

May 2013

The 11th WGIN Stakeholder Meeting – 4th December 2013, RRes, Harpenden

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Defra Wheat Genetic Improvement Network – Improving the environmental footprint of farming through crop genetics and targeted traits analysis

Section 1. Project Background

The UK government is committed to more sustainable agriculture but this vision is facing an ever expanding range of environmental, energy and climate change challenges. Wheat is grown on a larger area and is more valuable than any other arable crop in the UK. Established in 2003, the Wheat Genetic Improvement Network (WGIN) arose directly from a realisation in the early 2000s that over the preceding two decades there had been a widening disconnection between commercial plant breeding activities and publicly funded plant and crop research. The overall aim of WGIN is to generate pre-breeding material carrying novel traits for the UK breeding companies and to deliver accessible technologies, thereby ensuring the means are available to produce new, improved varieties. An integrated scientific 'core' which combines underpinning work on molecular markers, genetic and genomic research, together with novel trait identification, are being pursued to achieve this goal. The programme is managed by a team including representatives of the key UK research groups and breeders. They ensure the programme and its outputs are communicated to the wider scientific and end user communities, via a web site,

a stakeholder forum, focused meetings and peer reviewed publications. WGIN liaises with equivalent operations overseas to ensure the programme is internationally competitive.

The initial WGIN project ran for five years (2003-2008) and achieved considerable scientific success. In addition, the sustained networking activities and the availability of datasets generated by the project led to the establishment of many new wheat genetic improvement projects, including some funded jointly by the public sector and industry. Those funded by early 2008 were summarised in the [May 2008](#) Stakeholders Newsletter (SNL) and since then many additional projects have been funded (see [November 2010](#) SNL). There is no doubt that WGIN has a direct and significant impact on re-establishing the relationship between commercial plant breeding activities and public funded plant and crop research. However significant hurdles remain which currently prevent commercial implementation of much new research which should help to reduce the energy requirement and environmental impact of the UK wheat crop.

This project

The new WGIN Core Project started in 2008 to provide genetic and molecular resources for research in other Defra projects and for a wide range of wheat research projects in the UK. The resources under development include wheat genetic stocks, mapping populations, molecular markers and marker technologies, trait identification and evaluation, genomics and bioinformatics. The initially funded partners are the John Innes Centre, Rothamsted Research and The University of Nottingham but support has been allocated for sub-contracted projects which were awarded in open competition during 2009.

Section 2. Research Updates

Objective 2: Near Isogenic Lines - 2012-2013 Avalon x Cadenza Near Isogenic Line Field Trial

WGIN has been involved in identifying wheat genes controlling important traits like grain yield, crop height, and maturity. Four years of field trial data carried out at the Church farm field trials site of the John Innes Centre produced an excellent data set that is available from the WGIN website (<http://www.wgin.org.uk/about/RecentUpdates.php>). The analysis of this data to identify genes as Quantitative Trait Loci (QTL) can also be found on the website.

transfer this gene into wheat varieties that are under development. This process is known as marker assisted selection or MAS.

The MAS strategy can be very effective but there are limitations. For example the alleles of genetic markers linked to this gene in Cadenza might not be linked in other varieties because genetic recombination has broken this linkage. Even where they are still linked they might not be useful in discriminating the region when crossed to a range of other varieties, because the markers are not polymorphic in these crosses. Finally, we do not really know the identity of the gene in which allelic variation causes a yield increase. How does it work? What other alleles are desirable? How does this gene interact with others?

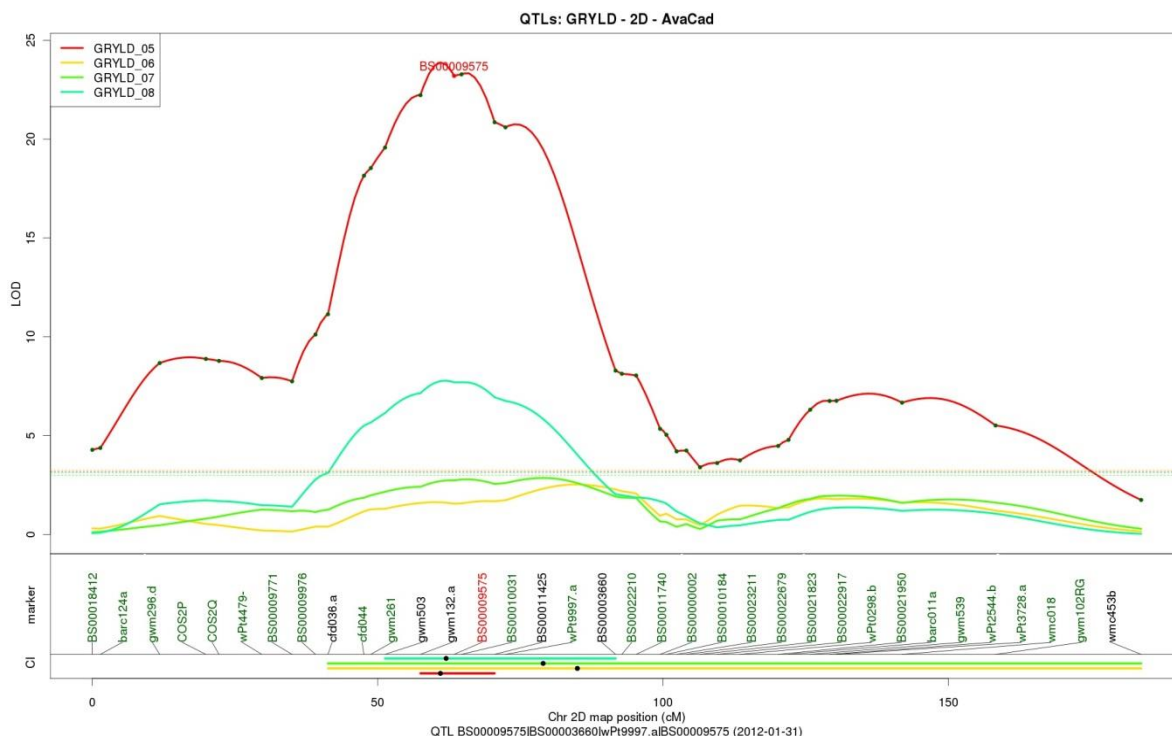


Figure 1: The QTL from Cadenza confirming a yield increase.

QTL are our first window into the chromosomal location of genes. This analysis gives a measure of the additive effect of the gene. That is a measure of the difference between Cadenza versions of the gene and the Avalon version. These gene 'versions' are called alleles. So, with yield as a target trait, breeders might use the genetic markers around the yield increasing Cadenza allele shown in **Figure 1** to specifically

To answer these questions WGIN has developed very specific genetic stocks in which only one chromosomal region is segregating. They are called Near Isogenic Lines or NILs. Like all WGIN materials the NILs are freely available and details of how they were developed are available on the website. The NILs have uniform genetic backgrounds therefore, the distribution of alleles to the progeny of a cross (segregation) can be

directly inferred by the behaviour (phenotype) of those progeny. Researchers can dispense with the relatively blunt tool of QTL analysis and move to the precise location of the DNA changes that make the functional difference between Avalon and Cadenza alleles.

Last year (2012), the first full scale field trial of the WGIN NILs was drilled at Church Farm. The NILs have been developed for each QTL (**Table 1**), by which two F₁ plants from each cross were continued to backcross 2 to form independent crossing streams with selection of flanking genetic markers at each stage. Multiple lines with each parental allele were then selected from each stream and self pollinated, resulting in NILs with at least 87.5% parental background. In fact the percentage of recurrent parent background is probably even greater than that, because the original donor parents were selected from 202 Avalon x Cadenza double haploid (DH) lines on the basis of carrying the chromosomal region of interest from, for example chromosome 1D of Cadenza (or ear emergence), with the other chromosomes originating as much as possible from Avalon.

Following multiplication and preliminary phenotypic assessment in the field during 2011 and 2012, all NILs have reached the stage of 6m replicated field trials. The unprecedented wet weather in the autumn delayed drilling until 26th October, with replicates two and three finally drilled on 8th and 9th November. Despite this establishment has been good and it is hoped that the results from phenotypic assessment of height, ear emergence and yield will provide reliable data to validate the QTLs discovered and facilitate the cloning of wheat genes with the utmost relevance to UK agriculture. There are 225 lines in the Avalon and 342 in the Cadenza backgrounds with QTL represented as shown in **Table 1**.

Avalon¹ Background	Cadenza Background
<i>1B ear emergence</i>	<i>1B ear emergence</i>
<i>1D ear emergence</i>	<i>1D ear emergence</i>
<i>2A height</i>	<i>2A height</i>
<i>2D height</i>	<i>2D height</i>
<i>2D yield</i>	<i>3A height, ear emergence & yield</i>
<i>3A height, ear emergence & yield</i>	<i>3B height</i>
<i>3B height</i>	<i>3B yield</i>
<i>5A yield</i>	<i>6A height</i>
<i>6A height</i>	<i>6B ear emergence & height</i>
<i>6B height</i>	
<i>6B height & yield</i>	
<i>1D ear emergence & 5A yield</i>	
<i>7B yield</i>	
<i>7D yield</i>	

Table 1: The traits and their locations being explored by Near Isogenic Line (NILs) analysis at the Church Farm field traits site of the John

The field trial data, and our analysis of it, will be presented on the website and at the next WGIN stakeholder meeting.

¹ The parent cultivar providing the QTL of interest.

Objective 8: Nitrogen use efficiency (NUE) and Quality QTLs linked to NUE (RRes)

As in previous years, a field trial (The Diversity Trial) examining interactions of NUE and genotype was drilled in the autumn of 2011 and harvested in August 2012. Grain and straw yields were recorded and samples taken for nitrogen analysis. As in the previous year, canopy spectral reflectance data were collected to assess post anthesis canopy longevity. A variety of instruments are being compared to optimise this technique (**Figure 2**).



Figure 2: Used the Crop Circle tool to assess crop/canopy longevity.

The Diversity trial examined 25 varieties subject to 4 levels of N fertiliser application (0, 100, 200 and 350 kg/ha) in a triple replicated design. The 2012-harvest varieties consisted of 23 elite current or older varieties and 2 selected double haploid lines from the mapping population (Avalon x Cadenza). Three elite varieties were added for harvest in 2012 (Conqueror, Hereford and Zeberdee) to increase overlap with the WUE and Take-all trials. This overlap will facilitate progress on Objective 12. The photograph in **Figure 3** shows part of the trial prior to harvesting and an example of the field data is shown in **Figure 4**. Of note is the



Figure 3: The WGIN Diversity Trial, just prior to harvest in 2012

extensive lodging in Maris Widgeon at 350 kgN/ha (bottom row, plot on right).

A total of 33 varieties were examined between 2007 and 2012, with an observed interaction between N-supply and seasonal performance (**Figure 4**). In 2007 varieties performed best at high N; varieties performed exceptionally well at low N in 2008; generally the rank order of performance is similar at low and high N, and is preserved in all years, but there are significant outliers. Each year had a major impact on yield, over and above genotypic effects and there was notable differential stability of germplasm due to climatic fluctuation.

The Avalon x Cadenza DH mapping population, which has been extensively investigated since 2007 as part of the WGIN programme (Objective 3), was also phenotyped and harvested in 2012. The phenotyping data (yield, NUE parameters, canopy senescence) is being collated for multiple years/sites and for two N inputs, for final mapping and definition of QTLs. In parallel, a study examining root traits in this population has been made at Rothamsted and recently published (Bai et al. 2013 see page 9).

Fresh grain material has been archived at -20 °C. In addition milled grain and straw have been archived from both experiments.

In the autumn of 2012, the Diversity Trial was drilled with 25 varieties. New varieties for the 2013 harvest are AC Barrie (chosen because of exceptional high protein content and quality) and Cocoon (a taller variety which may have high nitrogen acquisition and utilisation capacity), replacing the two Avalon x Cadenza lines.

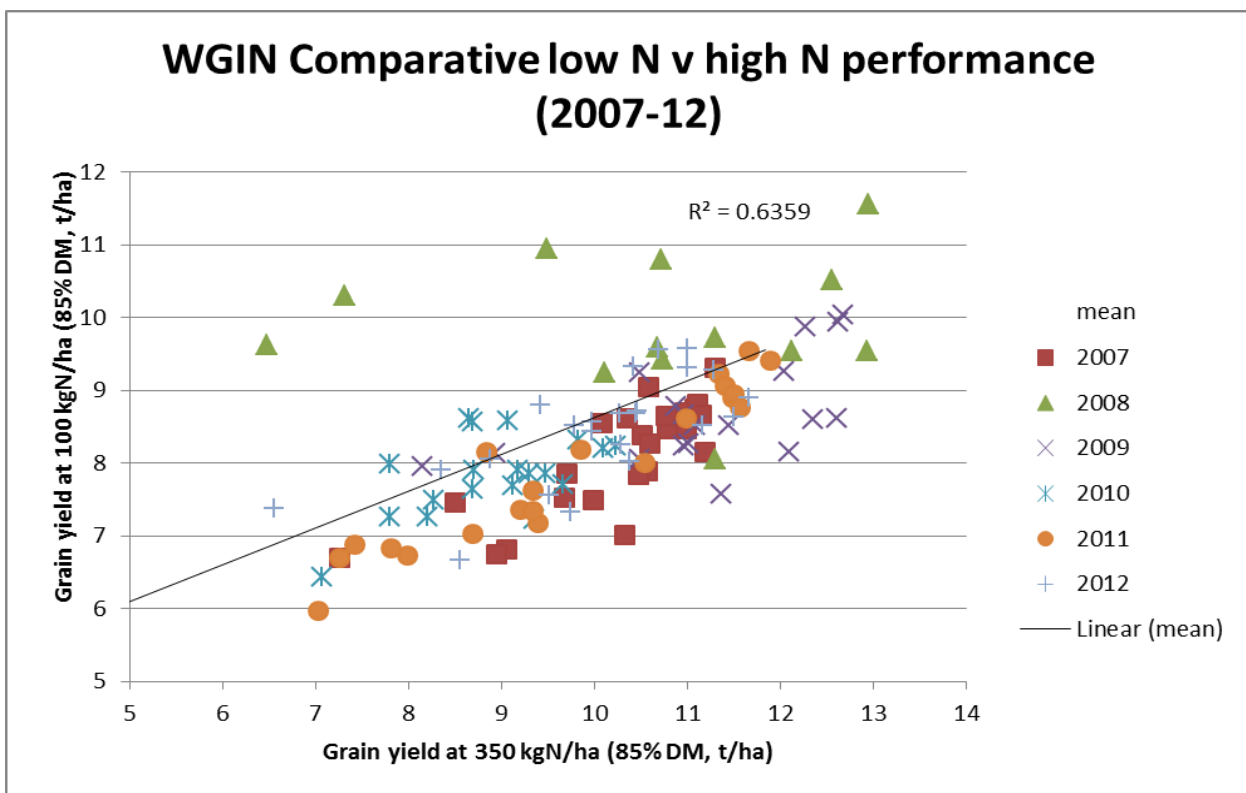


Figure 4: A summary of performance of the commercial varieties, comparing low (100 kgN/ha) and high (350 kgN/ha) N-application, for all years since 2007.

Objective 9: Improvement of water use efficiency and drought tolerance traits.

The WGIN Drought Tolerance research was featured in a key-note presentation by John Foulkes at the AAB 'Crop Resource Use Efficiency and Field Phenotyping' meeting held at Belton Woods, Grantham, Lincs, UK 25-26 March 2013. The title of the oral paper was "Increasing the efficiency of water use of wheat by identification of isotope-based screens indicative of drought tolerance". Co-authors were Simon Griffiths and Simon Orford at the John Innes Centre and Pedro Carvalho and Jayalath DeSilva at the University of Nottingham. The talk outlined how WGIN research has identified isotope screens, C isotope discrimination ($\delta^{13}C$) and ^{18}O enrichment ($\delta^{18}O$), for crop water use efficiency and water use, respectively. Cultivars combining high water-use efficiency and high water use were identified amongst a panel the 18 UK wheat cultivars in field experiments at Nottingham in 2009-2010 and 2010-2011 (Figure 5).

Work is ongoing in phenotyping a Savannah x Rialto doubled-haploid mapping population to discover novel genes for these drought tolerance traits in UK wheat for food and energy security. In several years, UK wheat crops have given enhanced yield when irrigated (Figure 6).

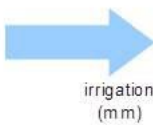


Figure 5: Effects of drought at mid-grain filling in The WGIN Irrigation x cultivar trial at Nottingham University in

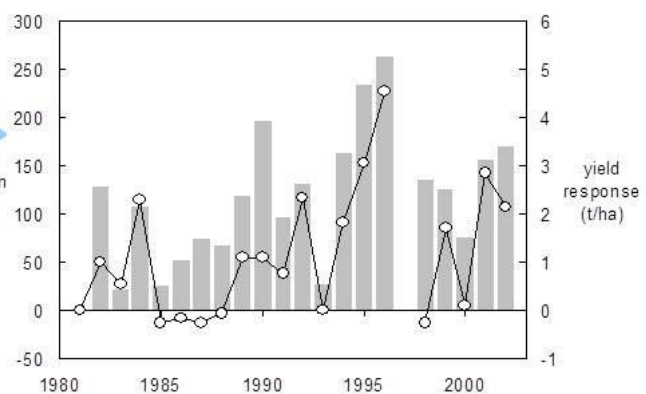
Impact of drought on UK wheat yields

Distribution of available water capacity (AWC) 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



Yield response to irrigation on light soil (Gleadthorpe)



Foulkes et al. 2001, 2002 J Agric Sci, Camb ;
Foulkes et al. 2007 Field Crops Res .

ADAS Gleadthorpe Notts
AWC = 140 mm

Figure 6: Response of wheat yield to crop irrigation

Objective 10: Take-all Disease - Identification and characterisation of hexaploid wheat germplasm which reduces take-all inoculum build-up in the soil

Take-all is a damaging root disease of wheat caused by the fungus *Gaeumannomyces graminis* var. *tritici* (Ggt). When disease levels are severe above-ground symptoms of take-all show as patches of prematurely ripened and stunted plants (**Figure 7**). Take-all epidemics develop during consecutive wheat cropping. In the first wheat crop in a rotation there is usually very little root infection. However, take-all inoculum builds up in the soil during this time putting subsequent crops at risk from disease. Within the WGIN 1 project we identified differences in the ability of winter wheat cultivars to build-up inoculum of the take-all fungus when sown as a first wheat crop. This new trait was given the name **Take-All inoculum Build-up (TAB)** (McMillan et al (2011) *Plant Pathology* 60, 200-206).



Figure 7. Below and above-ground symptoms of take-all disease. Left = a take-all infected wheat plant; Right = a take-all patch in the wheat crop.

In the WGIN 2 project, cultivar rotation trials were set up to investigate the significance of this new trait and explore whether different combinations of first and second wheat cultivars help to minimise or maximise take-all disease levels. In year 1 these experiments consisted of large 12 x 82m strips of either the low building (low TAB) cultivar Cadenza or the high building (high TAB) cultivar Hereward (total 8 large strips). After harvest in year 1 these strips were divided into eight smaller 10 x 3m plots and sown with eight different winter wheat cultivars that cover the four NABIM groups (Cordiale, Duxford, Einstein, Gallant, Hereward, Robigus, Solstice and Xi19). In year 1, soil cores were taken after harvest to assess inoculum build-up and in year 2 plant samples were taken in the spring and summer for take-all disease assessment. Yields were also taken by the Rothamsted farm in year 2.

Three cultivar rotation trials have now been completed (harvest year 2010, 2011 and 2012). As expected in all three rotation trials the cultivar Hereward built up more take-all inoculum in the soil in year 1, although this was only significantly higher than the cultivar Cadenza in two of the three trials. In these three trials the amount of take-all inoculum build-up in year 1 was very different due to changes in environmental conditions:

In the first rotation trial (harvest years 2009 and 2010) the presence of natural populations of the competing fungus *Phialophora graminicola* reduced take-all inoculum build-up across the trial site.

In the second rotation trial (harvest years 2010 and 2011) the very dry spring and summer in 2010 restricted inoculum build-up to extremely low levels under both Cadenza and Hereward.

In the third rotation trial (harvest years 2011 and 2012) the wetter conditions favoured inoculum build-up, but there was significantly less inoculum build-up under Cadenza.

In the second year of all three rotation trials there was a trend for significantly less take-all disease after the low TAB cultivar Cadenza was grown in the first year compared to the high TAB cultivar Hereward. There was also a grain yield advantage in the second wheat crop when Cadenza was grown as the first wheat. In the first rotation trial the take-all disease pressure was low across the trial due to the presence of *P. graminicola*. Despite this grain yields in year two (harvest year 2010) were on average (for all eight second wheat cultivars) 0.44 tonnes/ha higher after Cadenza than Hereward, although this was not significant ($P = 0.19$). In the second rotation trial, after an extremely low build-up year in year 1 (due to the dry weather), grain yields in year 2 (harvest year 2011) were 0.2 tonnes/ha higher after Cadenza ($P = 0.043$).

In the third rotation trial, in the second year (harvest year 2012), where the take-all disease pressure was highest, there were clear differences between the appearance of the second wheat plots sown after either Cadenza or Hereward in the first year. By June the plots sown after the high TAB cultivar Hereward showed large areas of yellowing, stunted and prematurely ripened plants typical of severe take-all infection (**Figure 8**). In this year there was an exceptionally high take-all disease pressure with an average take-all index (0-100) of 83.30 across the trial. Under these difficult growing conditions the second wheat yields were on average for all eight second wheat cultivars 2.42 tonnes/ha higher after the low TAB cultivar Cadenza in the first year compared to Hereward ($P = 0.006$). Straw yields were also on average 1.32 tonnes/ha higher after Cadenza sown as the first wheat ($P = 0.004$).

In all three trials the eight second wheat cultivars were generally all highly susceptible to take-all disease. However, there was evidence of some differences between the second wheat cultivars in their susceptibility to take-all disease, suggesting that different second wheat cultivars could work to help minimise or maximise disease. The known 'bad' second wheat cultivar Robigus was usually most severely infected. However, the ranking of the other second wheat cultivars was not very consistent between the three trials at different disease pressures.

The findings from these three rotation trials, done under very different climatic conditions reveal how significant the low TAB trait can be in reducing the risk of take-all root disease and thereby improving second wheat yields. This new trait is delivered by appropriate cultivar choice in the first year. Results from these three fully completed trials were presented at the WGIN stakeholder meeting on the 27th November 2012 and a manuscript is in preparation.



Figure 8. The wheat cultivar rotation trial. Appearance of second wheat plots of Hereward sown after the low TAB cultivar Cadenza (left) or the high TAB cultivar Hereward (right) in year 1. Photographs taken on the 27th June 2012.

Section 4. Sub-contractor projects

The Water Use Efficiency project funded at the University of Nottingham is now in its 2nd year of funding. Due to the lack of drought conditions in 2012, no grain sample analysis will be done. Instead the entire trial was redrilled in Autumn 2013.

Section 5. Events

11th WGIN Stakeholders Meeting – 4th December 2013

The 11th WGIN Stakeholders Meeting will take place on 4th December 2013 at Rothamsted Research. As in previous years, an afternoon panel discussion will take place centred around the topic “**Attaining Yield and Quality Stability over Sites and Seasons**”. If you are interested in contributing, please contact us on wgin.defra@rothamsted.ac.uk.

Section 6. News

The wheat breeders held a WGIN priority traits meet in January 2013 at the headquarters of the British Society of Plant Breeding in Ely, Cambridgeshire.

At the March 2013, WGIN Management Meeting, Dr David Cooper at defra announced that the WGIN 2 project would be extended until the end of the financial year (April 2014). In addition discussions were held on the potential research tools, resource and traits to be included within the core programme of WGIN 3.

The 2nd Avalon x Cadenza mapping populations workshop organised by Dr Simon Griffiths & Caroline Munnings, was held at the John Innes Centre in March 2013. The final programme is given overleaf. In total approximately 45 people attended from academia and industry. Most of the presentation in this workshop, are now available on the WGIN website.

Section 7. Publications

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

Caihong Bai; Yinli Liang; Malcolm J. Hawkesford
Journal of Experimental Botany 2013 64: 1745-1753

<http://jxb.oxfordjournals.org/cgi/reprint/ert041?ijkey=cOcai98zMSSzFrQ&keytype=ref>

Hawkesford, Malcolm John (November 2012) Improving Nutrient Use Efficiency in Crops. In: eLS 2012, John Wiley & Sons Ltd: Chichester
<http://www.els.net/> [DOI: 10.1002/9780470015902.a0023734]

Section 8. New Grants using WGIN Data

In the next issue of the WGIN Electronic Newsletter, to come out late this autumn, we plan to update the economic impact of the WGIN project since August 2011. Please let us know if you have received any new Grants using WGIN Data since August 2011 or if you are aware of any projects that are funded and are now using WGIN data or resources. Please let us know at wgin.defra@rothamsted.ac.uk

2nd Avalon x Cadenza Workshop

Wednesday 27th March 2013

John Innes Centre (Room G34/35)

Workshop Programme

- 10:00 Arrival/coffee
- 10:30 Genotyping in Avalon x Cadenza (Sacha Allen, University of Bristol)
- 11:00 Phenotyping nitrogen use efficiency (Malcolm Hawkesford, RRes)
- 11:30 Costs of resistance in Avalon x Cadenza (Mike Grimmer, ADAS)
- 12:00 Development of Near Isogenic Lines for AxC QTL (Simon Griffiths, JIC)
- 12:30 Lunch and discussion
- 13:30 Hagberg Falling Number in Avalon x Cadenza (Nick Bird JIC)
- 13:45 WESP Project (Steve Hoad SRUC)
- 14:00 Flowering time diversity (Hannah Jones, University of Reading)
- 14:30 Take All and the extended Avalon x Cadenza segregating population (Kim Hammond-Kosack, RRes)
- 15:00 Yellow Rust in Avalon x Cadenza- (Donal O'Sullivan, NIAB)
- 15:20 Coffee and discussion:
Breeders perspective on AxC and equivalent resources and opportunities for future community resource development (Chair- Ed Flatman, Limagrain)

For further information on the WGIN project please see www.wgin.org.uk or contact us at wgin.defra@rothamsted.ac.uk.

The contributors to this newsletter were: At Rothamsted Research: Kim Hammond-Kosack, Malcolm Hawkesford, and Suzanne Thrussell. At the John Innes Centre: Simon Griffiths. At University of Nottingham: John Foulkes. At defra: David Cooper..

