Rothamsted Research

where knowledge grows

Science Strategy 2012 - 2017

ROTHAMSTED RESEARCH

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BBSRC
bioscience for the future

Contents

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BBSRC bioscience for the future

Professor Maurice Moloney
Director of Rothamsted Research

Foreword

Rothamsted is almost certainly the oldest agricultural research centre in the world. Over its 168 year history, it has built an enviable international reputation as a centre of excellence and innovation for science in support of agricultural productivity, crop protection and soil science.

Our strength lies in our ability to move with the times and embrace the evolving scientific challenges through creativity and ingenuity. Our history is one of excellence and our future will ensure that we deliver the highest quality science for maximal impact on agricultural practice. This is a testament to the foresight of our founders Sir John Lawes and Sir Henry Gilbert, as well as the influential scientists such as Ronald Fisher, Sir Edward John Russell, David Jenkinson and Michael Elliott, who helped build Rothamsted's name and reputation.

We now live in a world with increasing threats to food, energy, water and land security. It is predicted that we shall need to increase world food production by 70% by 2050 and we will need to do this on less land, using less water, with fewer pesticides and fertilisers whilst ensuring a sustainable agricultural system. Governments, policymakers, manufacturers and farmers all need the scientific knowledge and technological tools to meet this challenge.

Fortunately, we also live in a period where biological sciences are providing the tools and technologies necessary to respond to these challenges. With the help of genomics and systems biology, we are now developing revolutionary approaches to crop genetics, nutrient and water utilisation, plant protection, nutritional value and soil revitalisation. These are global efforts which will combine the skills of Rothamsted in collaboration with many other laboratories in the UK and beyond.

Our Strategy covering the next 5 years reflects these new demands and priorities. It is designed to enable us to deliver the scientific knowledge and innovation needed to feed an increasingly hungry world. Our unequivocal commitment to these goals will ensure that Rothamsted Research remains a world-leading research centre in plant and soil science for sustainable agriculture, creating a new and exciting chapter in its long and illustrious history.

"Rothamsted Research has an exceptionally important role to play over the coming years"

- **Professor Douglas Kell**,
BBSRC Chief Executive

"If the world is to deal with the global imperative of ensuring food security in the future, then it will need the expertise of Rothamsted Research and the ideas developed in its new Strategy"

- **Professor Nick Talbot**,
Chairman of the Rothamsted Research Board of Directors

Rothamsted Research where knowledge grows: the vision

Rothamsted Research has a vision to provide the scientific knowledge, innovation and new practices to increase crop productivity and quality, whilst developing environmentally sustainable solutions for agriculture through world-leading research in plant and soil science.

Vision: to be a world leading biosciences research centre for sustainable agriculture

Our mission statement:

to perform world-class research to deliver knowledge, innovation and new practices to increase crop productivity and quality and to develop environmentally sustainable solutions for food and energy production

The purpose of the Strategy is to ensure Rothamsted Research is performing cutting edge scientific research on the critical factors responsible for plant productivity, crop quality and agricultural sustainability and engage with the public to translate results into robust technologies that can be used by policymakers, agribusinesses, food manufacturers energy companies and farmers to improve crop yields and enhance nutrition, contribute to energy security, reduce the carbon footprint of farming and protect and nurture the agricultural environment.

No single approach can deliver sustainable agriculture with high productivity and value. A broad perspective that encompasses the whole plant system is needed and a careful balance of approaches is required. This should include biotechnology, but also include areas of science such as agronomy and agro-ecology so we can understand how existing and new knowledge can be implemented through agricultural practice.

This Strategy will therefore be delivered through four outcome-focused progammes, which are consistent with the Biotechnology and Biological Sciences Research Council (BBSRC) strategy (1) and draw on the best expertise at Rothamsted Research.

These are:

1. **20:20 Wheat**: Increasing wheat productivity to yield 20 tonnes per hectare in 20 years.
2. **Cropping Carbon**: Optimising carbon capture by grasslands and perennial energy crops, such as Willow, to help underpin the UK's transition to a low carbon economy.
3. **Designing seeds**: Harnessing our expertise in seed biology and biochemistry to deliver improved health and nutrition through seeds.
4. **Delivering Sustainable Systems**: Designing, modelling and assessing sustainable agricultural systems that increase productivity while minimising environmental impact.

We believe this comprehensive strategy utilises the strengths of Rothamsted Research and not only embraces systems biology and biotechnology, but also draws on our deep knowledge of agronomy, soil science and agro-ecology. At the heart of this Strategy is a customer focus with a need to provide the knowledge and innovation to policymakers, manufacturers and most importantly the farming community who are integral to delivering sustainable food security. This strategy therefore combines our long-standing tradition, with vision.

Putting the strategy in context

The current world population of 7 billion is projected to reach 9.3 billion by 2050, an average increase of over 160,000 people every day (2). Coupled with other factors, particularly people moving from rural livelihoods to cities, rising global temperatures and extreme weather events becoming more frequent, an enormous stress will be placed on our natural resources and therefore our ability to provide adequate nutritious food and to safeguard our environment through clean air, soil and water.

The Food and Agriculture Organization of the United Nations (FAO) forecasts that global food production will need to increase by over 40% by 2030, and 70% by 2050 (3). In addition, global demand for energy and water could double by 2050 (4). Even now in the second decade of the 21st century nearly one billion people are undernourished and food prices are at an all time high, with price volatility leading to socio-economic impacts, such as civil unrest.

Increased food production must be achieved whilst ensuring agricultural systems are sustainable with a reduced environmental impact. Agriculture already currently consumes 70% of total 'blue water' withdrawals from rivers and aquifers; has caused the degradation of about 24% of the 11.5 billion hectares of vegetated land on earth; and is estimated to contribute to 10 to 12% of global greenhouse gas emissions.

The UK Government's Chief Scientific Adviser has concluded "The challenge for global agriculture is to grow more food on not much more land, using less water, fertiliser and pesticides than we have historically done". We therefore need to conduct the necessary scientific research to be able to deliver "Climate-Smart" agriculture and "sustainable intensification" (5,6).

The new Rothamsted Research Strategy aims to provide policymakers, manufacturers and farmers with the scientific knowledge and innovative methods to be able to meet this global challenge.

Our strategy is closely aligned with the BBSRC's recently published Strategic Plan (1), dovetailing into all three of its strategic research priorities on "Food security"; "Bioenergy and industrial biotechnology"; and "Basic bioscience underpinning health". Consequentially our strategy also complements the UK Government's national policies on food and farming and the United Nations' strategic priorities.

A feature of this Strategy is that it is designed to be flexible to meet the demands of the rapidly evolving scientific environment that surrounds it.

"The challenge for global agriculture is to grow more food on not much more land, using less water, fertiliser and pesticides than we have historically done"

– **Sir John Beddington**,
The UK Government Chief Scientific Adviser

Strategic Theme 1: **20:20 Wheat**

Increasing wheat productivity to yield 20 tonnes per hectare in 20 years.

Ensuring food security is a major challenge for the future. Wheat provides a fifth of human calories, but since 1980 the rate of increase in wheat yields has declined. The average farm yield of wheat in the UK is currently 8.4 tonnes per hectare. Our aim is to provide the knowledge base and tools to increase UK wheat yield potential to 20 tonnes of wheat per hectare within the next 20 years.

This strategic theme will be delivered through four programmes:

1. **Maximising yield potential.** With the requirement for novel approaches to increase yield, we will focus on genotype improvement to improve total crop biomass and grain yield through improved photosynthetic efficiency, altered canopy and root architecture, modified seed development and enhanced nutrient utilisation efficiency. This will be introduced utilising breeding, exploiting novel germplasm, transgenesis and other forms of genome remodelling. The potential for these approaches to offer substantial increases in yield is exemplified by the difference between C3 and C4 plants, where, for a given volume of water, photosynthetic efficiencies can be 50% higher in a C4 plant because of the suppression of photorespiration (7, 8, 9, 10).

2. **Protecting yield potential.** We will use advanced technologies to mitigate losses through pests and diseases. This will encompass the aetiological agents for Septoria leaf blotch, Fusarium ear blight and “Take-all” which have the highest negative impacts on wheat yields in the UK and elsewhere. Robust solutions to these diseases could contribute 5 to 10% in average yield increases (11, 12, 13).

3. **Determining soil resource interactions.** We will develop a mechanistic understanding of how soil properties and root characteristics interact to determine water uptake and nutrient acquisition. Efficient water utilisation is a prerequisite for efficient photosynthesis and yet wheat can be very sensitive to changes in osmotic potential resulting in reduced photosynthetic efficiency. The potential of this approach to contribute substantially to yield could be in the region of 10 to 18% (14, 15).

4. **Using systems approaches to crop improvement**. We will, through crop models based on physiological and environmental parameters, explore gene-environment interactions, deconvolute complex traits (e.g resource-use efficiency) and explore the performance of wheat ideotypes under climate change (16).

Strategic Theme 2: **Cropping Carbon**

Optimising carbon capture by grasslands and perennial energy crops, such as Willow, to help underpin the UK's transition to a low carbon economy.

The UK has an ambitious target of 80% reductions in greenhouse gas emissions by 2050. We will aim to provide renewable and sustainable alternatives for fossil fuel-based products and to translate these into robust technologies and practices that can be used by policymakers, agribusinesses and energy companies to help underpin the UK's transition to a low carbon economy and contribution to future energy security and mitigation of global climate change.

This strategic theme will be delivered through three programmes:

1. **Maximising carbon harvest.** We will study the genetics, biochemistry, physiology and agronomy of carbon flux in Willow and Miscanthus, and exploit the unique knowledge developed at Rothamsted on genetic regions in Willow associated with high biomass and energy production (17). At the biochemical level, the pathways and flux of fixed carbon in these highly productive lines will be analysed using metabolomics (18, 19). Our ability to cross and select improved willows using conventional breeding, underpinned with molecular marker technologies, provides a delivery route to industry, whilst Willow transformation is being developed to provide a rapid means of testing the function of potentially useful genes.

2. **Increasing carbon retention.** We will study the potential to increase carbon stocks in agricultural soils by using our long-term trials in perennial energy crops, particularly exploiting the C4 physiology of Miscanthus and the Highfield reversion experiment where wheat, grass and fallow land-use has been monitored since 1949. At our North Wyke site, we will investigate potential carbon sequestration in soils at the molecular level using the analyses of plant biomarkers and compound-specific stable ^{13}C isotope ratio mass spectrometry. The carbon cycle in soils is a continuum of “above ground” and “below ground” plant biomass deposition and relatively little is known about what controls the residence time of carbon in soils between these two end points. Understanding the contribution of roots to sub-soil carbon stocks and the underlying biogeochemical processes for carbon stabilisation in deep soils may inform strategies for enhanced sequestration of carbon (20, 21).

3. I**ntegrating carbon systems**. We shall examine patterns of carbon fluxes between sources and sinks in different perennial cropping systems by developing models to assess interactions between “above ground” and “below ground” plant biomass. We will take into account not only carbon used in growth of the living plant, or stored in reserves, but also secondary metabolites and losses through soil litter, volatiles and exudates. These models are highly relevant to the farming industry and land use planning (22) where the entire carbon (and nitrogen) flux of a farm operation must be optimised. In the future, based on such calculations farmers could access carbon credits for new land use practices, which markedly improve their overall carbon footprint compared to standard procedures.

Strategic Theme 3:
Designing Seeds for Nutrition and Health

Harnessing our expertise in seed biology and biochemistry to deliver improved health and nutrition through seeds.

Seeds are major components in a wide range of foods and animal feeds, so their composition is an important determinant of nutritional value. We will focus on understanding and optimising the nutritional value of the seeds of two crops, wheat and brassicas, with the aim of enhancing their impact on health and well-being.

This strategic theme will be delivered through three programmes:

1. **Cereal seeds as a source of dietary minerals and fibre**. We will determine the mechanisms for the synthesis and feruloylation of wheat cell walls (23, 24) and exploit this information to develop novel types of wheat with enhanced health benefits. Wheat cell walls are a major source of dietary fibre, with bread alone contributing 20% of the daily adult intake in the UK. However, the fibre intake by UK adults falls far short of dietary recommendations, contributing to increasing health problems. Wheat dietary fibre also contains high levels of phenolic acids (notably ferulic acid) which may reduce cardiovascular disease. Collaborations with Institute of Food Research (IFR) and the Universities of Reading and Birmingham are determining the molecular basis for these health benefits using *in vivo* and model systems. More than 2 billion people worldwide suffer from mineral deficiencies, notably of iron and zinc. We will also determine the genetic variation in content, form, location and bioavailability of these minerals in wheat grain and identify the mechanisms and genes that determine these differences (25). Genetic engineering will also be used to enhance the contents and bioavailabilities of these minerals.

2. **Metabolic engineering.** We will generate oilseeds (Brassica and Camelina) producing 20 to 30% of long chain polyunsaturated fatty acids (LCPUFA), typical of those found in oily fish i.e. stearidonic acid, EPA and DHA (26). This will be applicable directly as a source of healthy oils for infant and adult human nutrition, where they have been shown to have proven health benefits. They could also be used in aquaculture to enhance the LCPUFA content in farmed fish, which are currently only maintained by feeding them fish-meal, which is not a sustainable practice (27). IFR and the John Innes Centre will also explore the feasibility of this work in dietary intervention.

3. **Control of lipid catabolism.** We will control lipid catabolism in seed storage which is essential for an oilseed plant becoming established, prior to becoming photoautotrophic. In the latter stages of oilseed maturation, 10 to 20% of seed triacylglycerol is mobilised, leading to a loss of potential yield and relatively little is understood about the control of lipolysis and peroxisomal β-oxidation (28). In addition to storage oil catabolism, the latter pathway also plays a role in the generation of signalling molecules (29). This work will be conducted in the context of protecting the plant's physiology.

Strategic Theme 4: **Delivering Sustainable Systems**

Designing, modelling and assessing sustainable agricultural systems that increase productivity while minimising environmental impact.

We believe that it is possible to provide secure and increasing amounts of healthy food and make a contribution to the supply of renewable energy without reducing other ecosystem services. We will aim to show how such systems can be delivered through research into better ways of managing pest control, biodiversity, grazed grassland and soils with the overall goal of designing and quantifying sustainable systems.

This strategic theme will be delivered through four programmes:

1. **Sustainable crop protection**. We will investigate the appearance of new pest and pathogen species, the emergence of new indigenous problem species genotypes and use our knowledge of the ecological, genetic and molecular basis of adaptive traits to prolong the lifespan of chemical crop protection tactics (30).This will build on our existing work on the primary mechanisms of resistance and mathematical models of resistance evolution to translate this fundamental knowledge (31) into strategies for the better deployment of agrochemicals. We will also develop alternatives to traditional pest control by exploiting our long-established expertise in chemical ecology and the ecology of pests with their natural enemies (e.g. 32), supported by mathematical models for novel crop protection tactics within an ecologically-based framework to ensure their sustainability (33).

2. **Optimisation of nutrients in soil-plant systems**. We will exploit systems biology techniques ('omics', e.g. 34) to understand soil ecosystem function, investigating nutrients and pollutants in the soil, as well as carbon and nutrient cycling above and below ground through soil-water and soil-air interactions in agricultural systems. We will encompass modelling approaches to explore and resolve possible conflicting requirements of reliable agricultural and energy production and natural resource management. This work will also investigate physically-based predictive indicators of soil structural function. This will provide new knowledge on key soil parameters that are important to sustainability and the central drivers of nutrient cycling in soils (35).

3. **Movement and spatial ecology in agricultural landscapes.** We will gain a better understanding of the effects of spatial scale on the ecological functions of pollinators, pests and their natural enemies by investigating how they search for, find, and utilise patchily distributed resources. We have a unique research capability (36, 37) to study each of these processes both above and below ground, at the relevant spatial scale, from microns (10^{-6} m) through farms (10^{3} m) and agricultural landscapes (10^{4} m) to trans-continental insect migration (10^{6} m). Such information is essential to predict invertebrate distributions in farmland. We can then target pest control strategies, and optimise ecosystem services that other invertebrates provide (e.g. pollination).

4. **Quantifying sustainability**. We will determine an objective means of assessing sustainability, which still has no clear quantifiable definition. The focus will be on developing novel mathematical tools with which to quantify the sustainability of agroecosystems (38). This has the potential to act as a unifying framework (39) which can be applied to much of the work in the overall Rothamsted Research Science Strategy.

National Resources to support our Strategy

Our strategic scientific themes will be underpinned by four National Capabilities at Rothamsted Research:

The Long-Term Classical Experiments which have been running since the mid 19th Century, provide a unique experimental system and archive of soil and plant samples, permanently managed through the electronic Rothamsted Archive (e-RA) database. Unsurprisingly, many papers published in high impact factor journals use the Long-Term Experiments as a resource (e.g. 40). We will continue to build the resource with more data from modern molecular-based approaches such as metagenomic analysis of soil biodiversity.

North Wyke (Devon) Farm Platform is globally unique in that it can provide the research community access to a range of *in situ* state-of-the-art instrumentation in hydrologically isolated fields and farms to better address key issues in sustainable agriculture. The Platform's three independent 25 hectare farms allow scientific hypotheses and technologies to be tested on a whole working farm level to ensure they are applicable for farmers. The Farm Platform experiments will be used to develop models for farming practices to optimise productivity whilst minimising environmental impact. The Farm Platform will be a focal point of collaborative agricultural research with UK laboratories and offshore Universities.

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PHI-base is a database of interactions between pathogens and their hosts maintained at Rothamsted Research with input from the international community. It is an invaluable resource in the discovery of genes in medically and agronomically important pathogens, which may be potential targets for intervention strategies in the prevention and treatment of diseases. It is a unique resource that currently contains 1335 interactions associated with 1065 genes from 102 pathogenic species, as of November 2011 (41, 42)

The Rothamsted Insect Survey operates two national networks for monitoring insect populations in the UK. It is accessed by large numbers of external partners and its data used in many publications. The data from both networks have a range of applications in fundamental and applied aspects of insect population dynamics and ecology (43).

These Resources have national and international importance for the research underpinning sustainable agriculture. We will promote our investment in these capabilities to foster collaborative links with other researchers and we will share our data to ensure that others can benefit from these publically supported resources.

Enablers

Interwoven throughout each of these strategic work programmes are a series of cross-cutting themes that will enable delivery:

Collaboration

We believe that success can only be achieved through close collaboration with partners.

Throughout our 168-year history, we have established deep, long-term partnerships with Government, Industry, Academia and charitable organisations in the UK and internationally. Whist the list is too long to adequatey reproduce in this document, these partnerships come from a mixture of formal and informal relationships between individuals and between organisations.

But we wish to extend our collaborations further which is why we will be increasing our partnership working through productive and meaningful collaboration.

We are looking to expand collaborations with external partners

Delivering excellence and valuing diversity

Rothamsted already has a great cadre of talented scientists. But we believe they should be allowed to concentrate on their research and not be encumbered by administrative duties.

This is why we will be introducing ways of working with an emphasis on leadership and development, for all our current and future scientists.

We also believe that true innovation, creativity and scientific discovery comes when scientists of diverse backgrounds are brought together. We will actively encourage our scientists to be flexible, multidisciplinary and to push at the boundaries of their respective scientific disciplines. Rothamsted has a proud history of developing a multiethnic and multidisciplinary workforce and that is why we will continue to focus on this from Ph.Ds through our postdoctoral scientists to our principal investigators.

Rothamsted also has a unique training vehicle in the Rothamsted International Fellowships, funded by the Lawes Trust and other donors. These fellowships train scientists from developing countries in modern, but transferable, agricultural science and assist them in training their peers on return to their home.

Our future training and education plan will place a much stronger emphasis on mentorship and career development. This is intended to maintain our position as one of the most desirable venues to pursue a Ph.D in plant or soil science or agro-ecology, but also to build a stronger cohort of mid-career scientists, who will become the next generation of scientific leadership at Rothamsted and beyond. We will encourage our scientists to continually learn and train to develop new expertise.

Our training and education plan will place a much stronger emphasis on mentorship and career development and reduced administrative burden

Our Ph.D programmes have a 94% completion rate, which is significantly higher than the national average completion rate of 72% (44).

Public engagement

We believe that it is our duty to engage with other scientists and non-scientists alike. We particularly value our role in enthusing children about science in general and agricultural science in particular, at school level. This is why we have an extensive schools programme which we will continue to support.

We also believe in the importance of community. This is why we will work with the community in engagement exercises. It is important that Rothamsted Research is not just a teaching establishment, but also a listening establishment which is why we will enhance our public community feedback programme, utilising the principles of the Concordat on Public Engagement already established by the UK Research Councils (45) and embedding public engagement into the organisation. Rothamsted Research will continue to hold evening public meetings on topics relating to agriculture and environment. These are well-attended by local residents and provide lively debate on topics of the day.

Being open and transparent

We believe that openness and transparency is crucial. The public should be encouraged to ask questions about our research and be able to see the work we conduct, as ultimately it will be of benefit to them as a consumer.

Linked closely with our public engagement work we will ensure, where there is no legal barrier, our work is conducted in a transparent manner. For example, we will continue to have open weekends which attracted over 7000 visitors in a single weekend in 2010.

Origins and legal status of Rothamsted Research

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

Rothamsted Research Limited is an independent charitable company, limited by guarantee and governed by a Board of fourteen non-executive Trustee Directors currently chaired by Professor Nick Talbot. 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 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: www.rothamsted.ac.uk. The Chief Executive of Rothamsted Research is the Institute Director who reports to the Board Chair and is in attendance at Board meetings along with the Associate Directors.

Rothamsted Research has an annual income of around £26 million with largest part coming from the BBSRC in the form of milestone-driven strategic programme grants (approximately £13M). BBSRC also provides investment in equipment and facilities and is the employer of most of the staff at Rothamsted Research, though from October 2011 all new staff are Institute employees. 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 the ownership of intellectual property and similar rights being with Rothamsted Research along with the obligation to ensure this is commercialised by the most appropriate channels available.

LAT owes its existence to an endowment made by Sir John Bennet Lawes, the founder of Rothamsted whose family had lived at Rothamsted Manor since the 17th Century. In compliance with its Deed of Foundation LAT supports agricultural science nationally and internationally, primarily through the provision of facilities and funding to Rothamsted Research and Rothamsted International. The estates at Rothamsted and Broom's Barn, including many of the buildings used by Rothamsted Research are owned by LAT through its corporate trustee LAT Company Limited, which is also charitable company. There are six Trustee-Directors of the LATCo Board appointed with the approval of the Royal Society. The Institute Director and Company Secretary of Rothamsted Research are also the executive officers of LATCo.

As such, the entirety of “Rothamsted” is best thought of as an enduring “partnership” between three parties with coincident interests: LATCo, BBSRC and Rothamsted Research and these three elements are combined in and sustained by the Members of the Rothamsted Research charity, thereby facilitating the long-term operational functionality of the this association.

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

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