ROTHAMSTED RESEARCH

Annual Review 2015/2016

Soil is Life

Biodiversity Bounces Back

Healthy Crops — Healthy Food

MANAGING LIVESTOCK WASTE

GM aphid-repellent wheat

WILLOW POWER

The Field ‘Scanalyzer’ — A World First

MYSTERIES OF PLANT LIFE

ROTHAMSTED RESEARCH

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Rothamsted Research is an internationally recognised centre of excellence and innovation for science in support of agricultural productivity, crop protection and sustainable grazing livestock systems.

2015/16 was a very busy year delivering excellent science, establishing national and international collaborations, and re-defining our long term vision and strategic priorities.

Contents

Director’s Overview

ACHIM DOBERMANN

What are your reflections on your first year and a half at Rothamsted Research?
“Our primary achievement in the past 18 months has been that we have redefined our long-term vision and mission – or, as I prefer to say, our *purpose*. We needed to reach more clarity about what unique contributions we can make to solving the big problems faced by agriculture in the UK and worldwide. We conducted a thorough self-assessment, scanned the environment and major trends around us, listened to many experts, partners and other stakeholders, and also shared our emerging thinking widely. Based on all of that, we concluded that we are an institute that prides itself on doing excellent, high impact science with an integrated agricultural focus, but that we also need to explore new ways of working. We identified four themes, or grand challenges, on which we will concentrate our research in the next 5 – 10 years:

1. **Improving crop performance to close yield and efficiency gaps**
2. **Optimising future agri-food systems to deliver a ‘win-for-all’ agriculture**
3. **Developing smart plant and animal health solutions**
4. **Designing novel products for health, nutrition and bio-based industries**

We are now fleshing this out in more detail and are already interacting more closely with many national and international partners. The campus has changed massively; the Rothamsted Centre for Research and Enterprise (RoCRE) is now fully functioning and includes the newly built Lawes Open Innovation Hub and International Conference Centre. We have changed our management structure to ensure we can implement our new vision. Overall, I am very pleased with the new vision and the initial progress made, which reinforces our primary purpose as the leading institute in the UK for integrated agricultural science.”

What were the research highlights of 2015/16?
“It is difficult to pick individual examples when there is so much excellent work to choose from – but let me just point out a few. 2015 was the International Year of Soils and our scientists made a number of notable advances, particularly in understanding the biological functions of soil, moving towards a more quantitative understanding of soil resilience, and exploiting metagenomics. There were also advances in crop health research including insights into the interactions between insects and plant disease and the genetic control of plant resistance to disease. The results of the GM wheat field trials – conducted in 2012/13 to test novel plant-signalling defence mechanisms to repel aphids – were finally published. This was an important step and also a rare occasion in the sense that what we had found to work in the laboratory did not yet work as well in the field. We believe this is important, as is our responsibility to publish such ‘negative results’, and we learnt a lot from it. The international response to this publication

has been overwhelmingly positive. I would also like to highlight the progress made in the Farm Platform National Capability at North Wyke. After many years of hard work, a full baseline of data was established, published and made publically available through a new data portal. This is an outstanding starting point on which to build our hypothesis-driven grassland-livestock systems science. We also saw the installation and utilization of the world's first fully automatic, high-throughput, robotic, field phenotyping platform – a field scanalyzer – which will revolutionize this field. Finally, based on unique, long-term data from our Park Grass Experiment, a very important paper was published in the journal *Nature* providing unique experimental evidence that the decline in biodiversity due to atmospheric pollution is in fact reversible. I will stop there – but several hundred papers were published last year – and I encourage you to investigate them further."

People at Rothamsted Research – what are your priorities?

"People are the most important asset of any organisation and we have been working on many initiatives to create a modern work environment for everyone, including opportunities and support for professional development. We are working on a whole new career development framework that will ultimately lead to clear and uniform job descriptions and career paths, including better performance indicators. It is very important for us to get this right and we are approaching it from the bottom up, in an inclusive manner. Training in all its forms is very important for personal development. Offering high quality training for students and scientists provides them with a lasting legacy that they take with them in their future careers. We have doubled the number of new PhD students enrolling and I really want to further increase our efforts on that, particularly through strategic partnership agreements with a number of universities. Our aim is to have at least 100 PhD students here at any time, and there is probably room for even more, and also MSc students. We are also encouraging early-career scientists to be more active in coming forward with their ideas for grant proposals and participating in institute activities in the wider sense so that we enable them to fully utilise their potential."

"Having spent the last two years doing a lot of thinking about what we want to be and what we are capable of – now we need to move towards action."

Prof. Achim Dobermann, Director

What are your thoughts on new ways of working to tackle the big problems in agriculture?

"Scientists working largely in publicly-funded institutions and universities have certain ways of working that, on one hand, provide a lot of freedom to explore, but on the other hand, may also take far too long before outputs are taken up by the farming industry and others. Sometimes we don't even seem to reach that point at all, or we may run the risk of pursuing scientific ideas that do not really address big challenges or practical problems. I know this very well from my own research in the past. We have huge problems to solve in agriculture and many of them cannot wait 20 or 30 years. At Rothamsted we will aim to combine scientific discovery with a true innovation culture, moving faster towards translation through a leaner science approach. Our aim is not only to stimulate new ideas, but also to take them very quickly to prototypes that are tested and improved in an iterative fashion in collaboration with universities and industry partners in the real world. That culture will be embedded in our future research. This problem-solving approach will still be done in the context of excellent, strategic science and student-driven research projects, but it will make our research more relevant. During 2015/16 we have already become part of three of the four new Centres for Agricultural Innovation, namely Agrimetrics, CHAP (Centre for Crop Health and Protection) and CIEL (Centre for Innovative Excellence in Livestock). Our next step is to create new internal and external innovation mechanisms, including an agricultural research and innovation accelerator. In the past 18 months we have also greatly expanded our international collaboration with new links in China, Brazil, the CGIAR centres and East Africa. Innovation on a global scale will be the trademark of Rothamsted in the future.

What will you be focusing on in 2016/17?

"2016/17 is a critical period for us because we have spent the last two years doing a lot of thinking about what we want to be and what we are capable of, but now we need to move towards concrete action. We have to secure the next round of strategic funding to implement much of our new long-term science strategy. We will also make a number of strategic recruitments to infuse new talent into our science and also fill critical gaps so that we have all the expertise and strengths we need to work in a more integrated agricultural science approach. A key challenge is to build a portfolio of focused strategic programmes around the four themes that we have identified and, over the next 5 years, increase our grant income by at least 50%. We need to further develop an effective partnering approach with national and international institutions and organisations. We have signed strategic agreements with a number of UK and international partners and now it is time to implement these. I want to finish by saying that what is very important to me is the establishment of strong relationships with the UK farming community. The UK needs a strong and competitive agricultural industry more than ever now and Rothamsted must play a leading role in this.

Official opening of Lawes Open Innovation Hub and Rothamsted Conference Centre.

Rothamsted Research

AT A GLANCE

248 Total number **publications in 2015 with RRes authors**

621 **Total number of RRes staff, students and visiting workers** in 2015

84 **New Research projects***

*January 2015–March 2016

15 **Papers published in 2015 with an impact factor > 9**

140 Total number of **international people** joining RRes in 2015

37 Nationalities

- American
- Australian
- Barbadian
- Belgian
- Brazilian
- British
- Bulgarian
- Canadian
- Chinese
- Cuban
- Cypriot
- Czech
- Dutch
- French
- German
- Ghanaian
- Greek
- Hungarian
- Indian
- Irish
- Italian
- Malaysian
- Mexican
- Nigerian
- Pakistani
- Polish
- Portuguese
- Romanian
- Russian
- Slovakian
- South African
- Spanish
- Swedish
- Swiss
- Ugandan
- Venezuelan
- Zimbabwean

69 **Total number of students**‡

13 PhD students **successfully graduating in 2015**‡

22 PhD students **starting in 2015**‡

‡Based mainly at RRes with a few in collaborating universities

Grant funding for Rothamsted Research from 2015/2016 accounts†

	£ in millions
BBSRC – ISPG	13.47
BBSRC – Competitive	4.75
DEFRA	1.13
Industrial	3.39
Trusts, Foundations and Charities	0.78
European Union	0.53
Research Councils	1.56
Other Grants	1.31
Total	**26.92**

†unaudited figures

Celebrating our People

Rothamsted Research (RRes) is proud of its staff, students and visiting workers, and their achievements in the pursuit of science. It aims to provide the modern working environment necessary to allow them to succeed. In 2015 celebrations particularly focused on the significant contributions of women in science.

A number of scientists were recognized for personal and team achievements in 2015/ 2016. Prof. Michael Lee was presented with the British Society of Animal Science (BSAS) Sir John Hammond Award at the society's annual conference at the University of Chester in April 2015. This is a prestigious award and Prof. Lee received it for his world-renowned work on sustainable livestock production. Dr Bartek Troczka won the ACS-AGRO New Investigator Award at the American Chemical Society meeting in the US in August 2015. Bartek was a PhD student at Rothamsted studying insecticide resistance, and we are delighted that he is continuing with us as a post-doctoral researcher. Furthermore, Dr Margaret Glendining and Prof. Steve McGrath were given a prize by the Computer Graphic Institute for their contribution to the development of a soils website providing a portal to the soil database and observatory.

Athena SWAN is committed to the advancement of gender equality in academia and, in recognition of its working practices, RRes was awarded an Athena SWAN Bronze award. Since then RRes has established an Athena SWAN committee made up of employees from across the organization, to take forward the Athena SWAN principles, embed them into working practices and ensure continuous improvement for all. In March 2016 the committee marked International Women's Day with an event to celebrate the achievements of women in science and create a forum to discuss current challenges and how to address them constructively. Four women with successful careers in science shared their journeys with RRes staff which stimulated lively discussion about today's opportunities for women in science. The day concluded by celebrating the lives of three pioneering female scientists from the early days at Rothamsted, Dr Winifred Elsie Brenchley, Dr Mary Dilys Glynne and Dr Katherine Warington, and honouring their achievements by naming three of the new conference rooms after them.

Dr Winifred Elsie Brenchley 1883–1953

An agricultural botanist and leading authority on weeds. She was the first female scientist to break into the male-dominated field of agricultural science. Her insights into the effect of fertilizer on plant diversity in grassland are still relevant today and the quality of her work ultimately ensured she became Head of the Botany Department at Rothamsted.

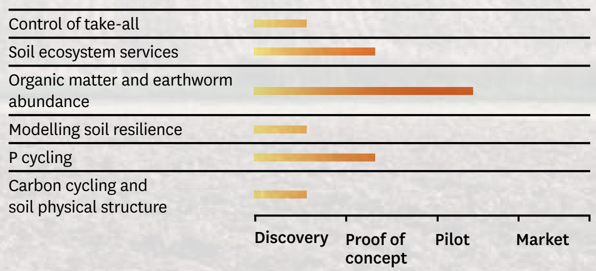
Dr Mary Dilys Glynne 1895–1991

A pioneering plant pathologist who developed methods that are still in use today for the identification of potato cultivars with resistance to disease. Her work on crop diseases made a significant contribution to improving crop yields during World War II when food shortages were severe.

Dr Katherine Warington 1897–1993

The first person to show that boron, as boric acid, is essential to the healthy growth of plants. Her work gained her world-wide recognition and she was respected by all who met her professionally.

SOIL IS LIFE: DIGGING DEEP IN 2015



Research Highlight #1

Healthy soil sustains life but it is a finite resource requiring careful protection. Sustainable soil management is crucial if the world is to be fed, and scientists at Rothamsted Research (RRes) are at the forefront of the research delivering this.

Soil is a miraculous mixture of minerals, organic matter, water, invertebrates and microbes. It supports 95% of all food production across our planet and is truly the foundation of all life. Despite being a finite and precious resource soil is being rapidly degraded by deforestation, erosion, salinization, urbanization, climate change and agriculture. Headline-grabbing predictions that suggest we may have as little as 60 years of growing time left are an exaggeration, but it is certainly true that protecting and maintaining healthy soil is a critical issue for all of us, and something that requires global action. In 2015 RRes scientists provided Parliament with written evidence for the House of Commons Enquiry into the Health of UK Soils and a Parliamentary Briefing document. These clearly defined the current perilous state that our soils are in, and RRes's commitment to sustainable soil management (1,2). Agricultural practices can negatively impact on soil health, but it's not as simple as that because the system is complex and full of contradictions. For example, at RRes there is a classical experiment on Broadbalk field that has been growing wheat continuously using conventional practices (including chemical fertilizers and pesticides) for 172 years. Despite this, yields have increased, achieving a record 13.5 tonnes per hectare in 2015, a seemingly impossible feat if the soil was being continuously degraded. What is obvious is that there is a clear yield gap between the average of 8 tonnes per hectare achieved on the majority of cropped land, and the exceptional yields that are achieved in some circumstances. It is likely that this yield gap is down to soil health and could be closed if the soil was managed more effectively. As any gardener will tell you, without healthy soil harvests are meagre. The challenge is in how to achieve healthy soils sustainably. If our accelerating global population is to be fed, particularly under the continued challenge of climate change, then it is essential that we understand how different management practices affect the complex physical and biological attributes of soil and use this knowledge to deliver sustainable agricultural intensification and long-lasting food security without destroying our soil. This is a global priority and RRes is leading from the front.

In clear recognition of the very real risks posed by soil degradation and the vital role that soils play in securing global food security and ecosystem function, the United Nations General Assembly declared 2015 as the 'International Year of Soils' (IYS). Soil scientists at RRes

In conversation with **Dr Jacqueline Stroud**

As a soil chemist on her first foray into biology Jacqueline explains why earthworms are so fascinating: *"Earthworms improve soil structure and water infiltration which, in turn, increases water and nutrient availability for plants. Their numbers have declined drastically in agricultural soils and we need to find management options to reverse this. I have been looking at how the addition of different types of organic matter influence earthworm numbers. Using farmyard manure increased populations of deep-burrowing earthworms* (Lumbricus terrestris) *by 38% compared with using compost which, incidentally, was no better for these earthworms than adding no organic matter at all* (3). *While farmyard manure may not be an option for all farmers, it does show what a huge difference the right type of organic matter can make to earthworms – and that's important. I'm really excited because, on the back of these studies, we have been awarded a 3-year national Soil Security NERC Fellowship to evaluate different tillage practices as feasible alternatives to organic matter amendments for boosting earthworm populations. I'm delighted as this will allow me to continue with research that helps farmers get the most from 'worm power'."*

celebrated IYS in style by organizing a number of events to showcase their long and prestigious history of innovative research, and their aspirations for the future. These included three well-attended Open Meetings where RRes scientists presented and discussed the 'big issues' in soil science with their counterparts from universities. These meetings drew the general public into lively debates about soils and climate change, soil fertility and degradation, and soil biodiversity and function. Other celebrations included an event for local schools that encouraged children to become 'Fascinated by Plants' and a public Research Exhibition Day. Visitors were treated to exhibitions and demonstrations on all aspects of soil science from the 'eye in the sky' drones being used to reveal patterns of organic carbon in farmland, to microbial communities in the soil – there are 1,000,000,000 individual microorganisms representing 10,000 species in every gram of soil – how amazing is that!

Numerous high-quality papers were published by RRes soil scientists in 2015, and indeed, Prof. Steve McGrath was again listed in the Thomson Reuters list of Highly Cited Scientists in the Agricultural Sciences; this includes only the top 1% of scientists from around the world and so is a very significant accolade. A good example of the research published in 2015 is a fascinating paper by Dr Tim Mauchline and collaborators on the complex and long-lasting relationships between wheat varieties and microbial communities in the soil (5). They were particularly interested in populations of the soil-dwelling bacterium *Pseudomonas fluorescens* which has potential as a biological control agent of the widespread soil-borne fungal disease of wheat, take-all (*Gaeumannomyces graminis* var. *tritici*). There is known to be great genetic diversity within the *P. fluorescens* species group, with the core genome representing as little as 45% of any individual isolate's

In conversation with **Dr Steve Granger**

Phosphorous (P) is an important plant nutrient in the soil – but it can prove to be a double-edged sword – here Steve, who is a soil chemist, tells us why: *"Insufficient P can retard plant growth and so farmers apply extra to ensure good yields. However, this incurs an economic cost and also an environmental cost when the excess is leached into waterways. If we understand how P is cycled in the soil, where it can either become bound or made available to plants, then we could increase the efficiency of its uptake by plants and reduce the quantity that farmers need to add. Recently a new non-invasive method has been developed, based on the ratios of stable isotopes of oxygen in phosphate, that can be used as a proxy to trace the origin and fate of P is soil/ plant systems. We have just secured a prestigious Rothamsted Fellowship to use this method to answer some of the many questions surrounding P cycling in the soil. We are just at the beginning but really excited to get started."*

In conversation with **Dr Andy Gregory**

For Andy research has focused on the relationships between carbon cycling and soil physical structure and he has worked in a variety of different systems. Here he talks about some of his most recent studies: *"Soil is comprised of different sized mineral particles between which are spaces where water and gas can be found. The quantity of carbon in the soil is important as it's the carbon that predominantly causes particles to aggregate together, providing the structure, drainage and aeration properties that plants need to grow. Cultivation can reduce the amount of carbon in the soil and so degrade its structure. Most recently I have been working with colleagues, both at Rothamsted and North Wyke, to evaluate carbon sequestration beneath bioenergy crops and grassland perennials. This is particularly interesting for* Miscanthus, *or elephant grass, because it is a C4 plant and leaves a different carbon trace in the soil than the previous C3 crops, making the carbon sequestered easier to trace. We have had some challenges because we need to take soil cores to a depth of a metre – quite a job – but the results are worth it. In the future I hope to evaluate the effects of other agricultural systems on soil structure and am particularly looking forward to the insights I can glean from using acoustics, magnetic mapping and electrical resistance methods to investigate soil structure."*

> *“We knew that plants and microbes in the soil interact in a multitude of ways but we didn’t realise just what an impact growing different varieties of the same crop could have on the communities of microbes living in soil.”*
>
> **Dr Jake Malone, John Innes Centre**

genome. Some genotypes may be involved in control of the take-all fungus while others may have very different attributes all together. By identifying the relationships between the abundance and distribution of genetically distinct populations of *P. fluorescens* and different wheat genotypes over two years Dr Mauchline and his team were able to gain insights into the factors that most influenced *P. fluorescens*. They found that the genotype of the wheat planted in the first year profoundly affected the overall abundance of *P. fluorescens* and the distribution of individual genotypes in the soil in the following year. In particular, when a wheat genotype supporting high levels of take-all disease was planted in the first year there was an increase in the overall abundance of *P. fluorescens* in the second year, and selection for genotypes that were aggressive against other soil bacteria. While we do not understand, as yet, the implications of these findings for take-all infection in the second year crop, the results do support the opinion that manipulation of plant-cropping systems, rather than soil inoculation with individual *P. fluorescens* isolates, may hold the key to sustainable biological control of take-all.

In 2015, Prof. Penny Hirsch’s research group, in collaboration with other leading research institutions, was awarded £1.6 million for research into soil security. The ecosystem services provided by soils are to be compared in different ecosystems, ranging from intensive agriculture through to extensive, semi-natural systems. The relative resilience of these soils to environmental pressures, such as climate change and human activity, will be elucidated alongside studies to determine how soil management might improve service provision and identify where trade-offs might occur, for example between improved soil fertility and decreased water quality. This project sits well within RRes’s soil science programme and will make a significant contribution to unravelling the complexities of soil health and sustainable food production.

Soil science research at RRes has always used excellent science to solve practical problems for farmers and 2015 was no exception. However, 2015 was also a special year as RRes fully supported the IYS in a bid to raise awareness of the global plight of soils. By the end of the year the International Union of Soil Sciences announced the Decade of Soil to maintain the level of activity and increase momentum – but as Prof. Steve McGrath said when he made a call-to-action at the FAO in Rome “soils are not just for a year, or even ten years, – but forever” – and we would all do well to remember this.

Further Reading

1. Written Evidence for the House of Commons Enquiry into the Health of UK Soils (2015): http://data.parliament.uk/writtenevidence/committeeevidence.svc/evidencedocument/environmental-audit-committee/soil-health/written/26773.pdf
2. Parliamentary Briefing, POSTNOTE No 502: Securing UK Soil Health (2015): http://researchbriefings.parliament.uk/ResearchBriefing/Summary/POST-PN-0502
3. Stroud *et al.*, (2016) Applied Soil Ecology 98:282-284
4. Todman *et al.*, (2016) Science Reports. In press
5. Mauchline *et al.*, (2015) Environmental Microbiology 17:4764-4778

Below:
Soil is Life! Open Day 2015 PhD students presented flash talks

In conversation with **Dr Lindsay Todman:**

Lindsay is a mathematical modeler who is joining forces with microbiologists to quantify resilience in agricultural soils – here she explains why and how: *“Climate change and land management practices cause frequent and severe disturbances to soils that influence their properties and functions. While the concept of soil resilience in response to disturbance is readily understood, it is notoriously difficult to quantify because there are so many interacting factors to consider. This is why a modelling approach is appropriate. To date we have used laboratory studies on the functional response (respiration/ carbon cycling) of soil microbial communities during the challenge of repeated drying and wetting cycles, to develop a model with metrics that define resilience mathematically – this is a big step forward (4). Our goal now is to use the metrics developed to see which soil properties and management practices lead to resilient responses. We are currently measuring microbial respiration in soil collected from 68 sites across England and Wales that vary in soil type and land use practices – although we are only just beginning we aim to be able to identify which soil types/ management combinations are more/ less resilient with respect to carbon cycling by the end of the project. This could help us anticipate the effects of future climate change and target management to mitigate for it, particularly in the least resilient soil types – this would really benefit farmers and I am excited to be a part of it.”*

Research Highlight #2

CLEANER AIR BENEFITS PLANT DIVERSITY

Unique new insights from the Park Grass Experiment demonstrate that negative effects of air pollution are not irreversible; since air quality began improving in the 1990s plant diversity in grassland has been bouncing back.

Plants need nitrogen to grow, indeed we use it as a fertilizer in our gardens and on agricultural crops to encourage vigorous growth. However, in natural ecosystems and managed pastures, meadows and grasslands with diverse communities of plant species, too much nitrogen is a bad thing. Nitrogen encourages competitive species to grow tall, so shading out smaller, less competitive species, which reduces plant diversity.

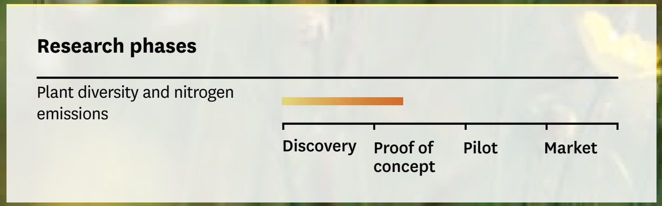
So where does this nitrogen come from if it is not being added as fertilizer? The answer is air pollution. Burning fossil fuels releases nitrogen into the atmosphere from where it is subsequently returned to the soil through deposition, mainly in rainfall. As nitrogen emissions have increased, so plant species diversity in UK grasslands has declined steadily, providing incontrovertible evidence for a negative relationship between the two. The 1990s saw the advent of new technologies, such as catalytic converters, that have successfully reduced nitrogen emissions – but has plant diversity responded to this breath of fresh air?

Answering this question requires careful analysis of species richness data from plant communities monitored during this period of changing air quality – the Park Grass Experiment at Rothamsted Research (RRes) is a unique source of such data. This experiment began in 1856 and is one of the long-running 'Classical Experiments' that are a prized National Capability at RRes. Its original purpose was to evaluate the effects of different fertilizers, including nitrogen, on yield and plant diversity in pastureland. Throughout the lifetime of this experiment the 'control' plots never received any fertilizer, thereby reflecting only the influence of nitrogen deposited from the atmosphere. Using archived data and samples Dr Jonathan Storkey and collaborators compared historical and modern records of plant diversity in these control plots (1). As expected, dramatic declines in plant diversity were observed between the 1940s and 1980s when air pollution was increasing. However, since the 1990s nitrogen deposition at Park Grass declined by 70% while plant diversity consistently increased. Species in the clover family, which are particularly sensitive to nitrogen, benefitted the most. Similarly, in treatment plots where applications of nitrogen fertilizer ceased in 1989, plant diversity subsequently increased to the same level as the plots that had never received any nitrogen fertilizer. Park Grass is a 'living barometer' of the impact of a changing environment on biological systems and this study makes a valuable contribution to understanding the implications of policy and management changes on the wider environment

Further Reading
1. Storkey *et al.*, (2015). Nature 528: doi:10.1038/nature16444

"It is really important to address effects on biodiversity by monitoring long-term community dynamics on permanent plots of grassland."

Dr Jonathan Storkey, Rothamsted Research



Research Highlight #3

HEALTHY CROPS — HEALTHY FOOD

"Annually 15% of global crop yields are lost due to disease problems. Combining the gold standard PHI-base and PhytoPath resources with whole genome in planta transcriptomics analyses, helps us define the 'genomic blueprint' of a crop pathogen. Armed with this knowledge we can discover the Achilles' heel of a pathogen and develop novel suites of practical control options."

Prof. Kim Hammond-Kosack, Rothamsted Research

Critical breakthroughs have been made in the fight against crop diseases. 2015 was an exceptional year with landmark papers published and new projects beginning.

Crops such as cereals are susceptible to a multitude of diseases, some of the most devastating being caused by microscopic fungi. Many are resistant to fungicides and infected plants are symptomless until invasion has progressed so far that control options are ineffective. Fungi and their hosts are locked in a battle the outcome of which is strongly influenced by their genetic attributes. Understanding the interplay between host and pathogen gene expression and gene function provides an unparalleled insight into how infection occurs and thus how it might be disrupted.

Experimental data that link pathogen and host genes with their function are collated within the Pathogen-Host Interactions database (PHI-base), a continuously-updated open-access internet resource (1). PHI-base is one of Rothamsted Research's (RRes) National Capabilities and celebrated its 10th anniversary in 2015. The great value of PHI-base comes from the numerous collaborations and scientific advances that it facilitates. For RRes scientists 2015 was an exceptional year in this respect beginning with a timely and scene-setting review of gene-function studies in *Fusarium* ear blight by Dr Helen Brewer and Prof. Kim Hammond-Kosack (2).

Septoria leaf blotch is a fungal disease of wheat caused by *Zymoseptoria tritici*. It causes premature leaf death, thus reducing photosynthetic capacity and yield; over a 1/3 of the crop can be lost. In a groundbreaking study by Dr Jason Rudd and collaborators, RNA sequencing and metabolomics were used to simultaneously link 300 metabolites with the activity of 3,000 fungal genes and 7,000 wheat genes during fungal invasion and reproduction (3). This revealed that the fungus hijacks the plant's defences for its own benefit. Early on in infection plant defences were suppressed by the fungus, allowing it to spread unhindered, albeit slowly, between leaf cells (the long asymptomatic growth phase). However, once established throughout the leaf, it switched to stimulating the plant into premature cellular suicide. It may seem counterintuitive for the fungus to cause the death of its host at this critical stage, but the associated sudden release of nutrients is perfect for fungal reproduction resulting in millions of infective spores. In this particular battle the fungus has the upper hand – but understanding the mechanism opens it up to manipulation. For example, a follow-up study showed that one particular wheat protein (TaR1) was key to fungal suppression of plant defences during early infection (4). Manipulating TaR1 levels allowed the plant to activate its defences earlier, and limit fungal spread.

While understanding the unique relationships between gene function and disease progression at the cellular level is essential, interactions that occur at the scale of whole organisms must not be forgotten. A fascinating study by Prof. Toby Bruce and collaborators found that the presence of aphids on wheat increased the negative impact of co-occurring *Fusarium* ear blight disease, which developed twice as fast on aphid-infested plants! In contrast, the aphids did worse on *Fusarium*-infected plants than on uninfected plants (5). This has important consequences for disease management as the 'perfect storm' created by dual attack by *Fusarium* and aphids puts crops at greater risk than would have been predicted previously.

Another high note of 2015 was the start of a cluster of new research projects led by Prof. Jon West: Arable Alert, Blight Alert and SporeID. These projects will develop automated air samplers and DNA-based techniques to improve disease control and provide information on site-specific and regional disease risk for a range of different crops. These valuable risk-assessment tools will play a key role in integrated disease management.

Further Reading

1. Urban *et al.*, (2015) Nucleic Acids Research 43: 645-655
2. Brewer and Hammond-Kosack (2015) Trends in Plant Science 20: 651-663
3. Rudd *et al.*, (2015) Plant Physiology 167: 1158-1185
4. Lee *et al.*, (2015) New Phytologist 206: 598-605
5. Drakulic *et al.*, (2015) Applied and Environmental Microbiology 81: 3492-3501

Research phases

	Discovery	Proof of concept	Pilot	Market
Effects of slurry separation	■	■		
Rates of nitrous oxide release	■			

"Nitrous oxide is 180 times more powerful as a greenhouse gas than carbon dioxide (CO_2) and urine patches are recognised as 'hot-spots' for nitrous oxide production and emission in grazed pastures."

Prof. Dave Chadwick, 'Upland N_2O' Project Lead, Bangor University

Research Highlight #4

DEALING WITH LIVESTOCK WASTE — NOT TO BE SNIFFED AT

'Muck' is an inevitable byproduct of livestock production. While it can be a valuable resource it also releases highly damaging greenhouse gases – but researchers at Rothamsted Research (RRes) are well on the way to identifying mitigation strategies.

Slurry is a mixture of excreta from livestock, rain water, wash water and sometimes animal bedding and food. It can be spread on arable crops and grassland as a free fertilizer and is increasingly being used as a substrate for the production of biogas using anaerobic microbial digestion. However, slurry needs to be stored until the time is right for muck spreading – and it is during storage that damaging greenhouse gases (GHG) are released and nutrients, such as deposited ammonia (NH_3), can leach into surface water causing eutrophication. If we consider just one GHG, nitrous oxide (N_2O), 30-40% of global emissions can be attributed to livestock production and, although nitrous oxide is known as laughing gas, this really is no joke.

For practical reasons the residual digested slurry following biogas production is often separated into liquid and solid fractions that may well differ in the quantity of GHGs they release during storage. In an elegant study published in 2015, Dr Tom Misselbrook and collaborators demonstrated that the mechanically separated fractions of pig slurry increased nitrogen losses (as ammonia) by 35% compared with unseparated slurry and that this increased to 86% for separated cattle slurry (1). Liquid fractions released far more ammonia than solid fractions, accounting for 75% or more of total emissions. Furthermore, disturbance of the slurry by mixing also increased ammonia emissions. These results clearly indicate that storage, particularly of liquid fractions, should be effectively contained. It is also possible that lowering the pH of the liquid fraction could reduce ammonia emissions. Disturbance by crust destruction and emptying or filling should also be restricted to the time immediately prior to spreading.

A large collaborative project, called 'Upland N_2O', was launched in 2015 to understand whether upland sheep grazing, which occurs on 30% of the UK's agricultural land (5.5 million hectares), differs in its nitrous oxide emissions compared with lowland sheep grazing. The researchers hypothesise that rates of nitrous oxide release from urine patches left by grazing sheep will be influenced by soil properties (e.g. pore size), urine composition (related to the herbage consumed), and climate. Dr Laura Cardenas, who is leading research on this project being done at North Wyke, will be using a specialised incubation system to determine the relative importance of each of these factors on nitrous oxide emissions under controlled conditions. This is essential to better estimate the GHG budget of upland and lowland pasture and identify mechanisms for its mitigation.

Further Reading

1. Perazzolo *et al.*, (2015) Agriculture, Ecosystems & Environment 207: 1-9

Research Highlight #5

GM APHID-REPELLENT WHEAT: THE IMPORTANCE OF FIELD EVALUATION

Research phases

GM aphid-repellent wheat

Discovery | Proof of concept | Pilot | Market

The GM wheat field trial was a triumph for objective scientific enquiry, a significant advance in the development of sustainable alternative pest management tools and a concrete example of the value of openly communicating scientific research.

Our arsenal of pest control options is dwindling. Insecticides kill pests but they also kill beneficial natural enemies (e.g. predators) and resistance in pests continues to evolve. There is an urgent need for safe, sustainable alternatives that can be used within integrated, or 'Smart', crop protection strategies. Options include the development of resistant crop cultivars that are compatible with natural enemies. While this may be achieved traditionally through plant breeding, genetic modification is also a powerful tool that can rapidly introduce traits, such as resistance to pests, into existing high-yielding varieties.

Wheat is the most important UK crop worth £1.2 billion per annum, and yields are threatened by aphids. At Rothamsted Research (RRes) GM wheat producing aphid alarm pheromone is under development as an ecological approach to aphid control – so how does it work? When under attack by natural enemies, aphids release an alarm pheromone that communicates to the rest of the aphid population that they are in danger and should take evasive action, such as leaving the plant. Prof. John Pickett and colleagues hypothesized that, if wheat could be engineered to release this pheromone, then it would become repellent to aphids and avoid becoming infested. Over a number of years GM wheat plants were successfully developed at RRes by Prof. Huw Jones and colleagues and, in a series of laboratory experiments, their repellency to aphids was confirmed.

When laboratory results are promising the next stage in any project is to take experimentation to the field scale for 'real-life' evaluation. RRes is famous for well-designed field trials and testing a novel GM variety was no different in that respect. As with all releases of GM organisms, this field trial was thoroughly risk assessed to ensure that any potential environmental risks were identified and minimized. Furthermore, the open two-way dialogue with all stakeholders and interested members of society further ensured that any concerns about GM crops were heard and addressed. The experiment concluded successfully despite threats of crop destruction made by anti-GM activists in the first year of the experiment. This was prevented by extensive dialogue and engagement, allowing all the control and experimental plots to be monitored and the data analysed appropriately. The results did not support the scientists' working hypothesis – there was no significant difference in aphid infestation on the GM wheat compared with the non-GM wheat (1). The researchers, although disappointed that the field experiment did not demonstrate aphid repellency, communicated their findings openly and widely because every experiment provides insight into how best to move forward. In this case the data provided a very strong guide for future research. It is possible that the aphids became habituated to the pheromone, as you would to a car alarm that continuously goes off. This could be remedied if plants released the pheromone in bursts, as aphids do, rather than continuously. Prof. Toby Bruce is confident that the GM wheat team can address this new challenge by continuing to pursue hypothesis-driven, objective scientific research – the only way to provide sustainable solutions to feed our ever-growing global population.

Further Reading

1. Bruce *et al.*, (2015) Scientific Reports 5.111813

2012–2015 Communications and Engagement Timeline

March 2012

A group called 'Take the Flour Back' (TTFB) formed and threatened to destroy the proposed experiment: Rothamsted Research publically invited the concerned group to dialogue.

April 2012

RRes scientists released a video called 'Don't Destroy our Research' because TTFB did not engage in dialogue.

May 2012

Protesters gathered at Rothamsted Research park threatening to destroy the experiment. Police stopped the protesters from entering the trial.

May 2012

An intruder was arrested on the experimental trial site.

May 2012

A petition co-ordinated by 'Sense About Science' that asked people to demonstrate their support for scientific research was signed by more than 4000 people.

Summer 2012 & 2013

RRes scientists hosted several hundred visitors to the experimental trial site and engaged in extensive dialogue and communication about their research.

June 2015

The results of the GM field trial were published with open access and widely communicated.

Research phases

	Discovery	Proof of concept	Pilot	Market
Gelatinous fibres	■			
Perennial biomass crops and biodiversity	■			
Micro-propagation of willow	■			

Research Highlight #6

WILLOWS: FROM STRENGTH TO STRENGTH

Research on willows as biofuel has moved rapidly from fundamental studies to commercial exploitation but 2015 was particularly memorable for a plethora of key publications.

Willows (*Salix* spp.) are an amazing group of fast-growing trees that thrive in the most inhospitable of environments. They produce large quantities of various chemical compounds in the bark and wood, including complex sugars, making them ideal as a sustainable source of biofuel and a diversity of bio-based products. Strangely enough, willows grown under the harshest conditions often produce the most accessible sugars. For example, trees on slopes or in wind-exposed areas grow at an angle in order to survive, and produce five times more sugar than upright trees. Nobody understood why until Prof. Angela Karp with her research team and collaborators employed several novel approaches to determine what was happening at the cellular level. Using X-ray micro-computed tomography (CT scanning) they first discovered that the lifespan of particular cells in tilted trees was prolonged in order for them to have sufficient time to produce gelatinous fibres, or G-fibres, that form the tissue known as 'tension wood' (1). Tension wood gives the tree the strength and flexibility necessary to grow at an extreme angle. Dr Cristina Gritsch and collaborators then revealed that G-fibres were enriched with a complex carbohydrate (polysaccharide (1-4)-β-D-galactan) that readily broke down into simple sugars within the wood, accounting for why tilted trees have higher levels of accessible sugars than upright trees (2). Genes specifically activated during tension wood formation were also identified, providing further insight into what drives changes in sugar levels at the cellular level (2). The Rothamsted Research (RRes) willow-breeding programme can now exploit these findings to select the best genotypes for a variety of industrial uses.

There is always a fear that the uptake of new crops, such as perennial biomass crops, will have negative impacts on arable farmland biodiversity, but Dr Alison Haughton and collaborators found the exact opposite (3). Using the most comprehensive analysis of currently-available national-scale datasets on biodiversity indicators, they found that not only were plants and invertebrates more abundant in perennial biomass crops, but also that they supported more distinct trait-based communities than arable crops. Strategic planting of perennial biomass crops in arable farmland has real potential to increase landscape heterogeneity, enhance ecosystem function and resilience, and strike a balance between energy and food security (3).

Using conventional willow-breeding strategies, it can take many years for promising genotypes to be produced in sufficient quantities for field evaluation, and guaranteeing they are completely free from disease is impossible. To speed up the process Dr Palomo Rios and colleagues successfully used a micro-propagation method to multiply willows rapidly. Not only could field trials begin earlier, but the trees were also guaranteed to be disease-free because they all originated from sterilized bud tissue (4). For the first time this allows export to markets that are currently inaccessible due to phytosanitary restrictions – and indeed the micro-propagated trees were successfully evaluated in Canada (4).

Further Reading

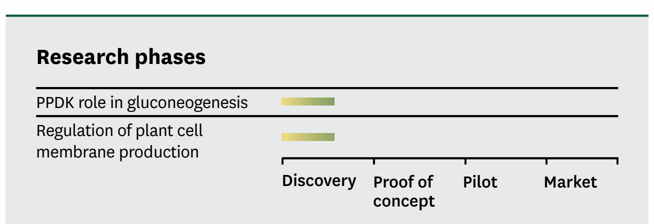
1. Beresford-Brereton *et al.*, (2015) BMC Plant Biology 15: 83-94.
2. Gritsch *et al.*, (2015) Journal of Experimental Botany 66: 6447-6459.
3. Haughton *et al.*, (2015) Global Change Biology Bioenergy doi: 10.1111/gcbb.12312.
4. Palomo Rios *et al.*, (2015). Canadian Journal of Forest Research 45: 1662-1667.

"When grown on land less suited to food crops, in integrated farming systems, perennial biomass crops like willow and miscanthus bring multiple environmental benefits that help offset some of the negative consequences of intensive food production. Multifunctional land use of this kind will be essential in meeting the diverse needs of the UK bioeconomy."

Prof. Angela Karp, Rothamsted Research

Research Highlight #7

UNRAVELLING THE MYSTERIES OF PLANT LIFE



"I have always felt that the transition from a seed to a seedling is astonishing. It's one of nature's little miracles and so crucial for agriculture. It requires water and sometimes a little light to trigger but after that it's all fuelled from the seed's internal reserves."

Dr Peter Eastmond, Rothamsted Research

We take for granted that seeds germinate and grow into plants that we can harvest and eat – but understanding how this little miracle happens will ultimately help us improve crop yields.

Seeds are packed with lipid and protein reserves but to unlock their potential and initiate germination and seedling establishment, these energy stores must be broken down into useable sugars – a process known as gluconeogenesis. In plants it has long been known that the enzyme phosphoenolpyruvate carboxykinase (PCK) plays a vital role in mobilizing these reserves. However, in a groundbreaking study using the model plant *Arabidopsis*, Dr Peter Eastmond and collaborators found that a second enzyme, pyruvate orthophosphate dikinase (PPDK), was also important (1). This was unexpected because a potential role for PPDK in gluconeogenesis had been dismissed 50 years ago. Furthermore, PPDK was only associated with specialized photosynthesis in C4 plants, so its role in gluconeogenesis in a C3 plant was a complete revelation. The two enzymes complement each other as PPDK is predominantly involved in the mobilization of proteins while PCK mobilizes lipids. The efficiency of reserve mobilization is directly related to seedling vigour, which itself is a key determinant of yield, so this new insight could ultimately help us develop more vigorous crops with higher yields.

Once any seedling has established it must respond to and grow in the environmental conditions in which it finds itself. How plants achieve this, however, was poorly understood until a second study by Dr Eastmond and his team, again working with *Arabidopsis*, provided further insights. They revealed that plant cells induce changes in the lipid composition of their membranes to control the rate at which they produce more cell membranes (2). This fundamental knowledge is crucial to unravelling how membrane production is regulated and coordinated with basic processes such as cell division and expansion, which underpin how a plant grows and adapts to its environment. Not only are these studies fascinating but they allow scientists to elucidate nature's miracles and use the information to advance sustainable crop production.

Further Reading

1. Eastmond *et al.*, (2015) Nature Communications doi: 10.1038/ncomms7659
2. Craddock *et al.*, (2015) The Plant Cell 27: 1251-1264

Research Highlight #8

THE FIELD 'SCANALYZER': A WORLD FIRST

Research phases

Evaluation of pre-breeding wheat varieties

Discovery | Proof of concept | Pilot | Market

> *"We are delighted to have this facility at Rothamsted. This will revolutionize the way that agricultural research is conducted."*
>
> Dr Malcolm Hawkesford, Rothamsted Research

The world's most sophisticated facility for the automated measurement of crop growth and health *in situ* in the field was launched at Rothamsted Research (RRes) in 2015, offering scientists an unparalleled opportunity to relate any plant genotype with its in-field phenotype.

Scientific endeavour has provided a wealth of information about the genetics of crop plants and the potential relationships between genes and function. However, relating the genotype of a particular plant to its resulting phenotype while it grows and matures under real-life field conditions, is quite a different challenge. The field 'scanalyzer' is a phenomenal piece of equipment that helps solve this problem. It is comprised of a large motorized measuring platform housing multiple high-tech sensors that can move effortlessly on a gantry just above the crop, continuously recording phenotypic data from each plant to a high degree of resolution and reproducibility. It has on-board illumination, is fully automated, works 24 hours a day throughout the season, and can cover a 10m x 110m area of crop – which is quite astounding. The hardware includes multi-wavelength sensors, an imaging sensor to measure chlorophyll fluorescence, and a laser system for 3D reconstruction and crop height determination. In this way plant physiology, architecture, health and function are all measured simultaneously and with great accuracy.

Unsurprisingly RRes scientists have been quick to put this new piece of kit to good use. It is already in operation to evaluate numerous pre-breeding wheat varieties that have been generated through the Wheat Genetic Improvement Network (WGIN) and Wheat Improvement Strategic Programme (WISP). The 'scanalyzer' could prove to be an invaluable tool for the evaluation of any new crop varieties under development for sustainable food production.

Engaging in Dialogue

Rothamsted Research (RRes) regularly organizes on-site events showcasing different aspects of ongoing research programmes. These events are carefully designed so that they are relevant to everyone who has an interest. RRes also participates in national events, with tailor-made exhibits, thereby having the opportunity to reach even broader and more diverse audiences.

Events for the General Public

February 24th 2015

International Year of Soils

Public Meeting on Soils and Climate Change.

May 6th 2015

International Year of Soils

Public Meeting on Soil Fertility.

May 17th 2015

Soil is Life Exhibition Day

RRes opens its doors to the public to discuss soil health and how to manage it.

May 18th 2015

Soil is Life Fascination of Plants Schools Day

Sixty children from local schools participated in an event highlighting the close relationships between plants and the soil.

June 30th – July 5th 2015

Royal Society Summer Science Exhibition

Scientists from North Wyke showcase their research in an exhibit entitled 'The Real Beef about Meat' and have the opportunity to engage with more than 15,000 members of the public and school students from all over the country.

July 29th 2015

Harpenden Spotlight on Africa (HSoA) Exhibition

RRes and HSoA join forces to highlight the value of research in improving the livelihood's of farmers in Africa.

December 6th 2015

Illuminating Life Prize giving

Winners of the first RRes Photo-Story competition receive their prizes.

July 16th 2015

International Year of Soils

Public Meeting on Soil Biodiversity.

November 25th 2015

Teatime Tales of Willow

The public hear about RRes research on willows and take a walk through the National Willows Collection to experience their diversity.

October 27 – 29th 2015

Illuminating Life Public Meeting and Exhibition

Advances in microscopy and the use of images to evaluate crop performance highlighted and launch of the children and young adults' Photo-Story competition.

March 15th 2016

Public Meeting on Pulse Production and Protection

Celebrating the International Year of Pulses raises awareness about the importance of pulses in sustainable food provision.

2016 INTERNATIONAL YEAR OF PULSES

Engaging in Dialogue

Two-way communication between scientists and stakeholders is a celebration of science and provides an essential positive feedback mechanism for developing good ideas and making the research relevant to its users; it informs the direction of innovative research and ensures that practical solutions are taken up by the farmers who need them.

Events for the Farming Industry

February 11th 2015:

Rothamsted Research Association (RRA) Meeting

Highlighting the latest information on forecasting and monitoring pests and diseases.

June 10 – 11th 2015

Cereals

RRes scientists engage with over 25,000 arable farmers about crop production and protection – from GM to field margins, blackgrass to leaf blotch, and take-all to using drones to sense crop health.

July 1st 2015

RRA Summer Meeting

Highlighting research on soils, blackgrass and sustainable systems.

July 2015

SARISA Newsletter Roots of Decline

Newsletter on soil health published and circulated to all members of RRA.

September 2015

Pollinator Survey

Farmers involved in a survey of pollinators on their farms.

July 16th 2015

Beneath Our Feet

Open day at North Wyke where visitors were invited to explore the Farm Platform and get to grips with sustainable grassland management.

December 2nd 2015

RRA Winter Meeting

Highlighting the latest information on pesticide resistance.

March 3rd 2016

RRA Spring Meeting

Highlighting the latest research on soils and their management.

The North Wyke Farm Platform A National Capability

Sustainable intensification of livestock production is a global challenge requiring solutions relevant to real-world farming. The North Wyke Farm Platform is a national and global research asset that makes a major contribution towards achieving this.

The world needs innovative solutions for the sustainable intensification of its major agricultural systems and the North Wyke Farm Platform, which is a Rothamsted Research (RRes) National Capability, provides the means to achieve this for lowland-grazing livestock systems. The Farm Platform is a world-class BBSRC-funded facility and a key member of the Global Farm Platform which attracts international researchers from different communities and disciplines who are all seeking to develop solutions for sustainable ruminant production.

The Farm Platform is comprised of three small farms ('farmlets'), each covering an area of 21 ha and containing five hydrologically-isolated catchments. Each 'farmlet' is managed using a different approach to grassland livestock production (mixed beef cattle and sheep), specifically:

- Permanent pasture: improved using inorganic fertilizers.
- Legume-rich pasture: replacing inorganic nitrogen fertilizers with biological fixation using sown legume and grass mixtures.
- Planned grass renewal: providing opportunities for introducing innovative varieties with desirable traits. Currently, high-sugar grasses and deep-rooting grasses are being studied.

In each catchment water, air and soil measurements are recorded regularly using a range of *in situ* state-of-the-art instrumentation. This combined with assessment of animal performance, health and welfare, product quality, and economics ensures that each system is assessed with respect to the key environmental, societal and economic indicators of sustainability. All these data are made publicly available and delivered within a data portal dashboard on-line.

Current areas of particular interest include: the replacement of nitrogen fertilizer with nitrogen fixation by legumes; using plants to manage soils and provide green-engineering solutions to flooding; efficient nutrient cycling in grassland; resilience of soil biota and their function under land-use change; C cycling, storage and sequestration; water resource use efficiency; systems modelling to design optimal grassland production systems; and life-cycle assessment of pasture-based livestock.

In February 2016, RRes North Wyke was delighted to host the first meeting of the North Wyke and Duchy College Research Advisory Group. This new grouping, established in conjunction with the Duchy College's Rural Business School, includes key farming representatives who will provide an industry perspective and specialist advice on the research being undertaken at RRes North Wyke and Duchy College Future Farm. New projects and partnerships continue to be developed ensuring that the opportunities provided by the Farm Platform are fully exploited.

RRes Scientists:

Martin Blackwell, Laura Cardenas, Adrian Collins, Jennifer Dungait, Hannah Fleming, Bruce Griffith, Paul Harris, Jane Hawkins, John Hunt, Michael Lee, Tom Misselbrook, Phil Murray, Robert Orr, Chris Rawlings, Andy Retter, Anita Shepherd, Hadewij Sint, Taro Takahashi, Simon White, Lianhai Wu

Building Global Collaborations

Effective collaborations bring together teams with complementary skills that accelerate research progress and knowledge transfer. In 2015 Rothamsted Research (RRes) established and consolidated numerous partnerships and research activities globally – here are the highlights.

RRes is proud of its numerous collaborative partnerships, both in the UK and across the globe. To date RRes has formal collaborations with more than 50 countries. However, in 2015 the number of new or strengthened collaborations exceeded expectations. For example, in a strategic alliance with LEAF (Linking Environment and Farming), the leading organisation promoting sustainable agriculture, RRes's North Wyke site became LEAF's eighth 'Innovation Centre'. These centres form a network that supports the development and promotion of integrated farm management. RRes also established a formal link with Alltech Crop Science to support PhD studentships and facilitate industry-relevant research in sustainable arable and livestock systems. These alliances will help target research and promote uptake by farmers.

RRes's International Programme, coordinated by Dr Simon Vaughan, is instrumental in forging global collaborations. In Brazil BBSRC-Newton funding was secured for the Alliance for Sustainable Agriculture (ASA), which is a coordination platform for collaboration with the Brazilian Agricultural Research Corporation (Embrapa). Activity began in 2015 with an ASA workshop on grassland-livestock systems in Brasilia, and joint bids to the BBSRC-Embrapa call for projects on wheat; five teams of Rothamsted and Embrapa staff succeeded in winning funds. Notably RRes also became involved in the BBSRC-Newton-funded Virtual Joint Centre (NUCLEUS) to deliver enhanced nitrogen use efficiency via integrated soil-plant systems approaches in the UK and Brazil.

In China BBSRC-Newton funding was also secured for the Centre for Sustainable Intensification of Agriculture (CSIA) which, like ASA, functions as a coordination platform, this time for collaboration with China. CSIA is led by RRes and the Chinese Academy of Agricultural Sciences (CAAS) and was signed into effect in 2015. There are four agreed areas for joint research: crop efficiency; soil management; next-generation integrated pest, disease and weed management; and agricultural innovation, practice and policy. Other academic partners are also involved, including the China Agriculture University (CAU), Nanjing Agriculture University (NAU) and North West Agriculture and Forestry University (NWAFU). Several initiatives were launched including three NERC-Newton Critical Zone Observatory projects examining soil and water processes in the Loess and Karst regions in China; a UK Science and Technology Facilities Council (STFC)-Newton project on Agri-Tech in China; a Newton Network+ project on remote and smart sensing for agriculture; and development of the BBSRC-Newton-funded Centre for Improved Nitrogen Agronomy (CINAg).

In 2015 RRes entered into a new cooperation agreement with a long-standing strategic partner in Kenya, the International Centre for Insect Physiology and Ecology (*icipe*). Future research priorities were identified at a workshop in Nairobi: next-generation chemical ecology for integrated pest management; comparative vector biology for plant, animal and human health; bee health; and soil systems research. Common ground for future collaboration was also identified with Biosciences eastern and central Africa (BecA): molecular host-*Striga* interactions; nutritional analysis and improvement in African crops; aflatoxin contamination issues in cereals; linking RRes phenotyping expertise with BecA's integrated genotyping services; and applied bioinformatics/ statistics. Capacity building through contributions to the Africa Biosciences Challenge fund (ABCF) training programme were also envisaged.

2015 also saw RRes involved in a BBSRC-funded workshop with the Instituto National de Investigación Agropecuraria (INIA) in Uruguay to establish partnerships in the area of grassland-livestock systems, long-term experimentation, chemical ecology, and soil genomics. BBSRC-CGIAR post-doctoral twinning awards were also secured to partner with the International Centre for Tropical Agriculture (CIAT) in Colombia on global sustainability in livestock systems and managing environmental impacts, and with the International Rice Research Institute (IRRI) in the Philippines on integrated control of bacterial blight in rice. Rothamsted International fellowship awards were granted to researchers from Nigeria and India working in chemical ecology and soil science.

RoCRE

Following a major building programme during 2014, the Rothamsted Centre for Research and Enterprise (RoCRE) hosted its first major conference in April 2015, officially opened the Lawes Open Innovation Hub in July 2015 and welcomed its first tenants into the hub in October 2015. By the end of 2015 RoCRE was host to seven companies on the Harpenden site including Agrimetrics – the first new Centre for Agricultural Innovation and, along with hosting a variety of international conferences, RoCRE has been busy ever since.

RoCRE is a globally recognised, self-sustaining nexus for science and development that extends over three buildings. Its key objective is to improve collaborative relationships between client companies and Rothamsted Research (RRes) scientists. With this goal in mind, RoCRE hosted a number of international agri- and environment-related conferences in its newly extended facilities during 2015. It was also instrumental in leveraging public funds for collaborative research, agri-business incubation, and to accelerate the transfer of innovation from the laboratory to the field.

In fact, 2015 proved to be an extremely successful year in this respect: George Eustice MP, Minister of State for Farming, Food and the Marine Environment, and George Freeman MP, Parliamentary Under Secretary of State for Life Sciences officially launched Agrimetrics, the world's first Big Data Centre of Excellence focused on the whole food system. The headquarters for Agrimetrics are at RoCRE and it is one of just four Centres for Agricultural Innovation created by the UK government through Innovate UK and under the UK Strategy for Agricultural Technologies. Besides Agrimetrics, RRes is involved in a further two of these new Centres, namely the Centre for Crop Health and Protection (CHAP) and the Centre for Innovative Excellence in Livestock (CIEL). This is an extremely auspicious start and will create the foundation and capacity to translate agricultural innovation into commercial opportunities for UK businesses.

RoCRE staff:
CEO: Chris Dunkley,
Asmaa Shariff.

Agrimetrics staff:
CEO: David Flanders.

Partners and Funders for RoCRE:
Rothamsted Research,
LAT,
BBSRC,
LEP

Agrimetrics:
BIS via Innovate UK,
SRUC,
NIAB,
Reading University

2015/2016 International Conferences & Key Events at RoCRE

April 29th – May 1st 2015

Monogram 2015

The first conference to be held at the new Rothamsted International Conference Centre with a focus on new technologies and challenges in plant breeding.

11th June 2015

Circular Economy Conference

Hertfordshire Chamber of Commerce.

July 5th – 8th 2015

European Symposium on Plant Lipids 2015

Showcasing the very best of plant lipid research and catalysing collaboration.

Sept 14 – 16th 2015

Resistance 2015

Bringing together scientists, the agrochemical industry and end users to address the challenges of resistance management.

January 2016

Agrimetrics up and running at RoCRE

About Rothamsted Research

Rothamsted has been at the forefront of scientific developments in crop-based agriculture and its interactions with the environment since its foundation by Sir John Bennet Lawes in 1843. It is the longest established, active agricultural research organisation in the world.

Rothamsted Research (RRes) is an independent charitable company, limited by guarantee and governed by a Board of ten non-executive Trustee Directors; the current Chair is Prof. Sir John Beddington who succeeded the previous Chair Prof. Nick Talbot, in 2014. The Biotechnology and Biological Sciences Research Council (BBSRC) and Lawes Agricultural Trust (LAT), as our largest funder and our landowner respectively, each nominate one Trustee. The Chair is jointly nominated by BBSRC and LAT. All Board vacancies are advertised in the national press; the positions are renewable, four-year appointments and, with the exception of the Chair who receives an honorarium in line with BBSRC, are unremunerated; we welcome enquiries from interested candidates at any time. The Institute is very grateful to all who freely give up their time for its benefit. Details of the current Board members are available at: http://www.rothamsted.ac.uk/about.

The Chief Executive of RRes is the Institute Director, Prof. Achim Dobermann, who reports to the Board Chair and is in attendance at Board meetings. RRes has an annual income of around £26 million, the largest proportion of which comes from BBSRC in the form of milestone-driven strategic programme grants (approximately £13 million). BBSRC also provides investment in equipment and facilities. BBSRC is a non-departmental public body that reports its activities to the UK government through the Department of Business Innovation and Skills (BIS). The terms of the funding from BBSRC are governed by the Institute Grant Agreement and a number of associated documents, including those on the ownership of intellectual property (IP) and similar rights, which remain with RRes, along with the obligation to ensure IP is commercialised by the most appropriate channels available.

Lawes Agricultural Trust

LAT owes its existence to an endowment made by Sir John Bennet Lawes, the founder of RRes, whose family had lived at Rothamsted Manor since the 17th Century. In compliance with its Deed of Foundation and charitable Objects, LAT supports agricultural science nationally and internationally, primarily through the provision of facilities and modest grant funding to RRes and Rothamsted International. LAT is now a charitable company limited by guarantee with eight Trustee Directors on its Board. The entirety of 'Rothamsted' and its activities are perhaps best thought of as an enduring 'partnership' between three parties with coincident interests: LAT, BBSRC and RRes and these three elements are combined in and sustained by the Members of the RRes charity, thereby facilitating the long-term operational functionality of the association.

Rothamsted Research Association

RRes is also supported by the Rothamsted Research Association (RRA), which facilitates interaction and dialogue between researchers and practitioners. RRA aims to ensure that new scientific knowledge of relevance to agricultural and land-management practices are rapidly transferred in a usable form for commercial, environmental and societal benefit. Members include farmers, land owners, consultants, advisors, industry representatives and policymakers. RRA is a charity operating independently from RRes and is managed by a Board of Directors representing a cross-section of interests, and predominantly elected from the membership.

Scientists, Partners and Funders

At Rothamsted Research we all work together and collaborate with external partners and funders to achieve progress: we recognise and value the work of everyone involved. Below we mention by name the people or organisations that were authors, contributors, partners or funders in publications and projects highlighted specifically in earlier sections of this review.

Soil is Life: Digging Deep in 2015

RRes Scientists:
Julia Burnell,
Gail Canning,
Ian Clark,
Jennifer Dungait,
Keith Goulding,
Steve Granger,
Andy Gregory,
Kim Hammond-Kosack,
Penny Hirsch,
Richard Hull,
Daisy Irons,
Adrian Joynes,
Tim Mauchline,
Steve McGrath,
Zia Mehrabi,
Phil Murray,
Verena Pfahler,
Stephen Powers,
David Powlson,
Goetz Richter,
Joshua Roworth,
Jacqueline Stroud,
Lindsay Todman,
Richard Whalley,
Chris Watts,
Rodger White,
Andrew Whitmore.

Partners and Funders:
AHDB,
BBSRC,
Centre for Ecology and Hydrology,
Cranfield University,
DEFRA,
Imperial College London,
John Innes Centre,
Lancaster University,
NERC,
SARIC,
University of Aberdeen,
University of East Anglia,
University of Edinburgh,
University of Manchester,
University of Nottingham,
University of Oxford.

Cleaner Air Benefits Plant Diversity

RRes Scientists:
Keith Goulding,
Andy McDonald,
Paul Poulton,
Tony Scott,
Jonathan Storkey.

Partners and Funders:
BBSRC,
Imperial College London,
Lawes Agricultural Trust,
Technische Universität München.

Healthy Crops – Healthy Food

RRes Scientists:
Ambrose Andongabo,
Helen Brewer,
Neil Brown,
Toby Bruce,
Gail Canning,
John Caulfield,
Alayne Cuzick,
Mark Derbyshire,
Jean Devonshire,
Jassy Drakulic,
Bart Fraaije,
Kim Hammond-Kosack,
Keywan Hassani-Pak,
Juliet Hooper,
Alistair Irvine,
Kostya Kanyuka,
Wing-sham Lee,
Artem Lysenko,
Stephen Powers,
Jason Rudd,
Mansoor Saqi,
Martin Urban,
Jon West,
Christine Woodcock.

Partners and Funders:
ADAS,
BBSRC,
European Bioinformatics Institute,
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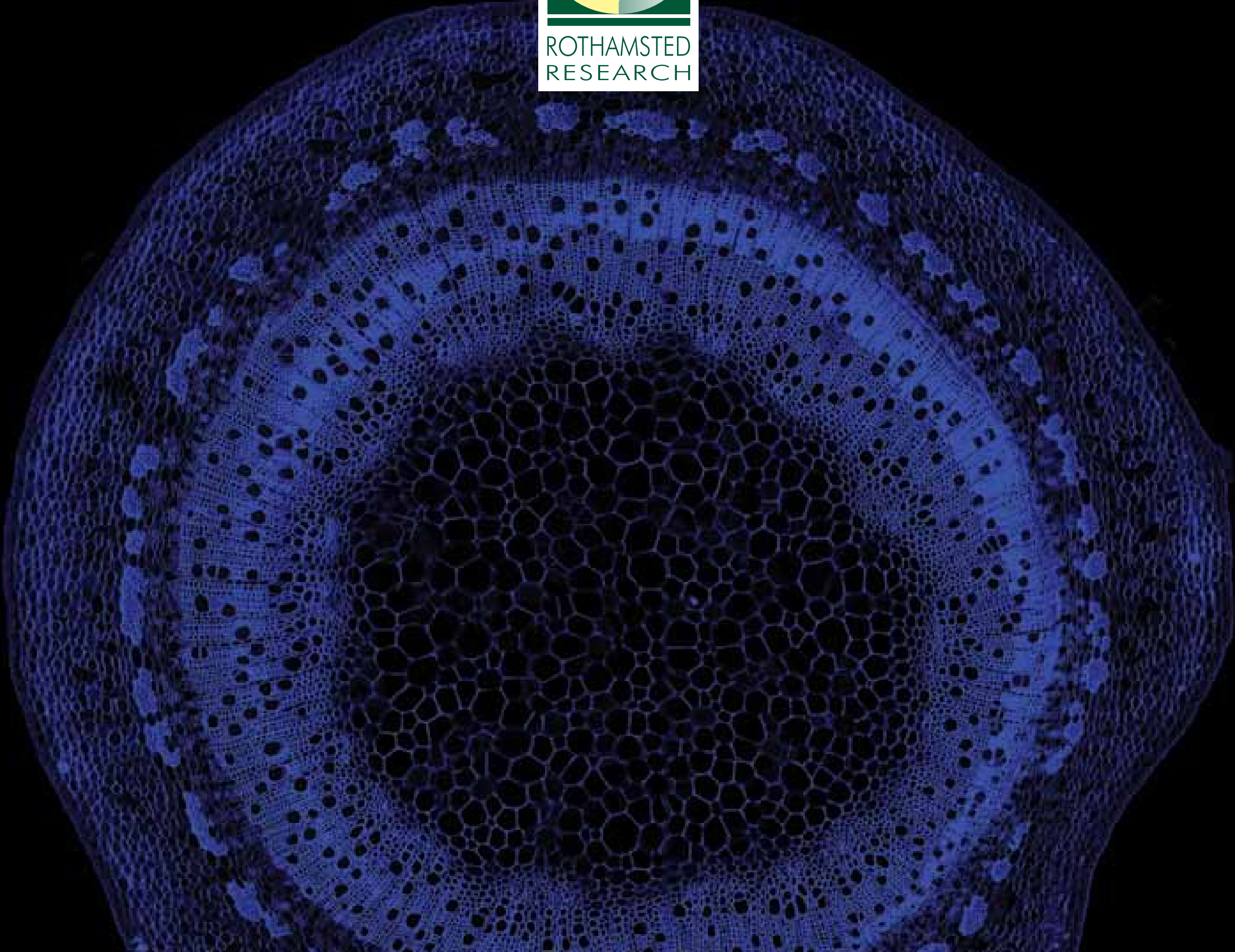

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Cover image:
A light micrograph of a section of a willow stem. The image shows a transverse 100 µm thick unembedded stem section stained with Calcofluor white showing the distribution of cellulose.

Image courtesy of Dr Cristina Gritsch

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