Looking back over the 12 months to the end of March 2017, I am reminded first of just how productive we have been. We have made new discoveries, forged alliances, shared knowledge, brought people together and stepped forward to support and lead.

We helped to found three of the UK’s four new agri-tech centres, staged a popular forum on innovation and, with the NFU, came up with what’s needed for a UK agri-science sector outside the EU.

We have engaged with the public, opened up about our research, and supported a new generation of young scientists. We have also ensured more opportunities for prospective PhD students.

We took on leadership of the Africa Soil Information Service, consolidated links with China, explored new ventures in Latin America and expanded ties in India and the Philippines.

I’ve asked the leaders of the four strategic programmes between 2012 and 2017, funded by the Biotechnology and Biological Sciences Research Council, to summarise the science and impact of their teams’ work. The heads of the four BBSRC-funded National Capabilities have done similarly.

I’d like to highlight just three examples that illustrate the breadth and depth of our recent research.

We identified a sugar controlling starch in cereal grain and are now helping to pioneer a chemical spray for enhancing crop yields; we provided the first evidence that grassland biodiversity can recover from pollution; and we revealed the risk from climate change of falling levels of selenium in soil, which threatens the health of up to 1 billion people worldwide.

There’s no doubt that 2016/17 was “a critical period for us”, as I predicted in the last annual report. We came through it all, and with flying colours.

Thank you, and well done.

Superscripts refer to published papers, see p24

ACHIM DOBERMANN
Director and Chief Executive

“We are pioneering a chemical spray for enhancing crop yields; we showed that damaged biodiversity can recover; and we revealed nutritional risks facing 1 billion people worldwide”
The programme focused on maximising yield; protecting this yield from pathogens and pests; investigating soil interactions; optimising wheat ideotypes; and predicting the impacts of future climates on production.

We screened for natural variation and exploited genetic engineering, aiming to achieve step changes in productivity. At the same time, we ensured these yield increases could be obtained sustainably by considering the efficiency of nutrient use, crop architecture and resource allocation.

To protect yields, we focused on the genomics of key pathogenic fungi, supplemented through a strategic alliance with Syngenta, which also facilitated additional work on maximising yield and on soil interactions.

Stackyard Field on Rothamsted Farm, looking towards Broadbalk; left, healthy Cadenza wheat

A selection of our academic papers indicates the knowledge base and tools developed over the programme. We identified heritable variation in photosynthetic traits in diversity panels. Transgenic approaches yielded new insights into the regulation of Rubisco by CALPase, and synthetic biology promises a step-change in photosynthesis.

We obtained new understanding of the regulation of genes involved in nitrogen uptake and remobilisation, including the identification of transporters and regulatory factors.

We improved assembly and annotation of the genomes of the pathogens Fusarium graminearum and Zymoseptoria tritici, and published comprehensive Z. tritici-wheat transcriptome and metabolome data sets, providing new insights into the infection process. Also, we are using the VIGS system to assess the function of plant genes in disease resistance and the VOX system to assess the function of fungal genes in the establishment of disease.

We extended models, which predict the relationship between soil strength and water potential, to include soil depth and tested them with field data. We linked wheat architecture to soil strength and discovered a genotypic basis for leaf stunting. We also linked the effects of impedance of root growth to leaf elongation and tiller number and to the degree of leaf stunting in UK wheats that is related to the Aht allele.

We assessed the effect of warming temperature on global wheat production using an ensemble of wheat models, and found production losses of 6% for each degree of warming with increased variability of yield across regions and seasons. We also reported that adverse climatic events will substantially increase by 2060 and cause more frequent crop failure across Europe.

Finally, we commissioned and established the world’s first gantry-based, automated field phenotyping platform; dubbed the Field Scanalyzer, this platform will be central to Rothamsted’s future contributions to digital biology and to systems-based approaches to crop improvement and plant breeding.

Publishers refer to published papers, see p24
Beneficiaries were researchers, farmers, wheat breeders, the agrochemical industry, government and society. Wheat is the UK’s largest crop, with an annual production of 14 million tonnes; market values for its seed and its processed products are around £1.4 billion and £14 billion respectively. Attaining a potential yield of 20 tonnes per hectare is a challenging target that requires a long-term integrated effort. In the past 20 years, farm gate yields increased by only 1t/ha to an average of 8 t/ha. Further improvements will come through genetic gains and better farm practices that both increase yield potential and decrease disease losses. The annual impact of a 50% increase in the UK’s wheat production could be more than £7 billion for both rural and urban economies; worldwide, the figure could be more than $350bn. In addition, production efficiencies will lower requirements for land, carbon, water and fertiliser.

Our programme produced substantial knowledge on yield gain, on production efficiency, including the importance of soil interactions, on targets for plant protection and on the influence of future climates.

Many projects were initiated with industry, notably a strategic alliance with Syngenta.

Global impact came through international collaborations, notably with organisations such as the International Maize and Wheat Improvement Center (CIMMYT) in Mexico, which eased knowledge transfer among developed and developing countries.

During its lifetime, the 20:20 Wheat® concept was widely acknowledged, by government ministers and the UK chief scientist among many others, and provoked considerable media coverage. The programme also featured in annual displays at cereals events in the UK.

Our programme generated more than 300 scientific papers, substantially increasing the knowledge base; and funding for additional supporting projects exceeded the original funding for the programme itself.

MALCOLM HAWKESFORD

“We want our findings to benefit wheat production globally”
The programme focused on lowland grassland systems grazed by sheep and beef cattle, and on arable systems dominated by cereal crops (wheat and barley) and oilseed rape.

The ultimate target was to increase farmers’ profit by reducing the cost of inputs (fuel, pesticides and fertiliser), by increasing yield or quality, and by reducing the costs to the environment of such things as greenhouse gas emissions, water pollution and the loss of biodiversity.

The programme’s high-level outputs provide farmers with more options to enhance productivity, efficiency and resilience with new integrative approaches to managing the whole-farm-system. On offer are improved availability of nutrients, better protection from pests, pathogens and weeds, and the use of novel plant semiochemistry.

Our sustainability science has shown that “land sparing” could help to eliminate net GHG emissions from agriculture. We mapped a route towards sustainable livestock systems as part of global food security.

We identified climate as the most important factor in determining the concentration of selenium in soils, and that climate change will lead to decreasing concentrations of this micronutrient in soils. The benefits of zero-till agriculture in a carbon-mitigation strategy were critically reviewed as widely overstated.

Our expertise in metagenomics and metatranscriptomics enabled us to exploit our data from Rothamsted’s Long-Term Experiments to develop a bioinformatics workflow for analysis of the taxa present in soil communities, the genes that they carry, and the conditions where they are actively expressed. We have promoted research on the root microbiome.

Our chemical ecology group has shown that novel olfactory ligands (germacrene D analogues) for modifying the behaviour of grain aphids, Sitobion avenae, can be rationally designed and produced using synthetic biology.

Our work on semiochemicals has revealed an “internet of fungi” in the soil, where plant mycorrhizae of neighbouring plants transmit signals between the plants warning of above-ground herbivory.

We were the first to demonstrate the potential for biodiversity to recover in an agroecological system following removal of a long-term anthropogenic stress. The research showed how diversity in the 160-year-old Park Grass experiment at Rothamsted declined and then recovered in response to increased and then decreased nitrogen pollution from car exhaust fumes.

Our research on the environmental effect of insecticides led to a high-impact paper that set out the scientific evidence base for the influence of neonicotinoids on pollinators.

Superscripts refer to published papers, see p24.
DELIVERING SUSTAINABLE SYSTEMS

IMPACT

We have secured external funding that more than doubles the programme’s original funding, published more than 350 papers, and given more than 80 invited talks at international conferences.

Our research papers have been published in high profile journals that include Nature, PNAS, Science, Nature Climate Change, Phil Trans B, American Naturalist and Ecology Letters. Our programme attracted large commercial contracts on bee toxicogenomics, herbicide resistance and stripe rust, and the establishment and leadership of a European network of RADAR systems to monitor insect pest movement. We also received funding from the Global Challenges Research Fund of the Department for Business, Energy and Industrial Strategy (BEIS) and from the Bill & Melinda Gates Foundation for our soil and crop research, notably with the Africa Soils Information Service (AfSIS).

We instigated the first cross-council strategic programme, between the Biotechnology and Biological Sciences Research Council (BBSRC) and the Natural Environment Research Council (NERC), which became Achieving Sustainable Agricultural Systems (ASSIST) and one of the five Institute Strategic Programmes of our new five year strategy to 2022.

Our work on pollinators, neonicotinoids and soil health led to us being invited to advise Parliamentary committees and a Department for Environment, Food & Rural Affairs panel on Sustainable Intensification: Implications for policy and 25-year plans. We continue to engage with the public and farmers on these and other issues.

We led the successful bid to run one of the four agri-tech Centres for Agricultural Innovation, Agrimetrics, which is the big data centre of excellence; we also played major roles in two other centres: Crop Health and Protection (CHAP) and the Centre for Innovation Excellence in Livestock (CIEL).

Our research has expanded our international partnerships. For example, we have worked with the World Agroforestry Centre (ICRAF); the Centre for Agriculture and Biosciences International (CABI); the International Centre of Insect Physiology and Ecology (ICIPE); the Global Farm Platform (GFP) for sustainable livestock production (14 global partners); the Brazilian Agricultural Research Corporation (Embrapa) and Virginia Tech on pest resistance and the use of semiochemicals; the China Agricultural University (CAU) in Beijing on soils; the Institute for Plant Protection (IPP) of the Chinese Academy of Agricultural Sciences (CAAS) and Nanjing Agricultural University (NAU) on soil health; the Smithsonian Tropical Research Institute (STRI) in Panama; the regional hub of the International Center for Tropical Agriculture (CIAT) in Kenya; and ETH Zürich.

JOHN CRAWFORD

“Our highly integrated programme epitomised the whole-systems approach”
Our targets were specific dietary components that have validated health benefits, notably reducing the risk of cardiovascular disease (CVD) and associated precursor states, such as metabolic syndrome.

These pathologies have major impacts on the provision of health care and, as such, represent a significant burden on society. We therefore aimed to deliver improved crops that would offer attractive, widely available and affordable foods to reduce the risks of chronic diseases.

Work within the programme was managed as two distinct projects, wheat and oilseeds, each with specific goals and challenges. In the case of wheat, we identified the key genes responsible for the synthesis of arabinoxylan (AX), the predominant dietary fibre in wheat food, and functionally characterised them\(^1\).

Importantly, we showed how these genes control AX amount and chain length, which determine extract viscosity in wheat grain. This soluble dietary fibre has been proven to be beneficial for human health, reducing the risk of CVD and other coronary pathologies\(^2\). Paradoxically, these discoveries for the development of fibrous, high-viscosity wheat, led to industrial grants to develop low-viscosity wheat for distillers and biofuel producers.

Given the recent increased levels of wheat intolerance and gluten sensitivity, there is a popular belief that diets containing wheat are potentially negative. To address this issue, and against the backdrop of the benefits of wheat soluble dietary fibre, we published detailed reviews of the scientific evidence that confirmed the importance of wheat in a balanced diet\(^3,4\).

In the oilseeds area, our significant achievement was the generation of GM Camelina plants. These plants contained health-beneficial omega-3 fish oils, such as eicosapentaenoic acid (EPA) and docosahexaenoic acid (DHA), in their seed oil\(^5\). The oil was shown to be functionally equivalent to fish oils, biochemically and in terms of animal nutrition, in both mammals and fish\(^6,7\).

These GM Camelina plants were also evaluated in the field on the experimental farm at Rothamsted, and shown to perform as non-GM plants\(^8\). These experiments confirmed the great potential of this new, land-based source of fish oil as an alternative and more sustainable source of these important fatty acids.

In different studies in oilseed rape, we showed that we could increase the content of seed oil by blocking a key enzyme (SDP1) in the turnover of oil during seed development\(^9\). Subsequent work showed that reducing SDP1 and increasing a master-regulator of lipid metabolism (WRI1) could increase the accumulation of seed oil even more, and thus provide a new tool with which to enhance the seed oil traits developed in this programme\(^10\).

We also demonstrated that a critical step in fatty acid breakdown, import into the peroxisome, was by a previously uncharacterised biochemical route; this work provided new insights into how the accumulation of plant oils could be further improved\(^11\).

Superscripts refer to published papers, see p24.
Our programme published around 150 peer-reviewed papers, significantly contributing to the knowledge and understanding of nutritional enhancement in plants and of how such scientific advances can serve the real world. Also, we have matched our initial investment with external, competitively-won funding; and we continue to advance our leading-edge research.

Cereals could be an even greater source of fibre in the human diet, important in reducing risk of cardiovascular and metabolic diseases, notably Type 2 diabetes, and of colorectal cancer. We are therefore exploiting natural genetic variation to increase the fibre content of wheat, focusing on white flour that, in the UK, accounts for about 80% of wheat consumption.

This work includes collaboration with major UK breeders, who are incorporating selection for fibre content in their breeding programmes, and with food manufacturers, who are exploring the impact on the functional properties.

In contrast to its role in human health, wheat fibre hampers processing for distillers and biofuel producers because of its impact on viscosity. Parallel studies are therefore underway to develop new types of wheat for these sections; we are working with breeders and with the Scotch Whisky Research Institute.

Our work on improving the composition of oilseeds made significant progress, most notably with proof-of-concept studies in Camelina in which we enhanced the seed oil profile by the transgenic accumulation of omega-3 fish oils.

This important achievement was further validated by GM field trials at Rothamsted, which confirmed that this new oil was stably accumulated under real-world conditions.

Even the economic importance of omega-3 fish oils, with annual sales of £4–6 billion, sourcing the commodity from agriculture rather than from the oceans is a breakthrough. Ecologically, demonstrating that our novel GM-derived oils can act as a drop-in replacement for fish oils in salmon feeding studies provides further evidence of the potential impact of this work on the fish farming sector.

Our GM Camelina story has been extensively covered in the media. In 2014, the story was highlighted as an exemplar of a modern-day challenge for a new Longitude Prize, launched by BBC Horizon; the work has also encouraged significant Public Engagement.

Research in other oilseed species has demonstrated the exciting possibility of producing oil in vegetative tissue and the ability to tailor seed oil profiles genetically, such as they can be used for different applications, from food to feedstock.
Our aim was to tackle climate change by optimising the conversion of carbon dioxide (CO₂), which is captured by plants, into useful renewable products, and by improving carbon sequestration into soils.

We focused on investigating how plants’ partitioning of carbon differs between perennial crops grown for biomass or pasture, how it changes during development and how it is influenced by genetic and environmental variation.

In parallel, we investigated carbon in the soil to understand how plants influence soil inputs, how these inputs turn over and how these soil processes are affected by environment. Results were integrated to develop a framework of carbon flows for optimising land management and production of renewables.

Under the sub-programme Maximising Carbon Harvest, we exploited existing mapping populations and diversity collections to apply new metabolic screens, developed for willow, to large-scale field experiments over a three-year cycle. New data on phenolic glycoside structures, and their biogenesis, revealed insights into pathway switching and diverse natural product formation.

Among the extensive metabolomic diversity that was revealed, we isolated novel and unexpected salicinoids with bioactivity against drug resistant cancer cell lines, which led us to seek IP protection. Via generation and metabolomic screening of poplar RNAi lines, we identified a P450 gene involved in salicinoid biogenesis. We also isolated the willow PAL and CNL genes and characterised them using Arabidopsis transgenic lines.

Under the sub-programme Increasing Carbon Retention, we identified soil inputs from different perennial bioenergy crops and forage grasses, and found that greater soil organic carbon (SOC) and root biomass accumulated under forage grasses than with willow or Miscanthus. SOC increased in re-sown plots compared with permanent pasture but only in a mixed ryegrass/white clover sward.

We showed that sequestration rates decline with duration from 1.6 to 0.5 tonnes of carbon per hectare per year, and that SOC retention rates reduce twofold to threefold over 14 to 18 years. An on-farm survey revealed high spatial variability of inputs. We also identified grasslands as a major carbon sink.

Under the sub-programme Integrating Carbon Systems, we improved gene discovery pipelines, which facilitated future work on life cycle and phenology. Earlham Institute (TGAC) provided increasingly high quality assemblies of the willow genome that supported analysis of RNAseq data. We resequenced another 32 lines of willow. We developed genotyping-by-sequencing (GBS) to create a high-density linkage map for the reference sequence genome and to provide new markers in the association mapping population.

Two further Rothamsted-bred willow varieties, Roth Hambleton and Roth Mourne, were awarded Plant Breeders’ Rights for the EU. We also developed a robust protocol for willow micropropagation for export of disease-free certified Rothamsted-bred willows to North America.

Using a process-based model, we quantified the effects of different growth strategies of willow and identified key traits important to accelerate the breeding process. We also demonstrated that energy crops can contribute to the bioeconomy pathways, while delivering multiple environmental benefits on arable and marginal land.

Leaves of Salix spp. from the National Willow Collection whose 1500 accessions represent more than 100 species (of around 450 species worldwide).

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<th>Programme researchers</th>
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<tr>
<td>Published papers</td>
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<tr>
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Superscripts refer to published papers, see p24.
Our programme has contributed to the provision of a low-carbon future for the benefit of society by developing the science to improve carbon sequestration in soils and by producing alternatives to fossil-fuel products in sustainable ways.

Our results provided improved scientific understanding of soil carbon dynamics of grassland and perennial biomass cropping systems; they highlighted the potential to enhance carbon stocks in soils through perennial cropping, including deep-rooting grasses. Direct beneficiaries include industry (bioenergy, biofuel and chemical enterprises); farmers; energy, environmental and agricultural advisory agencies; government; NGOs; and the public.

The Rothamsted willow breeding activity provides an immediate pipeline for delivery to market. Commercialisation of our newly registered willow varieties is through existing links with commercial producers of energy crops and renewable energy grower associations. Based on the recommendations of an independent market review, we forged new partnerships in the development of fossil-fuel alternatives that go beyond fuel. We began to patent the exciting discovery of willow salicinoids that are active against drug-resistant cancer cell lines, and we will pursue development through collaboration with pharmaceutical companies.

We published results in international journals and communicated them to farmers and industry through our presence at agricultural shows, by giving talks at industry-led events and by articles in trade publications, such as Farmers Weekly and Chemistry World.

We relayed scientific findings to Natural England, Renewables East and the Livestock Derived Organic Matter Group; we also informed government through contributions to reports and participation in workshops and consultations led by the Department for Environment, Food and Rural Affairs, the Department of Energy and Climate Change, Westminster Forum, the European Commission, the European Chamber of Commerce and the World Bank.

We hosted visiting workers, and trained PhD students as well as Bursary and Summer Placements. We gave TV and radio interviews, and “Teatime Tales of Willow” was just one of the many events that we held to engage with the public.

Our programme has contributed to the provision of a low-carbon future for the benefit of society by developing the science to improve carbon sequestration in soils and by producing alternatives to fossil-fuel products in sustainable ways.

We identified anti-cancer activity and how soils can store more carbon

ANGELA KARP

We identified anti-cancer activity and how soils can store more carbon
Information that includes spring forecasts of aphid phenology and abundance, weekly bulletins and web updates on population levels of key pest species throughout the season (25k web visits per year).

http://resources.rothamsted.ac.uk/insect-survey

Two new publications began in 2016: RIS Remarks is a weekly summary of the migration of non-aphid pest threats; Light Trap of the Month engages with our moth-mapping volunteers.

Other highlights include a new pop-up portable 6-metre suction trap to understand pest threats in challenging environments; examinations of climate sensitivity used our long-term data both on aphids and moths and on the common wasp, Vespula vulgaris; machine learning algorithms were tested for pest forecasting; and three PhD students are mining our historical samples for new data on pollen beetles, moths and aphid predators.

Superscripts refer to published papers, see p24

LONG-TERM EXPERIMENTS

We manage and maintain the unique Rothamsted Long-Term Experiments (LTEs), associated Sample Archive and electronic Rothamsted Archive (e-RA), to benefit the UK bioscience community and international research in the field of food security and agroecology.

https://www.rothamsted.ac.uk/long-term-experiments

Researchers throughout the world use the LTEs, with 10–20 papers published annually. In 2016, new results from the Park Grass Experiment, coinciding with its 160th anniversary, provided the first evidence of the impact of anthropogenic stress on biodiversity in an agricultural system followed by recovery after removal of that stress. In addition, the updating of germplasm on the Broadbalk Wheat Experiment, started in 1843, has steadily increased yields over time, to its highest ever yield of 13 tonnes per hectare in 2014.

While it is not possible to put an exact figure on the value of our National Capability, the LTEs have contributed over many years to improving the efficiency of the use of nutrients in soils, thereby decreasing the contribution of agriculture to diffuse pollution (nitrate and phosphate) in England and Wales.

Reducing losses of nitrate and phosphate to waters by only 1% of the total cost of fertilisers is worth £2.38M per year; similarly, a 1% saving on nitrogen purchased as fertiliser is worth about £6M per year.
NORTH WYKE FARM PLATFORM

We run a unique research operation to develop solutions for resilient grassland farming and associated food chains. Established in 2010, the operation consists of three 21-ha farmlets for studying processes under three management scenarios. It is equipped with state-of-the-art facilities and sensor technologies. North Wyke’s recognition as the leading research platform for sustainable grazing systems continues to grow both nationally and internationally.

Investment from the Centre for Innovation Excellence in Livestock (CIEL, see p33) helps us to develop the national capability in landscape emissions and animal housing facilities. Core data is freely available online from the platform’s data portal.

http://resources.rothamsted.ac.uk/farmplatform

Two of Rothamsted’s new five-year strategic programmes to 2022, Soils to Nutrition (S2N) and Achieving Sustainable Agricultural Systems (ASSIST), rely heavily on core data from the platform, the programmes dovetail with the platform for many of its campaign-style experiments.

North Wyke, in conjunction with the Duchy College Dairy Future Farm, continues to assess the impact of grassland management interventions on meat and milk quality. The work comes under the Sustainable Intensification Platform (SIP) project, funded by the Department for Environment, Food & Rural Affairs. North Wyke is also a LEAF (Linking Environment and Farming) Innovation Centre to promote an integrated approach to farm management.

Furthermore, international recognition continues via the Global Farm Platform (towards sustainable ruminant production) initiative. Jointly run centres (Newton-funded, as part of the UK’s official development assistance) have seen the installation of similar global capabilities in the US and China. Biocurators read and extract the phenotypes reported on molecular genetic analysis using controlled vocabularies. This data set facilitates novel discoveries for around 260 pathogenic fungal, protist and bacterial species.

PHI-base currently includes 4775 pathogen genes, curated from more than 2300 research articles. All the major plant and human pathogens are included. PHI-base provides phenotype information into the genome browsers of hundreds of plant pathogen genomes provided by the Ensembl genome annotation system and to ELIXIR. More than 270 research articles from researchers in the UK and worldwide cite PHI-base use.

PHI-base has a major impact in three agricultural industries: in chemicals, it helps to identify novel fungicide targets in pathogen genomes and to guide the development of novel chemistries; in life sciences, it enables the development of diagnostic assays for pathogen effector genes to support plant breeders; and in biotechnology, it supports the development of novel gene cassettes that alter pathogen gene expression in crop plants to protect them against diseases.

PATHOGEN-HOST INTERACTIONS DATABASE

The multi-species resource, PHI-base, links genotype and mutant gene information with disease phenotypes reported in peer-reviewed research articles. PHI-base is now an agri-data resource platform for the UK’s participation in ELIXIR, an intergovernmental organisation for managing life-science data from Europe.

www.PHI-base.org

PHI-base was developed to provide a knowledge database for agronomically and medically important pathogens; it empowers scientists studying pathogenic species by providing easy access to molecular research findings on plant and animal diseases.

Sclerotinia sclerotiorum, a fungal plant pathogen, releases sexual spores from fruiting bodies that cause white mold disease on a wide range of economically important crops.
DELIVERING SUSTAINABLE SYSTEMS

1. Lamb et al., 2016, Nature Climate Change 6: 488-492, the potential for land sparing to offset greenhouse gas emissions from agriculture.


CROPPING CARBON

1. Lamb et al., 2014, Molecular Ecology 23: 948-957, An efficient high-throughput metabolome analysis strategy and its potential for oil palm developmental fenestrae increase in austroriparian context.
5. Ruiz-Lopez et al., 2014, Plant 77: 198-208, Basic and applied investigation on the accumulation of fish oil omega-3 long chain polyunsaturated fatty acids in transgenic oilseed crops.
6. Tejera et al., 2016, J Nutr Sci 14: 227-235, Transgenic Camelina sativa seeds oil effectively replace fish oil as a dietary source of eicosapentaenoic acid; and triene.”


NATIONAL CAPABILITIES

ROTHAMSTED INSECT SURVEY

7. Stroud et al., 2016, Soil Biol Biochem 93: 70-81, Population genetics and the factors that drive the complex dynamics and response to stew applications.

NORTH YORK MOOR FRAMEWORK

8. Stroud et al., 2016, Soil Biol Biochem 93: 70-81, Population genetics and the factors that drive the complex dynamics and response to stew applications.

PH-BASE

3. Upreti, 2015, Front Plant Sci 6: 150, Using the pathogen-host interactions database (PH-Base) to investigate plant-pathogen interactions and genes implicated in virulence; and trophic levels; and trophic levels.
6. Rodríguez-Iglesias et al., 2016, Front Plant Sci 6: 120, Using the pathogen-host interactions database (PH-Base) to investigate plant-pathogen interactions and genes implicated in virulence; and trophic levels; and trophic levels.
More than 500 people were working across our sites in 1 January 2017, representing over 35 nationalities and collaborations with over 50 countries, making us one of the most diverse international organisations in the world.
Of more than 550 people attended five public events at Rothamsted, with topics ranging from insect flight and sustainable agriculture, healthy crops and healthy food, to celebrations of willow and of 160 years of the Park Grass experiment, with positive results: “Always interesting to hear staff talking about their work”, “It brought the experiment to life”; “Informative, interesting”; “I’m delighted to have made contact with helpful scientists”, among many verbatim quotes.

**SCHOOL EVENTS**

Schools: Eight outreach activities brought many schoolchildren to Rothamsted during the year. We ran popular tours of Bioimaging, hosted a delegation of young Chilean innovators, and challenged Year 7 students (11-12 year olds) to create posters and make presentations during a “Fascination of Plants Day”. We also ran a photo-story competition, “Illuminating Life: Personal Encounters”; in the 11-14 years age group, we awarded first prize to Zoe Birch of St George’s School in Harpenden. Zoe’s image, “A Welcome Break”, depicts an agricultural landscape in the Lake District.

**SOAPBOX SCIENCE**

Soapbox: Laura Crook of the weed ecology group spoke from her soapbox for an hour to shoppers in Milton Keynes. She talked about blackgrass and herbicide resistance, and her role in understanding both (and "enjoyed the whole experience", she says). Laura was one of 12 speakers, organised as part of Soapbox Science, a platform for promoting women and the science they do.
PARTNERSHIPS WITH IMPACT

Our international partnerships are based on complementary scientific excellence, strategic relevance and potential.

We collaborate in many countries but focus our institutional efforts in those regions having the greatest potential for co-developing and delivering excellent science with impact.

Our efforts in China concentrated on our first call for seed funding through the joint UK-China Centre for Sustainable Intensification of Agriculture with our partners at the Chinese Academy of Agricultural Sciences, the China Agricultural University, the Nanjing Agricultural University, the North West Agriculture and Forestry University and at the Chinese Academy of Sciences.

Activities in Brazil involved visits to the São Paulo Research Foundation (FAPESP) and to the headquarters of the Brazilian Agricultural Research Corporation (Embrapa) in Brasilia to discuss current and future collaborations. Two new projects with Embrapa partners also began.

In Europe, we focused on applications to Horizon 2020, the EU’s research and innovation programme, and on working with the European Technology Platform, Plants for the Future. We also welcomed new Marie Curie Fellows to Rothamsted.

Rothamsted International continued to support researchers from developing countries through Fellowships to train at Rothamsted. This year’s fellows came from Kenya, India and Pakistan.

BRAZIL
We lead two BBSRC/Embrapa/Newton-funded projects: the role of the rhizosphere microbiome for sustainable wheat production with Embrapa-Environment, and the control of Fusarium Head Blight disease with Embrapa-Wheat.

COLOMBIA, KENYA, MEXICO, PHILIPPINES
We undertook several networking, exchange and research activities under a Global Challenges Research Fund – Impact Acceleration Award (GCRF-IAA). Our main activities were three strategic workshops. These events were co-hosted by partners at the International Maize & Wheat Improvement Center (CIMMYT) in Mexico, at the Biosciences eastern and central Africa – International Livestock Research Institute (BecA-ILRI) in Kenya, and at the International Rice Research Institute (IRRI) in the Philippines. We focused on strengthening collaboration in the areas of molecular plant science, sustainable intensification, plant and livestock nutrition, and wheat and cropping systems. We also supported five R&D projects and nine “small group” exchanges through our GCRF-IAA.

These activities involved nearly 100 staff and more than 165 overseas researchers, advisors and industrialists.

BRAZIL, CHINA, INDIA
We lead two BBSRC/Newton-funded centres that deliver training, capacity building and research for the sustainable use of agricultural nitrogen: the UK-China Centre for Improved Nitrogen Agronomy (CINAg) and the Indo-UK Centre for the improvement of Nitrogen use Efficiency in Wheat (INEW). We are also a partner in a Brazilian-UK nitrogen centre known as NUCLEUS, and at the International Rice Research Institute (IRRI) in the Philippines.
The service aims to increase the productivity of smallholder farmers and to promote policy changes towards more sustainable agricultural production in Africa.

Soil health is our focus. We monitor it using innovative dry spectroscopic analyses and associated geospatial information. The results identify areas at risk of soil degradation and lead to appropriate preventive and rehabilitative interventions.

This year, we set up a new dry spectroscopy laboratory at Rothamsted to analyse samples more quickly and cheaply than conventional wet chemical methods, and hired two new postdocs, Cathy Thomas and Gifty Acquah, to run it.

Cathy’s focus is GeoPhenomics, how the soil affects the performance of a plant phenotype; Gifty will develop ways of analysing the many different types of material that come into the laboratory.

Our new instruments can perform mid-infrared (MIR) diffuse reflectance spectroscopy to measure nutrient availability, pH, organic carbon and mineralogy; laser diffraction particle size analysis to gauge soil texture and micro-aggregate stability; X-ray diffraction spectroscopy to determine soil mineralogy; and X-ray fluorescence (XRF) spectroscopy to assess a sample’s content of elements.

Rothamsted also serves as a reference laboratory for AfSIS by using wet chemistry as well as dry techniques to analyse samples; this cannot be done easily in Africa but is essential for calibrating the dry spectroscopy labs that are in operation in several countries across the continent.

Rothamsted has led AfSIS, funded by the Bill & Melinda Gates Foundation, since December 2016.

Cathy Thomas is a GeoPhenomics expert. She is studying how nutrients transfer from soils to crops or pastures. Her results could enable us to develop new ways of using soil measurements to improve fertiliser recommendations.

Gifty Acquah is a dry spectral specialist. She is developing methods and calibrations for analysing a range of materials including soil, plant, fertilisers, pasture samples, manure, organic sludges and dung samples.

Dry spectroscopy can map soil fertility parameters across large areas. Shown are spatial patterns of predicted total nitrogen (in permilles), for topsoil for Kenya. White pixels indicate excluded areas (water bodies and deserts). Each soil property is modelled independently and can thus show quite different spatial patterns.

Agrimetrics is UK agriculture’s centre of excellence for big data. It was launched in October 2015 as the first Centre for Agricultural Innovation. Headquartered at Rothamsted, the centre serves the agri-food industry, from farm to consumer, connecting the sector through data. Agrimetrics has two primary ambitions: to become a valued independent broker by facilitating data sharing; and to be the most reliable and innovative evidence base for the sector, enabling it to become more resilient and profitable, and to achieve sustainable intensification.

The centre has made significant progress over the past year in what was, in effect, its first year of activity. Staffing has increased from three to 16, and they are located on every site of the centre’s four founders: Rothamsted, the University of Reading, NIAB and Scotland’s Rural College. It has forged links to the other three agri-tech centres; made substantial progress in developing its data platform; completed industry projects; and obtained further funding from Innovate UK.

The Centre for Innovation Excellence in Livestock (CIEL), another Centre for Agricultural Innovation, runs across 12 research sites. Its focus is to develop industry-led, commercially sustainable innovations for the livestock sector. At Rothamsted, CIEL has invested in our North Wyke Farm Platform, improving our ability to measure greenhouse gases using eddy covariance (for carbon dioxide and methane) and an Aerodyne monitor (for nitrogen dioxide) at the landscape scale for each of three farmlets. These techniques have two advantages: they provide continuous measurements of gas concentrations and fluxes, and also capture short term bursts that might otherwise be missed; and they cover small-scale heterogeneity in the soil. CIEL investment on the farm platform has improved the measuring of ammonia at low levels from the water flumes, and improved soil moisture measurements and precipitation instrumentation. Further investment is planned in the development of a state-of-the-art small ruminant research facility.

The Crop Health and Protection Centre (CHAP) is a partnership of research institutions and commercial organisations that focus on current and impending issues of crop protection. The centre promotes effective research that will allow farmers and growers to adopt new, more efficient and sustainable approaches. As a founding partner of this Centre for Agricultural Innovation, Rothamsted has set up two research capabilities.

These agri-tech centres started to operate over the past year as part of the government’s Agri-Tech Industrial Strategy, announced in 2013. They aim to translate agricultural innovation into commercial opportunities, to stimulate inward investment and to revolutionise farming practices. The centres cover big data, livestock, crop protection and technology, and Rothamsted helped to establish the first three.

Left: Molecular biologist Kirsty McInnes prepares insect DNA for genetic analysis on the NanoDrop spectrophotometer, in the Crop Health and Protection Centre at Rothamsted.

CHRIS RAWLINGS
“Better integrated and accessible data are essential for innovation”

MICHAEL LEE
“We nurture sustainable and commercially viable livestock production”

LIN FIELD
“CHAP will allow us to deliver our science to many more stakeholders”
During 2016, we reached the halfway stage of the Rothamsted-Syngenta (RoSy) alliance, a partnership that aims to translate our excellence in wheat science into new insights and approaches that the company can use to develop better products and services for farmers.

The alliance had evolved in 2013 from existing relationships, and the ten complementary, multi-disciplinary projects that ensued have begun to yield impressive results.

In crop efficiency, we analysed wheat germplasm in the field for the photosynthetic traits that contribute to biomass and grain yield, and determined associations to genetic markers to exploit these characteristics.

We demonstrated that there is useful diversity in the field-rooting behaviour of UK wheat lines, which cannot be predicted easily from laboratory studies.

For hybrid cereals, we studied the dispersal of pollen to develop a tool for more efficient seed production in hybrid barley. Syngenta adopted this project’s results and began to develop commercial varieties.

Using a variety of winter wheat, we developed and introgressed a series of novel semi-dwarfing alleles, both semi-dominant and recessive, and began to assess the impact of these alleles on crop height and other canopy and flowering traits.

Under crop health and protection, we validated a unique source of tolerance to Take-all, a root pathogen; the source was hidden in the Syngenta wheat germplasm.

Using modelling supported by field experimentation, we demonstrated that it is more sustainable to integrate and balance chemical and genetic crop protection than to attempt to replace chemical control with genetic control or rely entirely on chemical control.

Through a cluster of projects on Fusarium and Septoria fungal pathogens, we developed a new virus-based protein expression system for cereals and began to use this system to identify disease-resistant wheat genotypes. We also began to assess the role of small-RNA in wheat-fungal interactions.

“The alliance has enhanced knowledge exchange between our scientists and the Syngenta researchers,” says Malcolm Hawkesford, who leads wheat research at Rothamsted. “This has helped to facilitate the delivery of the results and put them into practice.”

“Our experience has shown that outputs can be substantially enhanced by having strategic alliances,” adds Achim Dobermann, Rothamsted’s Director and Chief Executive. “We look forward to seeing the results, for farmers, from our joint work under this alliance and hold high expectations for the future of this relationship.”

Sometimes, simply sharing knowledge is not enough to deliver impact in agriculture. We need to engage and work with businesses to help them to translate our science into new solutions for farmers.
ROTHAMSTED OPEN INNOVATION FORUM

Our inaugural Rothamsted Open Innovation Forum, in January, featured over 30 speakers and secured generous support from Syngenta, Bayer, the Wellcome Trust, BBSRC, the International Fertiliser Association and AgFunder, an online equity crowdfunder.

Organised jointly by the Rothamsted Centre for Research and Enterprise (RoCRE) and our Knowledge Exchange and Commercialisation team, the event drew on the best thinking from leading European markets and from as far afield as Pakistan, Australia, South Africa, Singapore and America.

The forum sought to use “open innovation” to inspire key global security solutions. It included a series of workshops to address some of the main problems identified by industry leaders; the resulting projects are being developed to make a real difference on the ground.

The forum attracted significant press and social media interest; for a period, “#ROIF” became one of the five highest trending UK-based terms on Twitter.

We are providing ongoing support for the nascent collaborations and partnerships that emerged, including the opportunity to become part of AgRIA, our new Agricultural Research and Innovation Accelerator for pre-competitive ideas, which is based in the Lawes Open Innovation Hub.

During 2018, the global food challenges under the ROIF name will be developed further leading, it is hoped, to ongoing collaborative projects involving Rothamsted and its key partners.
The case for investment in the agri-food science base has been made by the Agri-Food Technology Leadership Council and follows the Industrial Strategy Challenge Fund consultation. Outside the EU, the UK’s agricultural science has an opportunity to work to an improved model and become more effective at delivering what is needed. The government should invest a proportion of the funds that would have contributed to the EU budget (and to the Common Agricultural Policy) in agricultural science to make farming highly competitive in the new market environment.

Building on the success of the Agri-Tech Strategy, the UK could remain a leader in the field internationally. Improved funding models and mechanisms should be set up with four main aims. First, encourage greater collaboration with more concrete outputs by being more strategic, less bureaucratic, better joined-up and accessible. Second, improve balance between needs of fundamental, applied and translational R&D that specifically address long-term needs of agriculture. Third, agree spending on agricultural research, relative to our competitors and to meet our productivity, efficiency and environmental goals. Fourth, channel investment within domestic policy to support knowledge exchange, on-farm innovation, and adoption of new practices and technologies.

UK policy should seek to provide effective frameworks that are conducive for both responsible innovation and international competitiveness. Collaboration should be increased between groups of stakeholders: research organisations (including Agri-Tech Centres); funders and their funding mechanisms; public/academic and private/industrial (including farm businesses and NGOs); countries, in the EU and internationally; and government departments and agencies, and their policies. Effective coordination and collaboration will require long-term and reliable funding mechanisms, demonstrating value, driving culture change, providing career opportunities and facilitating genuine knowledge exchange between and within all these stakeholders. Measures of success include more impactful research, faster adoption, greater returns on investments, long-term wealth creation, higher productivity and environmental stewardship. These factors all lead to more innovative farm businesses that are able to seize new opportunities and adapt to change.

We convened a workshop with the NFU at Rothamsted in November on “How to deliver an improved UK agri-science sector outside the EU.” Attendees included leading organisations involved in agricultural science, technology and knowledge transfer, and our discussions yielded the following edited statement of recommendations.

Many organisations attended the workshop and engaged in the development of these recommendations:

- ADAS
- AHDB (Agriculture & Horticulture Development Board)
- Agrii (Agri Intelligence)
- Agri-Tech East
- AIC (Agricultural Industries Confederation)
- AICC (The Association of Independent Crop Consultants)
- Bayer AG
- CPA (Crop Protection Association)
- Cranfield University
- Harper Adams University
- IBERS (Institute of Biological, Environmental & Rural Sciences)
- Innovate UK
- John Innes Centre
- LEAF (Linking Environment & Farming)
- NIAB (National Institute of Agricultural Botany)
- NFU (National Farmers’ Union)
- Rothamsted Research
- BBSRC and Defra representatives, and Anthea McIntyre, MEP West Midlands, attended the workshop as observers.
In November, the BBSRC introduced the Collaborative Training Partnership (CTP) scheme with industry to fund 189, 4-year PhD studentships starting in 2017, 2018 and 2019. Ten CTPs, each led by a non-academic research organisation, succeed the BBSRC’s Industrial CASE Partnerships (ICPs). Rothamsted is accepting 15 students under the CTP led by Waitrose, with its international food production and supply companies, and in association with the University of Warwick, Lancaster University, and the University of Reading. The first cohort will join us in October 2017 to address challenges in sustainable crop production, sustainable soil and water, and biodiversity and ecosystem services in agriculture.

Rothamsted is supporting opportunities to engage with industry in three ways: through two of the BBSRC’s Doctoral Training Partnerships (DTPs), one led by the University of Nottingham and the other led by the University of Bristol (for South West Biosciences); through the Centre for Doctoral Training (CDT), a consortium of universities and research organisations that offer Soils Training and Research Studentships (STARS) funded by the BBSRC and the Natural Environment Research Council; and through the Waitrose CTP.

We also decided to build on the legacy of our founders, John Bennett Lawes and Joseph Henry Gilbert, by offering the Lawes and Gilbert PhD studentship. Funded by the Lawes Agricultural Trust, the first student will start in October 2017 on projects aligned with two of our strategic research programmes, Achieving Sustainable Agricultural Systems (ASSIST) and Soil to Nutrition (S2N). More studentships under the scheme are due to become available in 2018, our 175th anniversary year.

Masters and PhD students now have access to the new Joint Graduate School for the Environment, launched in October 2016 and combining the expertise of Rothamsted, the Centre for Ecology and Hydrology, and the Lancaster Environment Centre of Lancaster University. Ten students are already enrolled on inter-institute collaborative projects focusing on three themes: sustainable agricultural intensification; earth observation and environmental informatics; and soil and water resources.

The Lawes Open Innovation Hub will soon be hosting its first doctoral intake within Rothamsted’s own intellectual hothouse for agricultural entrepreneurship, our new Agricultural Research and Innovation Accelerator (AgRIA). Five PhD students, registered at Cranfield University on the Soil AgRIA Programme, arrive in October to work on projects that have an entrepreneurial component.

The projects are designed to accelerate the application of science and engineering advances to soil technology development, and so tackle widely-acknowledged constraints to soil and land management, both nationally and globally.
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APRIL 2016

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OCTOBER 2016

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NOVEMBER / DECEMBER 2016

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INVASION OF THE SUPERMOTHs Biblical two-mile wide clouds of pesticide-resistant insects set to descend on UK

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Soil selenium levels predicted to drop

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News & Events

Longest running scientific experiment

Facts about BROADALK EXPERIMENT

RESEARCH / SCIENCE

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News & Events

Longest running scientific experiment

Facts about BROADALK EXPERIMENT

RESEARCH / SCIENCE

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News & Events

Longest running scientific experiment

Facts about BROADALK EXPERIMENT

RESEARCH / SCIENCE

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News & Events

Longest running scientific experiment

Facts about BROADALK EXPERIMENT

RESEARCH / SCIENCE

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News & Events

Longest running scientific experiment

Facts about BROADALK EXPERIMENT

RESEARCH / SCIENCE
We set tough targets because they are the ones worth hitting; let’s make the most of the ride.

Looking ahead in the last annual report (2015/16), I spoke about all the thinking we had done, about having to secure the next round of strategic funding and about demands to lift our grant income significantly.

I mentioned the need to infuse new talent into our science and to develop effective partnerships with national and international institutions and organisations. I stressed how important it is for us to establish solid relationships with the UK farming community. Now more than ever, the UK needs a strong and competitive agricultural industry and Rothamsted must play a leading role with this.

Well, we have come a long way. We have a new strategic plan and can now look ahead to the next five years, to 2022, and also beyond that.

First, we have set ourselves six Grand Challenges as we pursue our plan to improve sustainably, economically and culturally how much nutritious food is produced and used. Each of our three science portfolios will address two challenges apiece.

Secondly, I want us to lift our heads regularly from current pre-occupations and remind ourselves of where we are going. For me, as indeed in May 2017 when we launched our new strategic plan, it’s 2030, the year when the current 17 Sustainable Development Goals of the United Nations end.

That is all the time we have to make the more transformative changes towards a more sustainable development path. And if we fail, it’s going to be incredibly hard to catch up afterwards. So, in our context, what does that mean?

In 2010, there’ll be at least 8.5 billion people on earth. But, if we’ve been doing the right things, we should have eliminated extreme forms of poverty by then, and extreme hunger, and many of the most severe under-nutritional problems, as well as some of those related to over consumption.

Nutrition, as well as through a wide range of grants from other sources.

By 2030, we may already have seen other newly engineered plants from our Tailoring Plant Metabolism programme. Varieties that have come out of our Designing Future Wheat programme. Varieties that have the right architecture and are more nitrogen efficient; that combine disease and insect resistance and are enriched with dietary fibre and micro-nutrients that can make white bread much healthier than it currently is. These would be fantastic outcomes.

In 2030, we can imagine half a million acres of our Lolium avenaria 3 growing in North America and supplying more than half of the world’s aquaculture fish oil needs sustainably. By then, farmers in East Anglia could have started to grow GM Camelina too, and be supplying fish oil for the Scottish and Norwegian, salmon and sea bream aquaculture industries. Wouldn’t that be something? A new crop, a new industry, in our country.

And by 2030, we also want to ensure that every farmer in the UK is able to close existing yield gaps through a combination of agronomic improvements, other newly engineered plants from our Tailoring Plant Metabolism programme. Varieties that have come out of our Designing Future Wheat programme. Varieties that have the right architecture and are more nitrogen efficient; that combine disease and insect resistance and are enriched with dietary fibre and micro-nutrients that can make white bread much healthier than it currently is. These would be fantastic outcomes.

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By 2030, we may already have seen other newly engineered plants from our Tailoring Plant Metabolism programme. Varieties that have come out of substances discovered in our fantastic willow collection.

And by then, I’d also like to believe that we have broken the cycle of intensification and of being heavily dependent on the use of agrochemicals. Increased productivity will come from fewer inputs. And we won’t need a neonic debate any more. There will be more integrated pest control that, yes, involves chemicals but in a targeted, smarter manner.

In 2030, I hope we can clearly say and measure what a healthy soil looks like. We will have new tools that allow us to go to a field and tell a farmer on the spot: ‘This is really healthy. What you’re doing here is moving the soil in the right direction.' As a result, governments will finally be able to implement policies that reward farmers for doing the right things, for building natural capital for future generations.

And if we fail, it’s going to be incredibly hard to catch up afterwards. So, in our context, what does that mean?

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