DEFRA Project AR0714: A study of the scope for the application of crop genomics and breeding to increase N economy in cereal and rapeseed based food chains. (2003-5)

- **Objective: Guidance to research policy (DEFRA/CGINs)**

The University of Nottingham

defra
Department for Environment Food and Rural Affairs

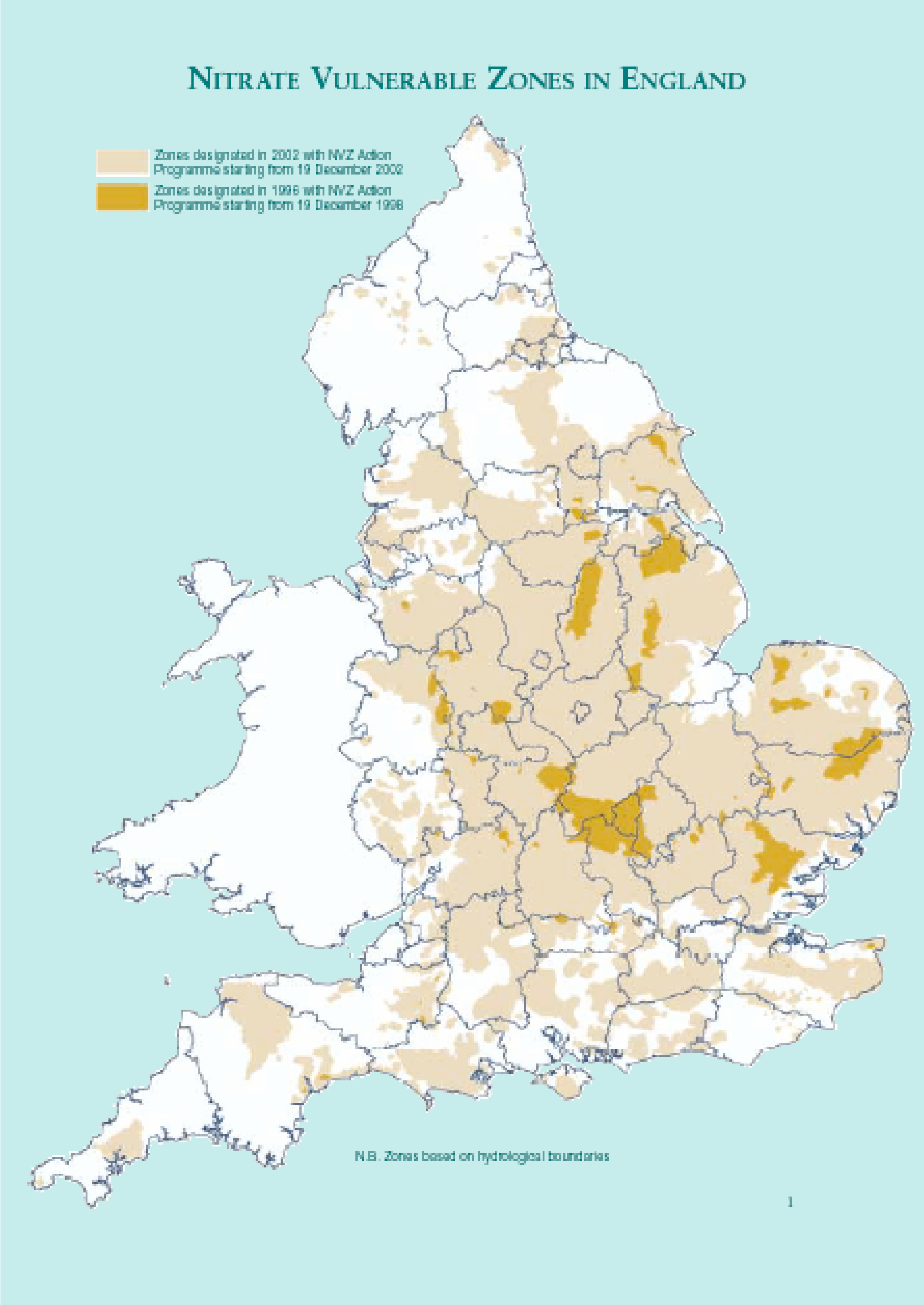
ROTHAMSTED RESEARCH

NIAB

Drivers for optimizing NUE

- N fertilizers →
  - ❖ cost for the grower
  - ❖ nitrate leaching (bread-making wheats high risk)
  - ❖ emissions of N_20/NH_3 → eutrophication/ acid rain/ climate change
  - ❖production by industrial fixation uses fossil fuels

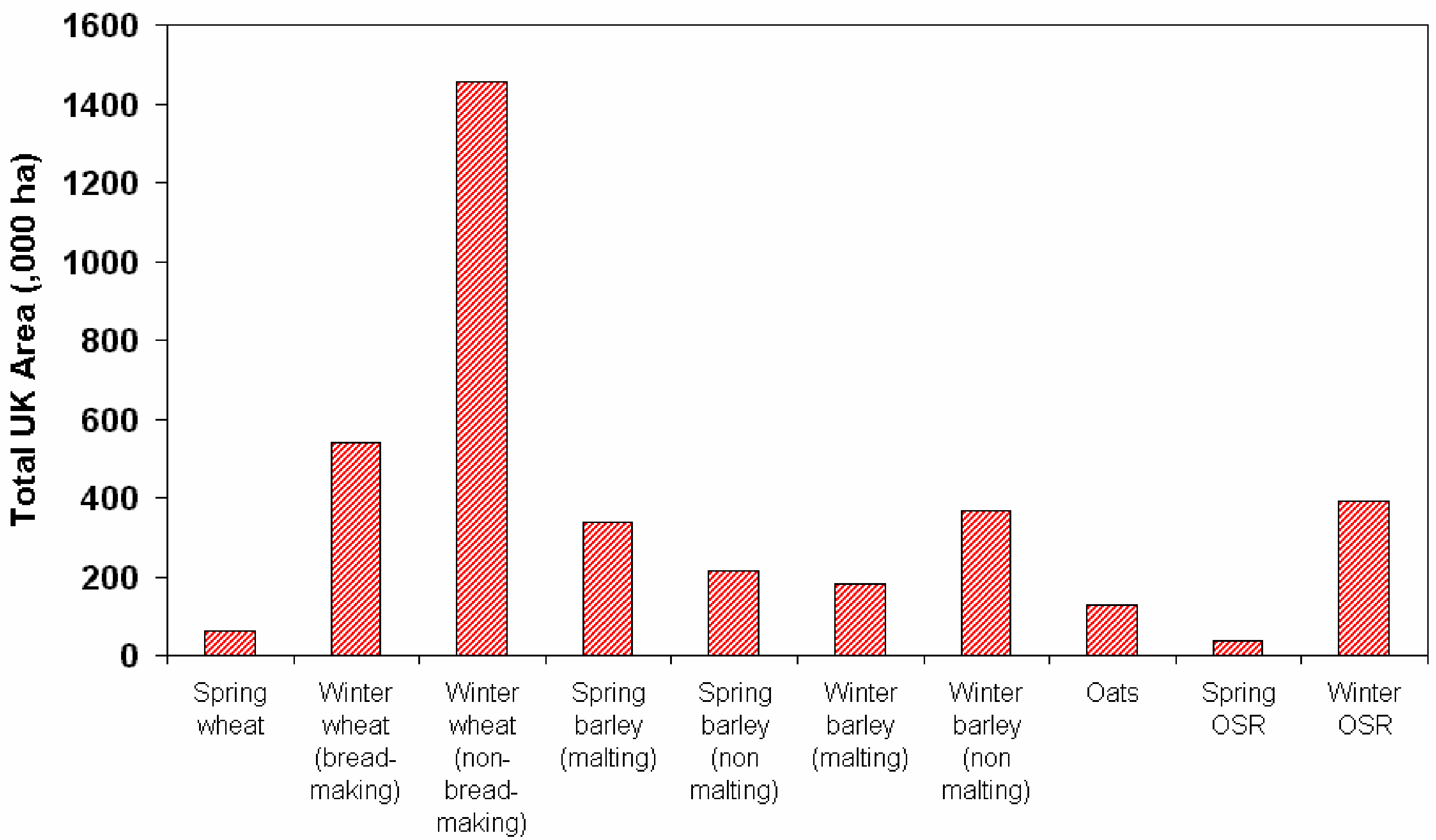
- **Minimising environmental impacts requires resource-efficient crops.**



Talk outline

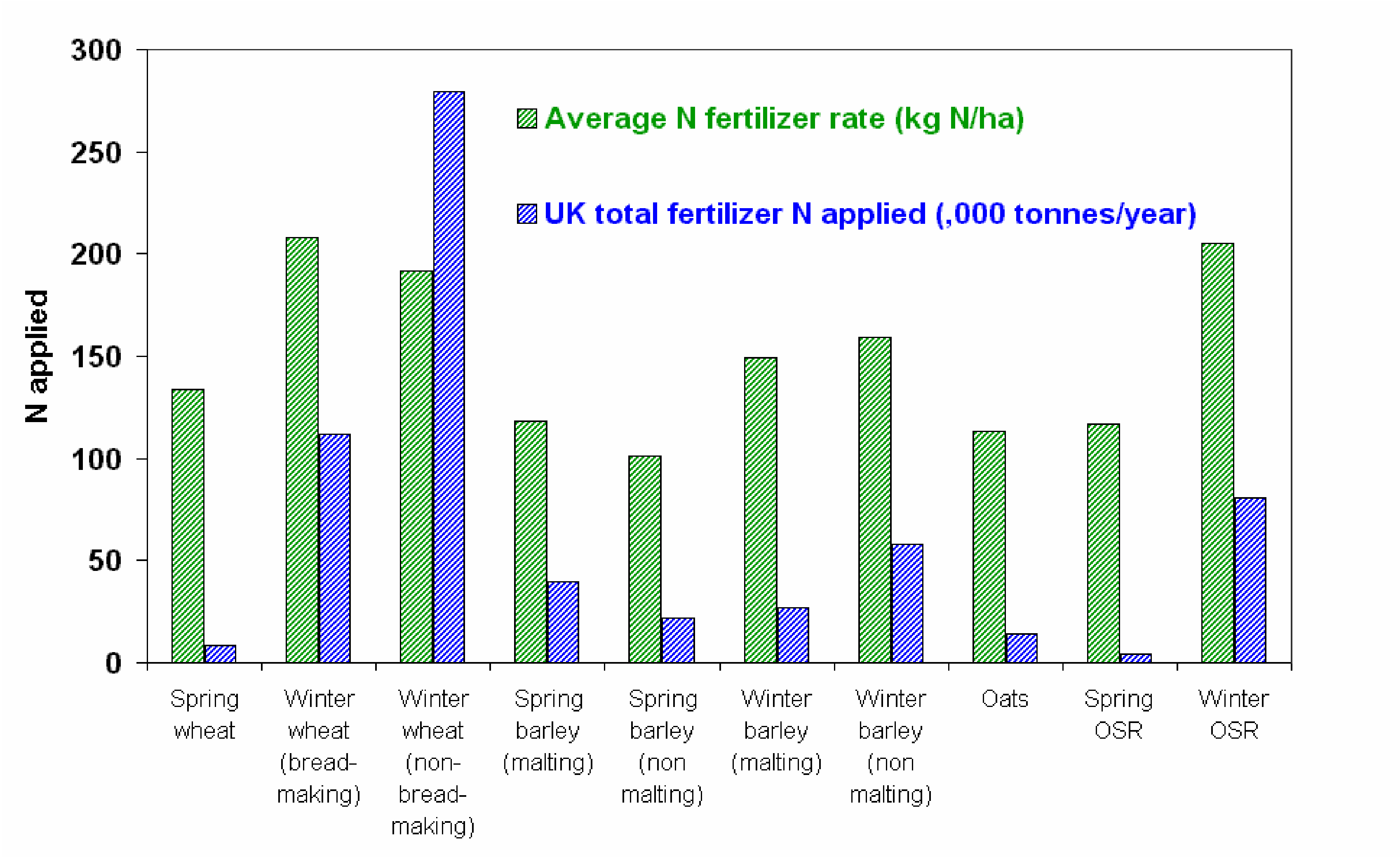
- Potential impacts of optimizing NUE
- Evidence for genetic diversity in NUE
- Traits
- Genomics platforms
- Draft recommendations
- LINK proposal

→ UK crop areas



DEFRA June Census data.

→ National average UK Fertilizer N Inputs

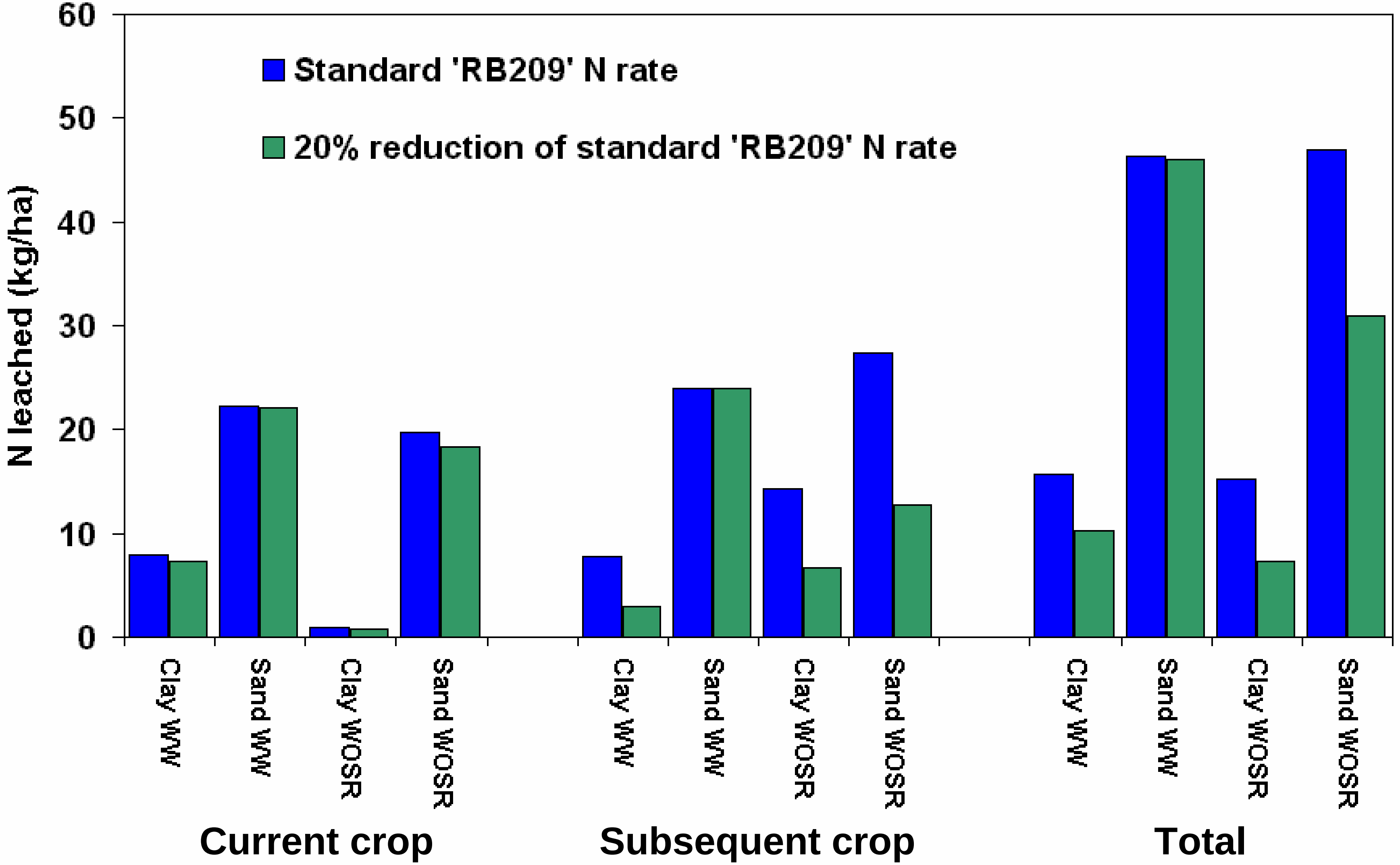


DEFRA June Census and British Survey of Fertilizer Practice 2002.

→ *Annual N balances for cereals and rapeseed crops in the UK (after DEFRA Project IS0208).*

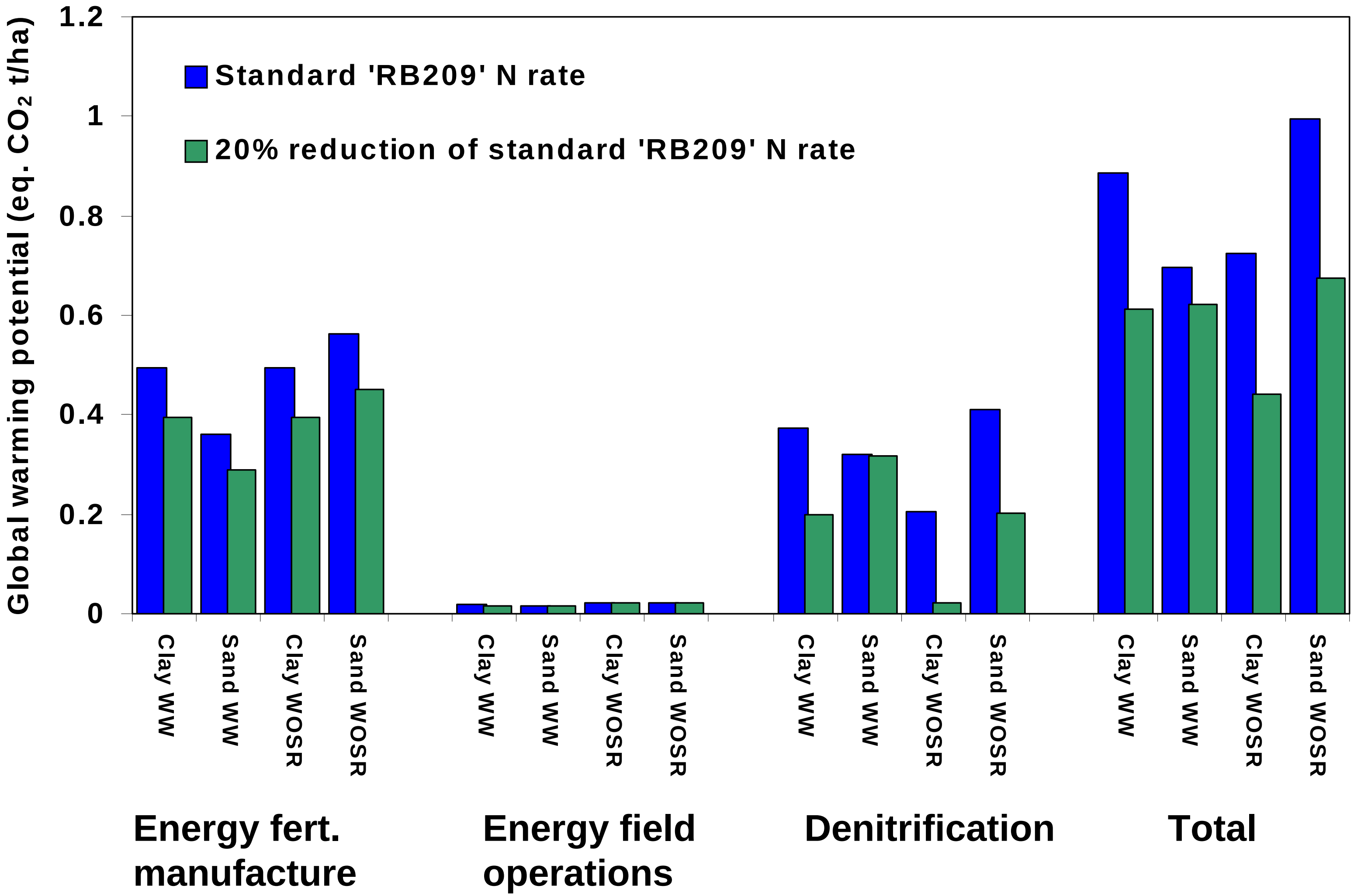
Crop	**N fertilizer applied**	**N offtake**	**N balance (input-offtake)**	**N exported (from agriculture)**	**Net N input (from agriculture)**
	t/UK	*t/UK*	*t/UK*	*t/UK*	*t/UK*
Winter wheat-feed, seed, export	200,806	144,215	55,839	21,632	179,174
Winter oilseed rape	75,824	35,165	41,026	0	75,824
Winter wheat-milling	144,690	96,252	47,536	72,189	72,501
Winter barley-feed, seed, export	70,486	49,477	20,464	0	70,486
Spring barley-feed	30,085	29,261	150	0	30,085
Spring barley-malting	16,561	8,755	7,875	1,751	14,810
Winter barley-malting	16,108	7,659	8,510	1,532	14,576
Spring oilseed rape	5,454	2,955	2,808	0	5,454
Winter oats	9,140	8,553	755	4,704	4,436
Spring wheat-milling	7,217	6,287	929	4,716	2,501
Spring oats	3,917	3,055	863	1,680	2,237
Triticale	1,230	1,535	-334	0	1,230
Rye	711	851	-152	851	-140

→ *Lowering N fert requirements ~ marginally more effective in*



Nitrogen losses derived from SUNDIAL model: Smith *et al*. (1996) Agronomy Journal 88, 38-43.

→ *Lowering N fert requirements ~ marginally more effective in reducing Global Warming Potential (per ha) in WOSR t*



Nitrogen losses derived from SUNDIAL model: Smith *et al*. (1996) Agronomy Journal 88, 38-43.

→ Conclusion:
After winter wheat, WOSR is the 2nd most important UK crop in terms of potential environmental impact on N leaching and emissions of greenhouse gases.

→ *Definitions*

<u>N Uptake Efficiency</u>:

→ N-uptake/N-available

- **<u>N Utilization Efficiency</u>:**

  → Grain yield/N-uptake

- **<u>N Use Efficiency</u> (NUE):**

  → Uptake efficiency x Utilisation efficiency

→ *Previous field studies on genetic variation in NUE components indicate:*

- **N-uptake efficiency accounts for more of variation in seed yield than N-utilization efficiency under low N levels ~ 65% (…. under high N levels ~ 35%).**

Nyikako (2003) - 3 WOSR DH populations in N. Germany, Apex x Mohican; Mansholt x Express; Bristol x Lirajet

- **Similar findings under low N reported by :**
  - **Horst et al. (2003) – WOSR cultivars in N. Germany**
  - **Kessel (2000) – WOSR breeding lines, hybrids, 15 old cultivars in N. Germany**

- **Genetic variation in the rate of N uptake per plant reported in spring OSR cultivars under intermediate N**

Yau & Thurling (1987) – 40 diverse cultivars of Japanese, Canadian, European origin in Syria

Nyikako (2003). PhD Thesis. University of Gottingen, Germany; Kessel, B. (2000). PhD Thesis, University of Gottingen, Germany; Horst et al. (2003): Chapter . In Lynch, J.M. (ed) Innovative soil-plant systems for sustainable agricultural production. pp 75-92.;Yau, S.K. and Thurling, N. (1987). *Field Crop Res*. 16, 139-155.

→ Germplasm diversity analyzed in UK NL/RL trials 1988-2003 (140 trials, 36 sites, 149 varieties)

N-use efficiency (kg DM/Kg N available) for genotypes in OREGIN diversity collection[1] and in LINK CORDISOR[2] project and the range expressed in the 149 varieties examined in NL/RL trials 1988 - 2003.

Variety	Mean	Mod N	High N
Apex[1,2]	13.59	24.52	13.31
Boston[1]	13.85	35.53	13.59
Bristol[2]	13.36	23.56	13.11
Canberra[2]	14.67	28.6	14.16
Capitol[1]	13.80	26.40	13.52
Castille[2]	15.55		15.13
Courage[2]	14.80	25.54	14.42
Disco[2]	15.18	29.76	14.74
Elan[2]	14.98		14.57
Escort[1,2]	14.58	27.17	14.2
Expert[2]	15.60		15.17
Fortis[2]	15.17	26.6	14.73
Harty[2]	13.39		12.96
Ontario[2]	15.02	27.59	14.5
Recital[2]	15.13	26.05	14.75
Royal[2]	15.84	27.49	15.45
Shannon[1,2]	14.62	27.32	14.22
Target[1]	13.94	-	13.52
Winner[2]	16.03	28.13	15.54
Min	11.42	22.39	11.05
Max	16.05	31.51	15.60
Mean	14.41	26.80	14.02
LSD	0.4032	0.3210	0.3577

→ *Differences identified in ability to maintain yield under moderate-to-low N levels in UK WOSR cultivars*

Summary of variety x N interactions (-ve value = variety maintains yield relatively better under low N). Interaction significant < 0.01 [unless marked (†)P < 0.05].

NUE			
High N		All sites	
Var.	Reg. Coeff.	Var.	Reg. Coeff.
Huron	-0.38	Cancan	+0.84
Nickel	-0.44	Courage	+0.42
Bristol[2]	-0.66	Canberra[2]	+0.29†
NLS_01/85	+0.69†	Tequila	+0.90
Sahara	*+0.69†*	Mendel	+0.44†
RNX1002	*-0.92†*	Concept	+0.97
SW_Gospel	*-0.77†*	Elan[2]	+0.52†
WRG_198	*-0.78†*	Pamir	+1.15
Vital	*-1.04†*	Blaze	+1.24
EGC053	*-0.28†*	Commanche	+0.19†
ADV-9036-195	*+0.43†*	Verona	-0.88
		Liverpool	-0.75
		Disco[2]	-0.26†
		Bilbao	-0.60
		Royal[2]	-0.32
		Expert[2]	-0.56
		Toccata	-0.64
		Recital[2]	-0.28†
		Exact	-0.44†
		Borneo	-0.32†
		Labrador	-0.37†
		Triangle	-0.32

Genotypes in OREGIN diversity collection[1] or LINK CORDISOR[2]

Priority traits for the improvement of N economy in UK cereals and OSR in the short and long-term

Priority Traits	
Short term	**Long term**
Root growth -Increase root length density at depth -Increase root longevity (hence post anthesis uptake)	**N signalling** - Improve NO_3 uptake (reduce negative feedback)
Root activity -Increase N transporter density	**Rubisco** - High specificity for CO_2 (red algae)
Stem N storage -Optimise stem N storage according to crop species/end-use market	**N Remobilization to seed** - Optimize 'stay- green' traits
N remobilization to seed -Optimize leaf-to-leaf and leaf-to-grain transfer according end-use (GS/GOGAT)	
Seed protein composition - Reduce % rumen degradable protein (wheat fed to ruminants) - Increase % essential a.a. (wheat fed to non-ruminants) - Increase % glutens (wheat for bread-making)	

Winter oilseed rape ideotype for improved NUE.

Low N relocation from pod wall to seed (delayed senescence): increase NutE

Low amount of N lost in shed leaves (optimise leaf-to-leaf transfer, GS/GOGAT): increase NutE

Low stem N storage: reduce requirement for fertilizer N

High root length density at depth: increase NupE

→ *Genomics review*

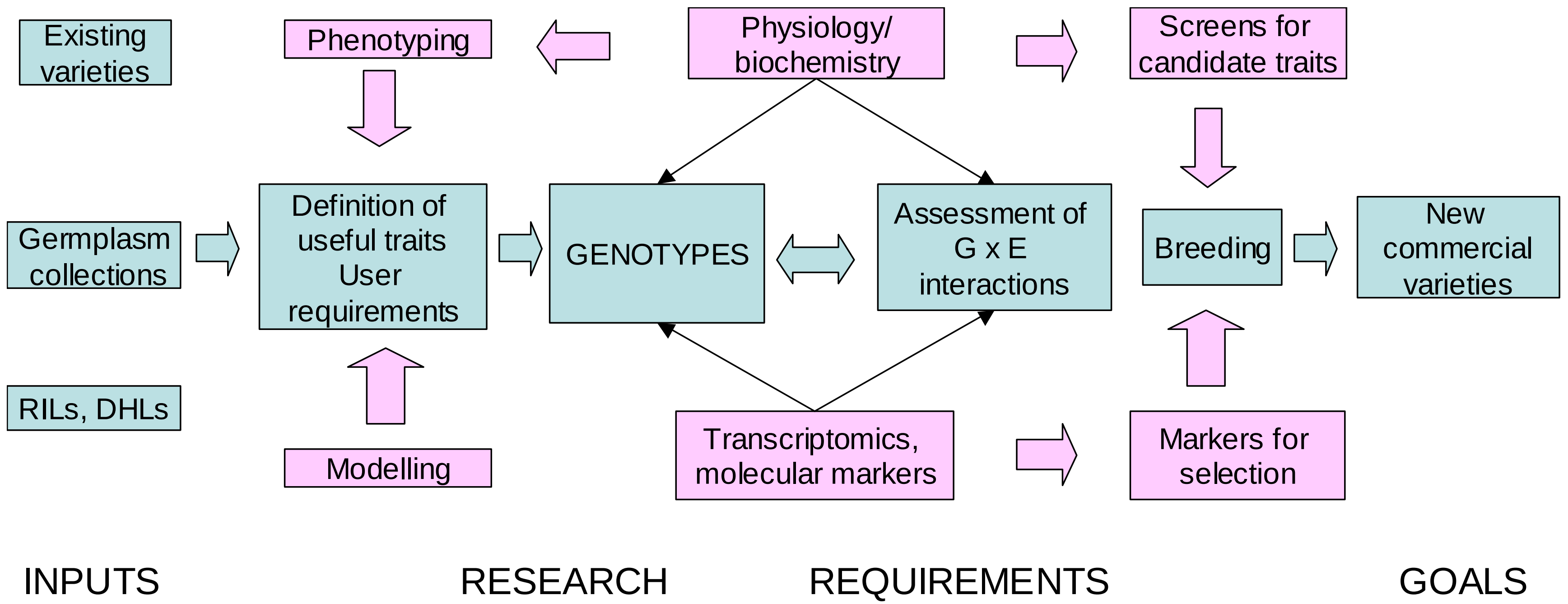
- Future genomics developments of importance to plant breeding and optimising NUE:

- New genomics resources [physical maps etc]
- Global gene expression analysis [eg. tiled genome arrays, Affymetrix arrays] including cross-specieis application
- Development of highly informative markers [eg. SNPs]
- Molecular mutational approaches [TILLING etc]
- Candidate gene association studies;
    - o information from genetic ‘models’
    - o Analysis of non-random associations of alleles and phenotypes [‘LD’]
- Comparative approaches;
    - o Comparative genetics/genomics
- Bioinformatics and resource management

- Expected outputs:

- Identification of traits and underpinning genes suitable for breeding
- Identification of molecular markers to facilitate breeding

→ *Draft generic recommendations*



→ *Draft specific recommendations (WOSR)*

- Phenotyping genetic diversity ~ development of smart screens
- Genetic analysis of stem N storage underlying N-utilization efficiency
- Core DH mapping population allied to OREGIN for genetic analysis of traits underlying N-utilization efficiency
- Genetic analysis of root traits underlying N-uptake efficiency
- Complementary studies to optimise methods of managing segregating populations in breeding programmes (manipulating N levels during selection) to select N efficient lines

Link Proposal

- **Proposer:** Richard Martin **(**North East Biofuels)

- **Project title:** IDENTIFICATION OF GENETIC MARKERS TO REDUCE THE NITROGEN REQUIREMENT OF OILSEED RAPE

- **Date submitted:** ?/?/2005

- **Start date and duration:** 1/7/2005, 66 months

- **Collaborating partners**

  Research ADAS, WHRI, University of Nottingham

- **Industry** North East Biofuels, Syngenta Seeds Ltd, Saaton Union Ltd, CPB-Twyford Ltd, Monsanto UK Ltd, Terra Nitrogen, United Oilseeds Marketing Ltd, HGCA, BP, BASF, Greenergy Fuels Ltd.

- **Estimated total cost:** 920K

Objectives

- **Quantify the yield losses between high and low N environments for modern & novel varieties**
- **Identify the key plant traits that cause variation in N requirement.**
- **Develop methods for rapidly measuring the key traits**
- **Identify QTL for the key traits**
- **Estimate the effect of reducing N requirement on N leaching and green house gas emissions**

Benefits to the industry, science and the environment

- **Industry**
  - Identify varieties with a low fertiliser N requirement
  - Identify genetic markers that breeders can use to rapidly select varieties with a low N requirement
  - Reduce N fertiliser costs by up to £45 ha^{-1}
  - Improve viability of using oilseed rape for biodiesel.

- **Science**
  - Elucidate physiological mechanisms by which specific plant traits affect N requirement.
  - Elucidate the genetic control of the most important plant traits
  - Determine the utility of genetic markers across novel and elite germplasm
  - Identify candidate genes through syntenic relationships between OSR and Arabidopsis.

- **Environment**
  - Reduce N leaching after OSR >50% on other soils.
  - Reduce green house gas emissions from OSR production by ≈ 40% (288,000 t eq CO_2 p.a)