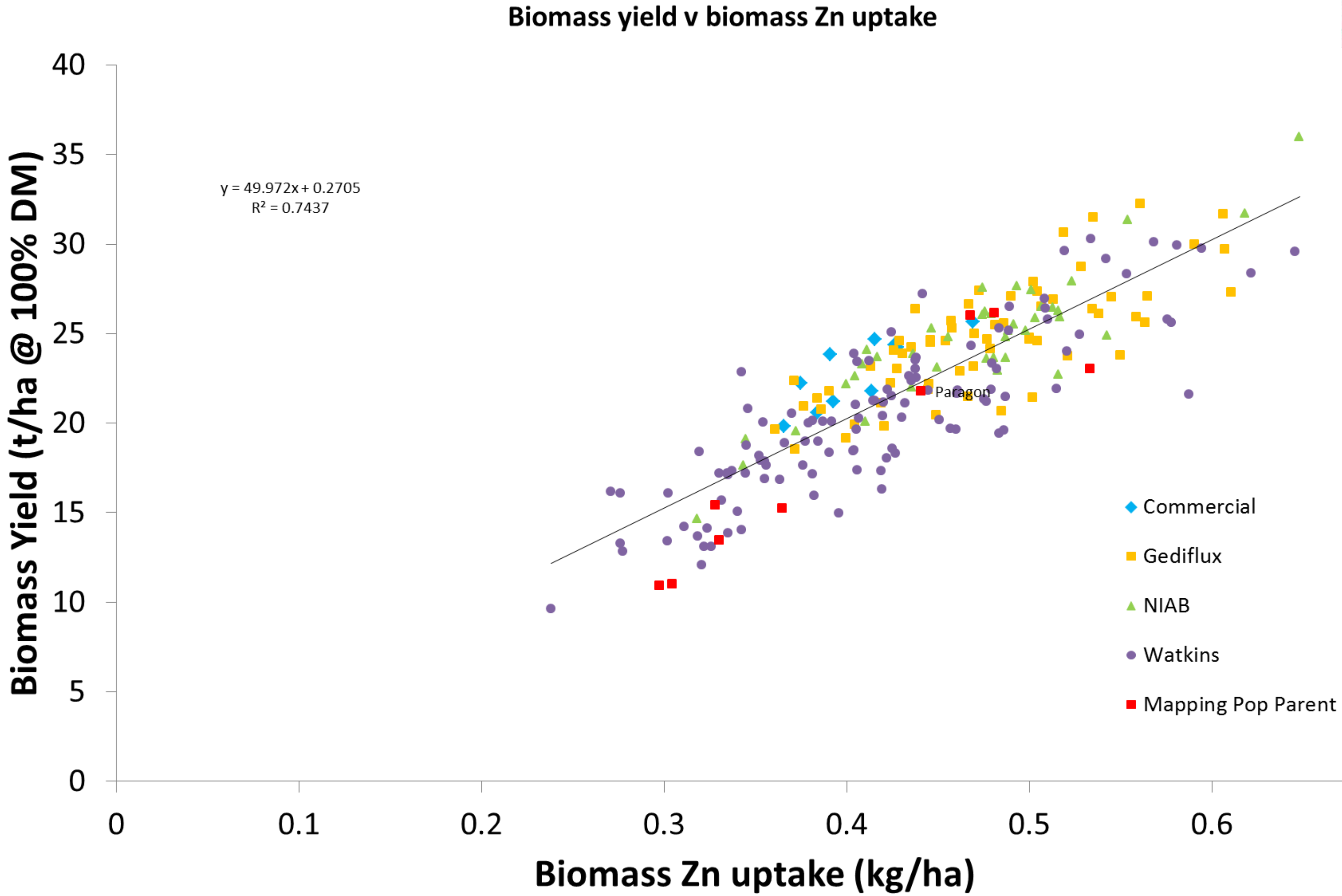
Zn uptakes increases with biomass yield



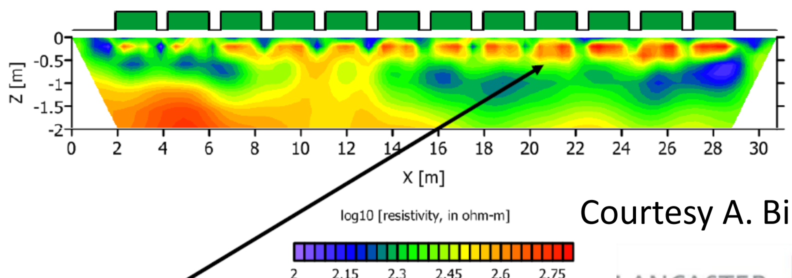
What about roots?

Mapping populations

Penetrometer

Non-irrigated
Absolute inversion 13-May-11

ERT Electrical resistance tomography



Courtesy A. Binley

LANCASTER UNIVERSITY

Appears to show significantly reduced water content down to 0.5m, especially in the plots towards the end of the line.

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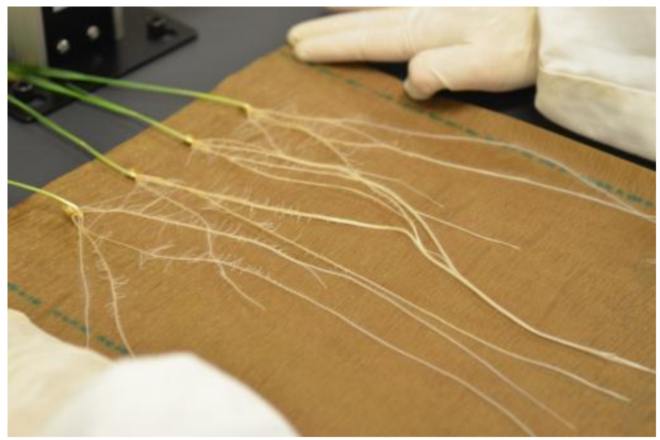
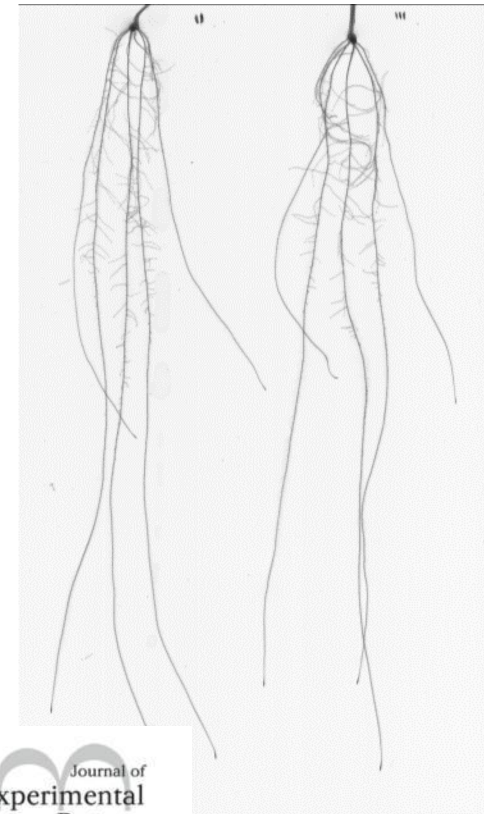
A QTL approach to dissect traits





Journal of Experimental Botany, Vol. 64, No. 6, pp. 1745–1753, 2013
doi:10.1093/jxb/ert041 Advance Access publication 5 February, 2013
This paper is available online free of all access charges (see http://jxb.oxfordjournals.org/open_access.html for further details)

Journal of Experimental Botany
www.jxb.oxfordjournals.org

RESEARCH PAPER

Identification of QTLs associated with seedling root traits and their correlation with plant height in wheat

Caihong Bai[1,2], Yinli Liang[1] and Malcolm J. Hawkesford[2,*]

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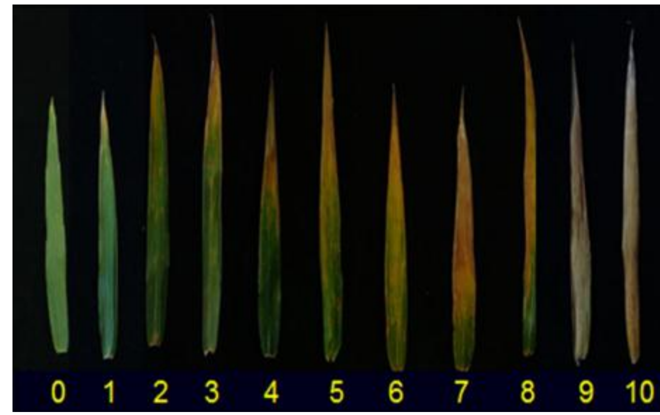
Major root QTL and associated PH and TGW QTL

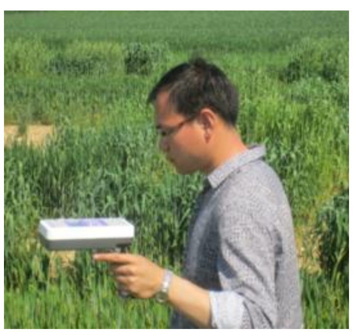
The phenotyping challenge

Black Horse 2013

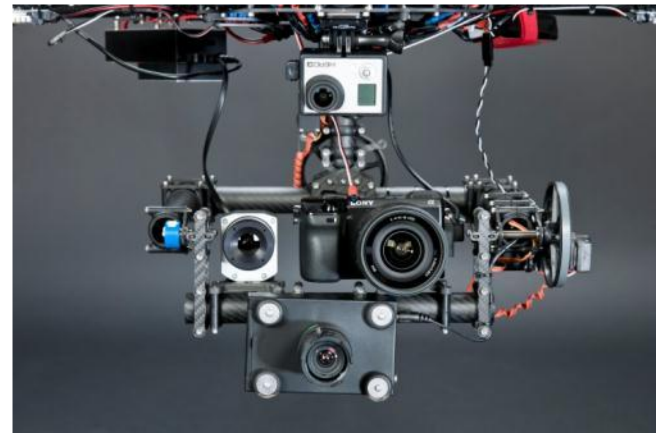
Scale

- Visual
- Hand held – contact
- Hand held non contact
- UAV
- Phenomobiles
- Ground-based fixed site
- Post harvest high throughput analysis





Phenotyping from the air - UAV NDVI



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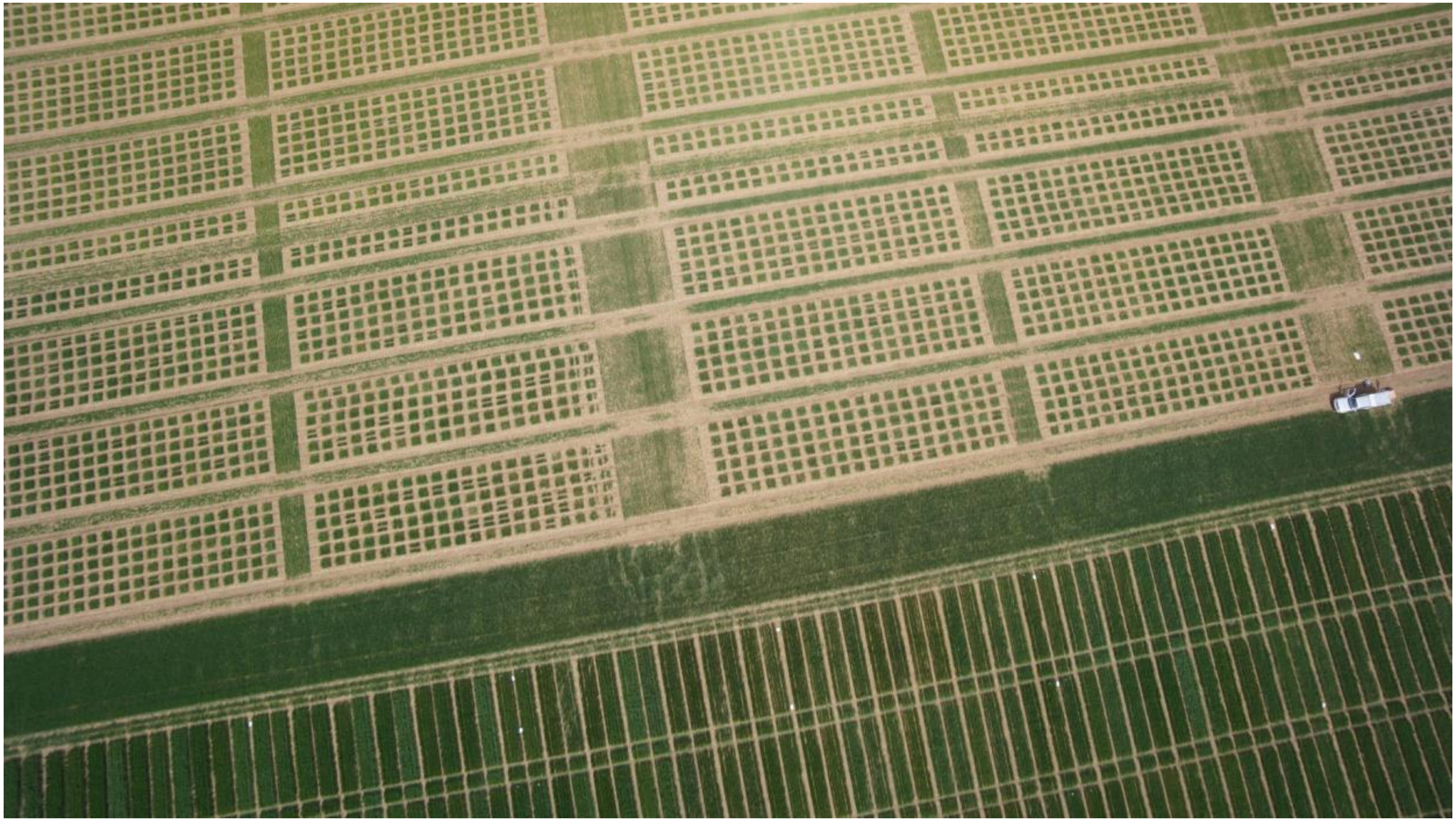
Mapping populations, Meadow 2014

Trials, Meadow 2014

Low
N

High
N

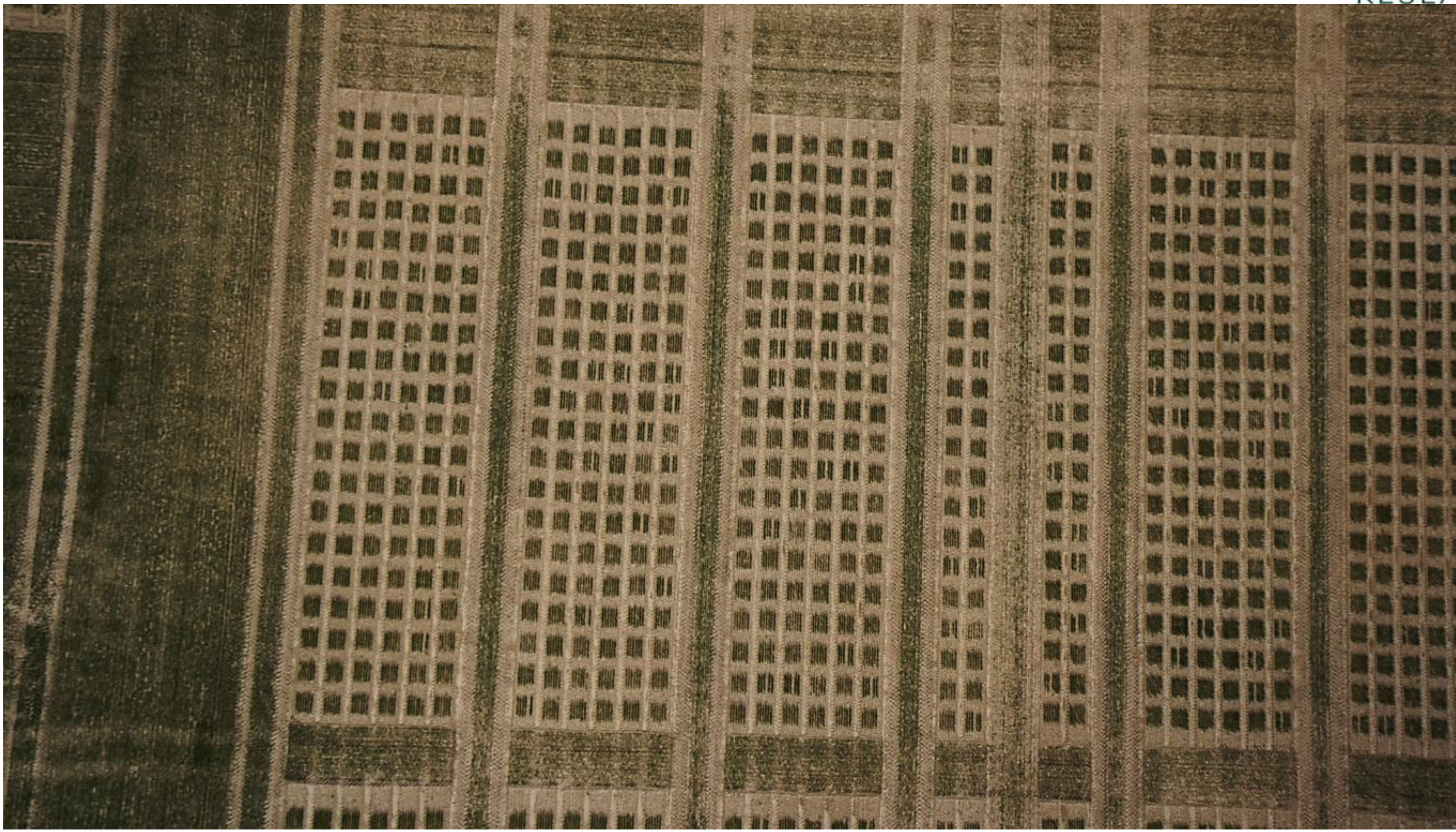


Mapping

A x C

24th April 2014

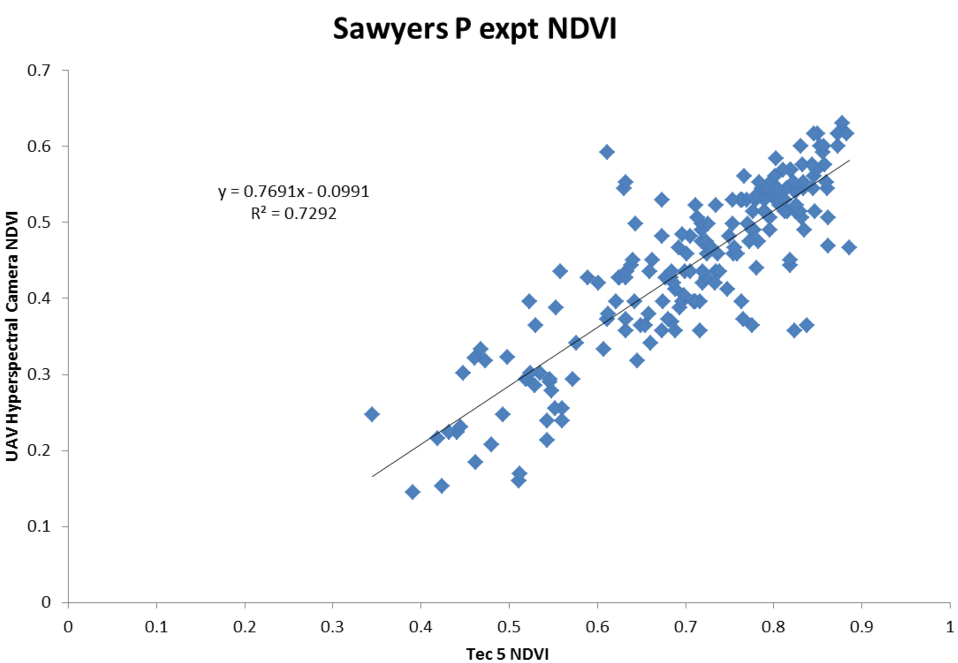
Mapping population, Meadow 2014

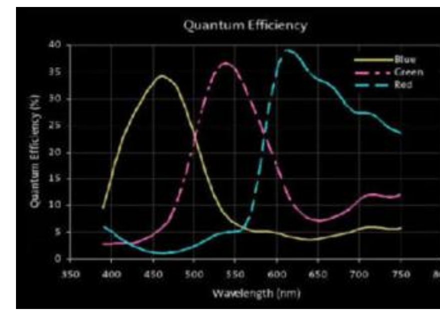


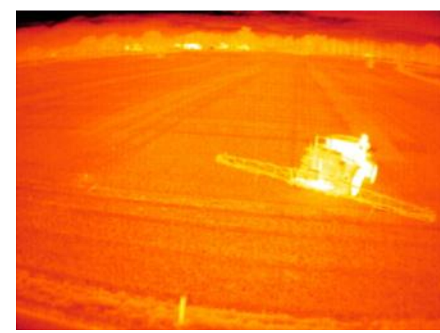
UAV capabilities

ROTHAMSTED RESEARCH

- Programed flight
- RGB
- Multi-spectral
- Thermal

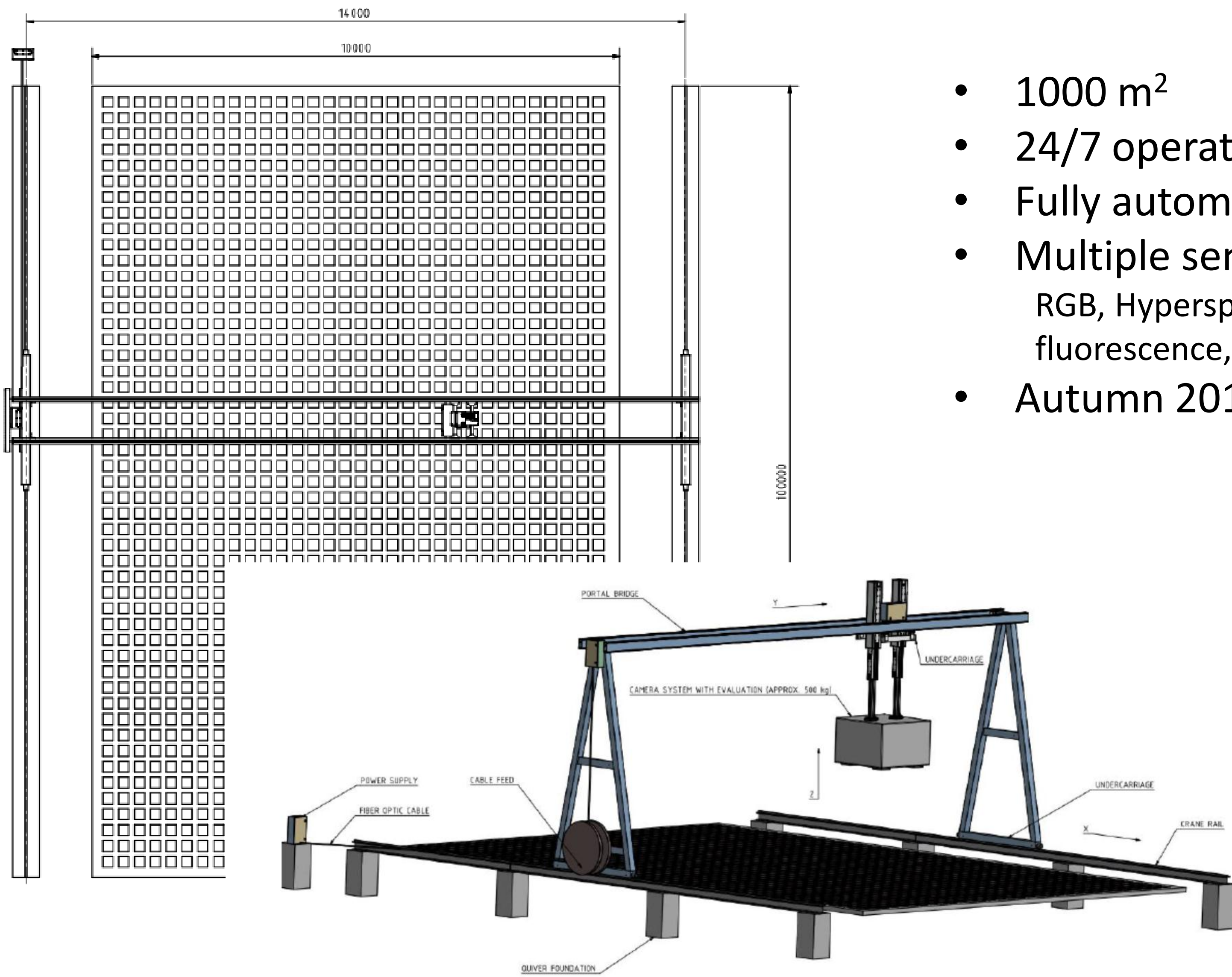






BBSRC
20 Years of Pioneering
Great British Bioscience

New Rothamsted automated ground-based phenotyping centre



- 1000 m^2
- 24/7 operation
- Fully automated
- Multiple sensors
  RGB, Hyperspectral, IR, fluorescence, NDVI, PRI
- Autumn 2014

ROTHAMSTED RESEARCH

BBSRC 20 Years of Pioneering Great British Bioscience

Summary

- Substantial NUE diversity amongst modern germplasm
- BUT potential for much more by mining land races, diploid progenitors and wild relatives
- Essential to be precise about dissecting NUE traits

Rowland Biffen (1874–1949)

Thanks

- RRes Farm staff
- WISP, WGIN and 20:20 teams
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- Summer students and visitors