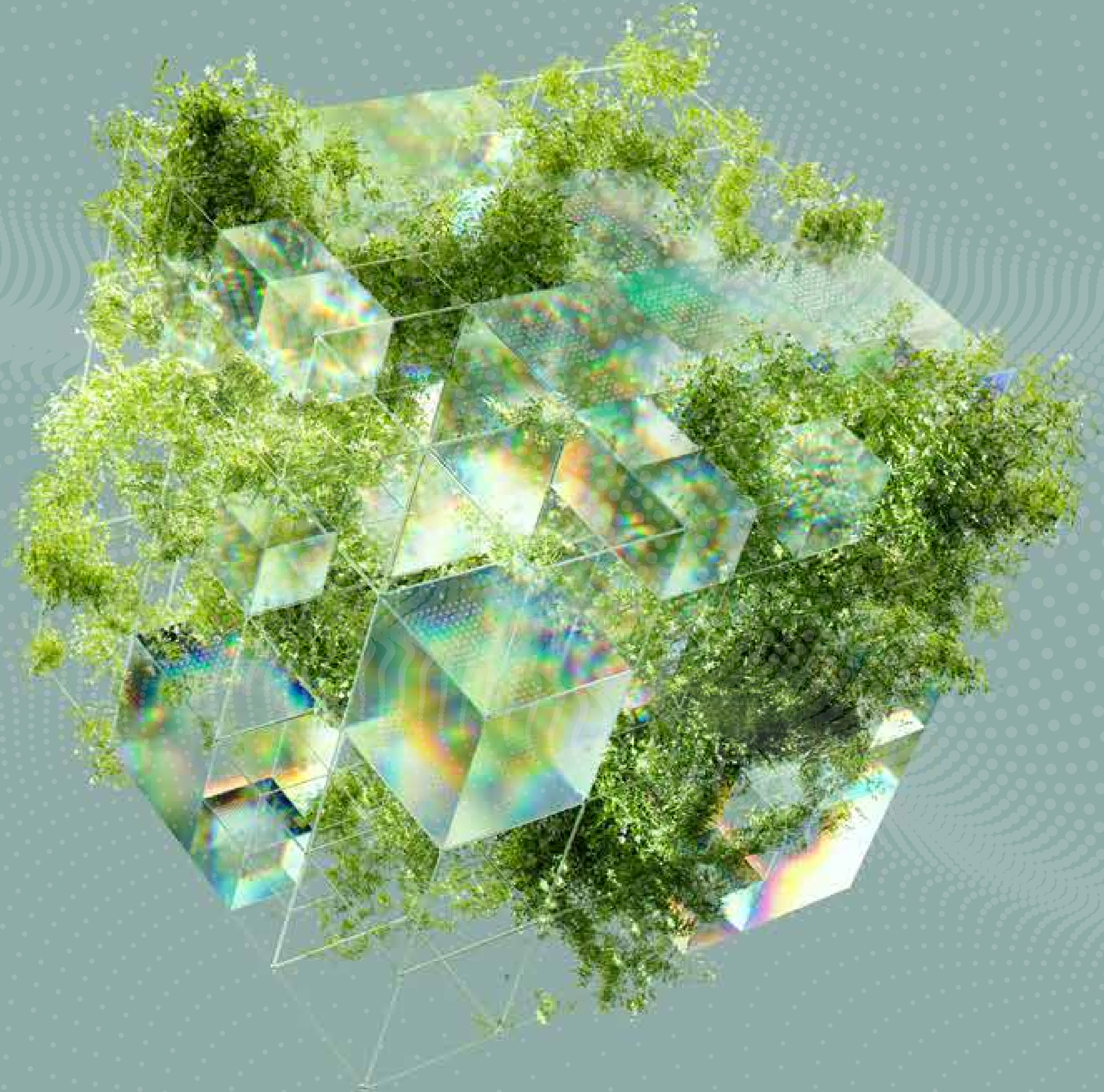


2023 Yearbook

ROTHAMSTED RESEARCH

From the Director

Artificial intelligence (AI) – often defined as the machine-driven capability to perform tasks and solve problems, imitating human intelligence – is among the government's top list of emerging technologies. Through 180 years of experimental science, and method development in robust data capture and analysis, Rothamsted is in an exciting and very strong position to use AI to mine the richness of its globally unique data sets for the benefit of researchers, farmers, government and industry nationally and internationally.

In one form or other AI has been with us for decades. Ever since Alan Turing began his early thought experiments on what AI was, it has been slowly evolving - but often in ways that the public have barely noticed.

Early computers couldn't think. They could execute commands but couldn't remember what they had done. As processing power developed, however, simple forms of AI quickly emerged and in the 1960s and 1970s the concept rapidly advanced.

The 2020s, however, have arguably experienced the biggest changes. With the launch of Chat GPT, AI moved almost overnight from being the interest of computer scientists and science fiction writers to an attractive and handy tool that anyone could use. With a few simple instructions, the new software could replicate in seconds well written prose about almost any subject. It has revolutionised public perceptions of the new technology, made many writers fear for their jobs and, with similar advances in video and audio, launched us into an uncertain world where AI generated deep fakes are beginning to impact public discourse.

AI, and its cousin, machine learning, are certainly grabbing the headlines for these reasons. But they are also opening new ways of driving scientific endeavour which may transform the way we conduct our research.

An early example has been Deepmind's protein shape predictor Alphafold. There are over 200 million known proteins, with many more found every year. Each one has a unique 3D shape determining how it works and what it does. Figuring out the exact structure of each could sometimes take years. The new program has studied over 100,000 proteins to enable it to accurately predict how a chain of amino acids might fold. This has the potential to rapidly accelerate drug discovery. It also has huge applications in plant science, with the ability to turbocharge the green engineering that will future-proof our crops.

At Rothamsted, with our vast quantities of data, we have always been early adopters of computing innovation. A mechanical Millionaire Calculator used by our early statistical pioneers still sits in our storeroom. A huge mainframe computer, the mighty Elliot 401, was installed in the 1950s, and helped build on our reputation for statistical excellence.

As such, it will come as no surprise that we are now investing heavily in our potential to use AI. A major step forward this year was securing £4m from BBSRC to install a high performance computing capability on site. This will be transformative and deliver world class data analysis across all our research portfolio.

One of the great drawbacks of agricultural research is that it is relatively slow. We have always placed great emphasis on practical field-based experimentation - indeed it is vital to be sure that what might work in the lab or glasshouse, works as well in field conditions. But if you have to test your ideas in the field every year, you might only get 40 experimental seasons across an entire scientific career.

That may have been acceptable in the past, but the problems facing agriculture and the environment are now so acute, that we have to find ways to speed things up. AI will be part of the solution. Paired with huge advances in genomics, we are surely on the verge of a revolution in agricultural science.

Our goal is to use advanced monitoring technology to capture real-time information about all aspects of the farming systems, such as is currently possible at our North Wyke Farm Platform. In future, this will include more measurements, such as changes in the hugely complex soil microbiome, chemical analysis, crop performance and the changing climate. We are using this wealth of data to develop digital twins which act like real systems. This will allow us to conduct limitless virtual experiments, altering the various factors that underpin agriculture and assessing what changes we need to make to achieve particular outcomes, such as more climate resilient farms.

Given the pressures our farmers currently face, such timely information will be invaluable. Our "real-world" experimental work will always remain at the heart of what we do, but by using and exploiting the data generated in new and innovative ways, we can massively accelerate our research and deliver much more for farmers, conservationists and policymakers.

And in case you were wondering, this foreword was generated by human thought, not an AI program. Sometimes a personal touch is needed!

Professor Angela Karp
Director and CEO

New Strategic Research Programmes get underway

Growing Health

- With industry partners, chemical ecology research is being used to develop novel technologies for pest management and pathogen monitoring, including developing routes to upscaling pheromone production, and validating a novel field tool that can detect pathogens and direct precision fungicide applications.
- Soil microbiome research is being translated into practice in collaboration with industry partners, to develop novel microbial soil health indicators based on changes in abundance of groups of bacterial genes with conserved functions, which can be monitored using low-cost techniques, as 'soil health barometers'.
- In a new partnership with a large food company and their supply chains, we are providing guidance on baseline soil sampling using optimal sampling designs and protocols, and support for future verification and reporting using measurements and modelling, with a focus on assessments of soil C sequestration.

Resilient Farming Futures

- Our construction of a new replicated experimental plot scale platform as a UK climate change facility is ahead of schedule. This new facility provides a unique means of exploring the impacts of abiotic stresses on crop yields and regulatory services and is a focus for collaborative connectivity with academic and industry partners.
- Our strategic partnership with the Catchment Sensitive Farming (CSF) initiative in England and our detailed assessment of the resilience of water quality to extreme weather in 7 sentinel test landscapes is providing much needed evidence to this policy delivery initiative on the robustness of on-farm best management measures to climate change.
- We have established a working relationship with, and direct feed into, the Defra Environmental Land Management (ELM) Monitoring and Modelling Strategy Group (MMSG) and are using Defra farmer attitudinal data licensed to RFF by Defra to run specific scenarios for policy appraisal.

Green Engineering

- A precision-bred (genome edited) high lipid forage crop was developed and trialled in the field for the first time. The trait has the potential to improve livestock production efficiency and lower ruminant methane emissions.
- We have continued to develop GM crops producing lipids for human health and nutrition. To accelerate translation of engineered lines, we obtained Ministerial Consent to carry out field trials throughout the lifetime of the Green Engineering Programme. These will test improved engineering iterations and brand-new ideas under real-world conditions.
- We have developed new polymeric materials directly from willow biomass as an alternative to those made from petroleum derived phenol. This has potential to contribute to the development of new sustainable materials, helping the UK to meet its Net Zero targets.

New Strategic Research Programmes get underway

Delivering Sustainable Wheat

- Rothamsted continues to make a major contribution to the programme through its work on development and implementation of high-throughput phenotyping in the field.
- Genetic screening to identify wheat lines with improved tolerance to heat and drought stress has started. Transgenic lines over-expressing and silencing meiotic genes have been generated and evaluation of their meiotic phenotype and yield components under normal and stress conditions is underway.
- Introgression of QTLs for high arabinoxylan into elite UK cultivars has shown that high fibre in white flour can be combined with good yields and processing quality.

- Analysis of crosses between Watkins landraces and the UK elite cultivar Paragon have enabled a 'mineral atlas' of the genome to be produced. A major QTL for the essential mineral calcium has been identified and this is now being stacked with QTLs for high fibre to improve the calcium status of consumers.
- The *Zymoseptoria tritici* research projects have begun to capitalise on fungal genomics and mutagenesis approaches which, when combined with whole genome re-sequencing, has been rapidly advancing virulence gene identification and characterisation.

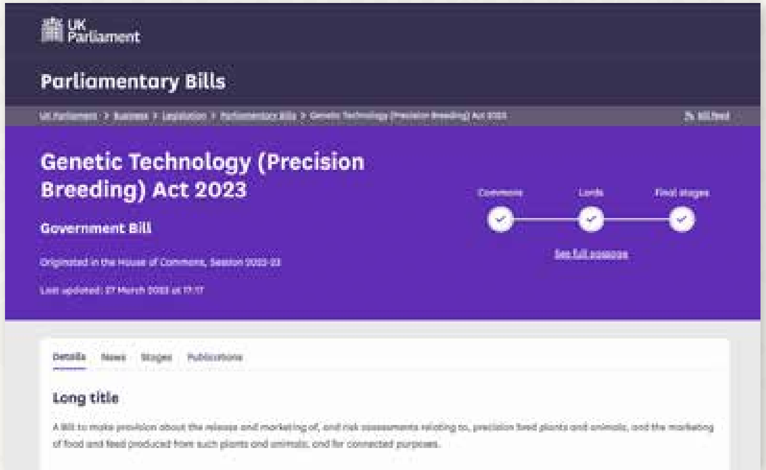
AgZero+

- As the large scale monitoring campaign of UK farms gathers pace, this ambitious five-year research programme is supporting the UK's transition towards domestic food production that is sustainable, carbon-neutral and has a positive effect on nature. It brings together a community of researchers and farmers to evaluate innovative farming methods and to define practical pathways to achieving "net zero plus" arable and livestock farm systems.
- The programme is now well advanced in surveying farm pairs across the UK with differing management strategies to achieve multiple outcomes including soil carbon, greenhouse gas emissions and biodiversity.
- The field sampling campaign is being supported by large scale analysis of satellite data and modelling to upscale alternative scenarios. Outreach is built in to the programme and in 2023 a series of practical video guides to sustainable farming was launched.

It's the law:

Precision Breeding Act comes into force

On Thursday 23 March 2023, The Genetic Technology (Precision Breeding) Act received royal assent, following 10 months of debate across both Houses of Parliament.



Under the provisions of this Act, a new science-based and streamlined regulatory system will be introduced to facilitate greater research and innovation in precision breeding — with stricter regulations remaining in place for genetically modified organisms (GMOs).

A parliamentary bill for gene-edited food crops to be developed, grown and sold in England has passed into law.

The bill updates regulation of precision-bred organisms in England and seeks to enable breeders to use gene-editing technologies, such as Crispr-9/CAS9, to develop more resilient, healthier, and higher-yielding crops.

Benefits to the environment from the technology could include less land being used for farming and a reduction in farm inputs such as water, fertilisers, and pesticides — as well as a reduction in overall greenhouse gas emissions, says genetic engineering pioneer, Prof Johnathan Napier.

"The UK's bioscience sector is now open for business," he said. **"Early benefits of gene editing for UK agriculture could include gluten-free wheat, oilseeds with heart-healthy fats, disease-resistant sugar beet and potatoes that are even healthier than those we have now.**

"Gene editing can also help accelerate the improvement of orphan crops like cassava, millet, cowpea and yams, which are critical to food security in less developed parts of the world."

New long-term experiments

First research paper from our new long-term experiments suggests that agro-ecological changes will take time.

Initial results from a new set of long-term experiments at Rothamsted suggest that more regenerative approaches to agriculture, such as no-till and diversified cropping, are not a short-term fix for more sustainable food production systems but will require a long-term commitment.

An experimental setup of 24 cropping systems that combine a variety of regenerative agriculture practices was established at sites in Hertfordshire and Suffolk in 2017/18. It has so far shown that, in the short-term, reduced tillage has resulted in lower wheat yields but the effect varied with crop rotation, previous-crop and site.

Plots with added organic matter significantly increased spring barley yield by 8% on average, though the effect again varied with site. The ploughed crop plots tended to produce higher caloric yield overall than systems under reduced tillage.

"The initial results suggest that it takes time for regenerative approaches to restore the health of soils and the ecosystem. In addition, there may be a decrease in yields as the system transitions to a more sustainable state," said study team leader Professor Jon Storkey. **"With so many variables in play, only a long-term, integrated approach will be able to tell us "what really works" in regenerative farming."**

Rather than just focussing on crop yield, these new Large Scale Rotation Experiments (LSREs) are being monitored to study the synergies and trade-offs of each approach. The experiment has been established as a long-term resource for inter-disciplinary research.

Professor Jon Storkey said:
"Inevitably trade-offs will need to be made between maximising crop yield and protecting the environment, but these experiments will help us better understand the system behaviour, and ultimately identify the optimal balance for multiple systems and approaches."

As the experiment matures, the LSRE will use novel computing and statistical analysis to evaluate the importance of long-term data. This will provide the evidence base for alternative pathways to sustainable agriculture. It will also serve as a demonstration site for encouraging the transition to more sustainable farming systems.

Livestock

Intensive grazing can still deliver environmental benefits

A new study comparing traditional (set stocked) cattle grazing with a highly-stocked cell-based approach suggests that grassland can recover just as well from the higher density approach, provided the animals are moved on a regular basis.

The findings could have major implications for livestock management, allowing farmers to use less land to deliver similar quantities of high-quality protein without adversely affecting soil conditions.

The study, undertaken at Rothamsted's North Wyke farm in Devon, compared soil disturbance in traditionally grazed and cell-grazed fields. In cell grazing animals are penned into smaller areas of the field which are then regularly moved to make more efficient use of the land. In this way more grass is grown and harvested, which in turn promotes the recovery of soil structure in the non-grazed areas. This allows for more cattle to be raised on the same area of pasture by making sure all the grass is grazed more-or-less equally.

By measuring soil compaction in both systems over a season, the researchers found that there was no significant difference in how grazing affects soil structure and how well the pasture recovered over the winter break.

"The results suggest that with careful management of cell grazing, stocking rates on grassland could be increased with no detrimental consequences in soil structure beyond what would normally occur on grazed pasture," said Dr Alejandro Romero-Ruiz who led the study. **"This means we can deliver more high-quality protein using the same land - thus contributing to meet the growing demand for animal-origin foods."**

In a perfect system, livestock would graze all parts of a field equally. In reality, the animals tend to cluster around features like water troughs leading to uneven grazing and bare patches. Cell grazing reduces these problems. The research team developed a so-called "Moovement model" linking grazing patterns with soil structure and soil functions which may have applications to assess the impacts of grazing in other localities.

> **"A better understanding of how livestock move and interact with their environment will potentially also offer solutions to reducing the impact of cattle on soil health and the environment."** said Dr Alejandro Romero-Ruiz.

100 years of the National Willow Collection

In 1923, driven by post-World War I concerns of basket scarcity, the first cuttings of the National Willow Collection were planted. Initially based at the Long Ashton Research Station, the unique germplasm collection was transferred to Rothamsted in 2002. The repository now boasts over 100 pure willow species and over 1500 accessions. This living heritage serves as an invaluable resource for ground-breaking biological and pharmaceutical innovation.

A new biomass fuel

Willow grows extraordinarily fast. This makes it ideal as a biomass feedstock. Regularly coppiced, a stand of willow can generate significant quantities of carbon-neutral wood chips from multiple harvests over its up to 30-year plantation life. Unlike first generation energy crops like maize, willow can be planted on lower quality land, grown with fewer inputs, on most soil types sequesters carbon below ground and helps bring biodiversity back to farms.

Rothamsted's perennial energy crops research team is part of a UK-wide initiative Biomass Connect, aiming to support the growth of the UK biomass industry as part of the drive towards net zero. The team also leads Accelerating Willow Breeding, using techniques such as micropropagation and genomic selection to find optimal willow varieties for different growing environments.

William Macalpine, willow breeder said: **"We have been working hard to help de-risk the potential adoption of perennial bioenergy for potential UK growers or land managers. We are doing this by highlighting the best varieties available now and laying the foundations for producing new varieties using advanced breeding techniques."**

New products from ancient trees

Willow bark contains an effective painkiller called Salicin. After its discovery, scientists developed the structurally similar, synthetic drug Aspirin. Rothamsted has been actively bio-prospecting the trees in the National Collection for new useful chemicals. Miyabeacin, a new compound with activity in a range of cancer cell lines was identified and extracted from willow at Rothamsted in the 2010s with a research paper published in 2021. New research is also exploring willow phenolics which can be used to make more sustainable bio polymers and contribute to the move away from fossil fuel derived industrial products.

Jane Ward, natural product chemist said **"If we can harvest useful compounds from willow easily and economically, its potential to be a viable addition to farming systems will be hugely enhanced. Results so far are promising and are relevant for products in multiple commercial sectors."**

The battle against Blackgrass

This pernicious weed of arable crops constantly outwits our efforts to control it, but we can learn a lot from its survival strategies.

Blackgrass is one of the most problematic and damaging agricultural weeds for winter wheat in Western Europe. Severe infestations can result in yield loses of up to 70%, squeezing farm productivity and ultimately imperilling food security. It costs UK farmers around £400 million per year and as few as 12 plants per square metre could reduce crop yield by 5%.

Rothamsted and its partners have been mapping blackgrass across the UK since 2014. Assisted by a network of over 60 citizen scientist farmers, the team have developed detailed plans of where the weed is thriving and how that relates to on-farm practices.

Until recently this was a painstaking process – responding to farmer tip-offs by tramping through fields and physically counting blackgrass plants. But all that is about to change. Using drones and farm machinery equipped with sophisticated visioning technology, the team believe they are close to being able to pick out the hard-to-spot blackgrass spikes automatically.

"This could give us fast, real-time data on how the plants are spreading and where they're surviving current management," says Rothamsted weed ecologist Dr David Comont. **"Combining this with AI based number crunching, we hope that new management strategies for control can be rapidly developed."**

Smart spraying

Even if blackgrass patches can be identified, however, that still leaves the problem of removal. New forms of in-field control are urgently needed – and smart spraying may be one option. Rothamsted is partnering with Bosch, BASF Digital Farming and Chafer Machinery to use precision farming technology and artificial intelligence to tackle the problem. Sophisticated cameras and software, combined with innovative boom sprayers can detect, identify and map blackgrass at different growth stages within cereal crops across a farm. The information can be used to map in-field populations so that integrated weed management plans can be developed.

The project is still in its infancy, but the team hope that it could result in reduced herbicide volumes being sprayed in-field.

A shape-shifting adversary

Away from control strategies in the field, blackgrass presents lab-based researchers with an intriguing challenge. The fact that blackgrass is so highly adaptable in farming systems makes it hard to devise reliable methods of controlling it. However, this same adaptability may also shed light on how we can make our crops more resilient – particularly as our climate shifts.

"We need to figure out what we can learn from blackgrass," says geneticist Dr Dana MacGregor at Rothamsted Research. **"If we want to future-proof our crops, studying how weeds deal with new stresses like a changing climate or altered cropping patterns, could help us to identify new or useful traits that aren't currently present in our highly-bred crops."**

MacGregor has been delving into the genome of blackgrass, and she and her collaborators recently made an extraordinary breakthrough. They discovered that the weed has tiny circles of DNA outside of its main chromosomes. These evolve separately from the genetic material in the nucleus and the genes for herbicide resistance appear to be encoded in this extra-chromosomal circular DNA. This may give the plant a fast-track solution for evolution, accelerating its ability to adapt to new circumstances.

"If we can harness some of this plasticity, our options for rapidly developing climate resistant strains of major crops could massively expand," says Dana MacGregor.

Banking on change

Two significant new scientific resources came on stream in 2023.

Pest genome

New open resource will accelerate research towards better targeted crop protection.

A new database of 19 insect genomes encompassing some of the most damaging pests of crops worldwide was made publicly available in 2023. It includes some of the most common pest threats faced by UK farmers including wireworm, cabbage stem flea beetle and pollen beetle, as well as other globally important species.

It is hoped that the new database will help speed up the development of novel pest control approaches that can overcome resistance and create more nature-friendly solutions to crop protection.

The four-year Pest Genome Initiative (PGI), a consortium of Rothamsted Research and the agriscience companies Syngenta and Bayer, firstly sequenced the genomes, and then assembled them into their constituent chromosomes before adding information about what individual genes code for.

Professor Field said: **"It's important we understand differences between insect species, so that we can both protect crops from pests and conserve beneficials."**

The team say their efforts will help in the development of crop protection products that are more species-specific and overcome the problem of resistance. They will also help develop non-chemical pest control methods, such as manipulating insect behaviour; focusing on the genes that control how insects find mates and host plants and hence shepherd them away from crops.

Rothamsted's Professor Linda Field, one of the research leaders, said the future of farming would be 'smarter' and involve less pesticide use: dovetailing the electronic surveillance of insect movements and measures that encourage natural pest control, with these newer, more targeted pesticides.

She said: **"Currently as much as a fifth of all crops are lost globally to pests, and this is predicted to increase to 25% under climate change. Whilst non-chemical control methods can have some success in reducing crop losses, pesticides remain a necessary weapon in our fight against devastating crop losses and will so for the foreseeable future."**

In recognition of the fact that the future of pest management will involve both better targeted chemicals and other techniques, the project also assembled the genomes of three beneficial insects, the European hoverfly, and the pirate bug, both of which predate crop pest species, as well as a species of parasitoid wasp that lays its eggs inside the crop pest, the cabbage stem flea beetle.

Crop Microbiome Bank

The construction of the UK Crop Microbiome Cryobank (UK-CMCB) – the first publicly available resource of its kind anywhere in the world – is now complete after three years of painstaking research.

Scientists from the UK's foremost agricultural research institutes created the facility, which will safeguard future research and enable sustainable yield improvement for six major food crops including barley, oats, faba bean, oil seed rape, sugar beet and wheat.

The project, funded by UKRI BBSRC, was led by CABI (which houses the resource) and brought together experts from Rothamsted Research, Scotland's Rural College (SRUC), James Hutton Institute and the John Innes Centre. It uses state-of-the-art cryo research techniques to preserve important crop microbiome samples obtained from different crops cultured in a range of UK soil types. The resource also includes living microbial material as well as genomic and metagenomic sequences (DNA) from the crop root environment.

Dr Tim Mauchline, plant and soil microbiologist at Rothamsted Research, said, **"The UK-CMCB allows us to better understand the profile and function of microbes in our soils, which is important in advising farmers how to produce crops more sustainably.**

"Advancing research on biological solutions to mitigate crop pests and diseases is also imperative to help ensure the UK's food security at a time when chemical fertilisers and pesticides are in the spotlight amid the growing concerns of climate change."

Mauchline and his colleagues drew on Rothamsted's extensive experience of soil microbiome research in farming systems for their contribution to the project.

"This is the first time the root microbiome has been studied at such great scale for such an important range of crops. It will give us unique insights into how the soil microbiome interacts with different plants in a range of soil types and generate new microbial candidates for plant inoculation." he said.

The new cryobank facility – likened to a "Noah's Ark" of UK microbes – used UK-developed cryotechnology that uses liquid nitrogen to keep the valuable crop microbiome samples secure at very cold temperatures for generations to come.

Around the World

Netherlands

Research at the universities of Maastricht, with Leeds, Wageningen and Rothamsted Research, shows that the expectation that gluten causes gastrointestinal complaints plays a crucial role in whether or not people experience these symptoms.

China

Following a campaign to encourage farmers to improve nitrogen use efficiency led by China Agricultural University and in which Rothamsted was a partner, an assessment showed that ammonia emissions were cut by by up to 50% without affecting yields of wheat and maize.

Nigeria

Mabel Ifeoma Onwuka, a Rothamsted International Fellow in 2017, was one of 5 laureates receiving the 2023 Women's World Summit Foundation prize for women's creativity in rural life.

USA/St Louis

Alison Lovegrove and Peter Shewry received a Heroes Award from the US Foundation for Innovation in Healthy Food for their work on high fibre wheat varieties.

USA Maryland:

Rothamsted is a partner in a new US/Canada/UK initiative to explore the potential of using "green ammonia" to mitigate climate change whilst still supporting food production.

Mexico

Rothamsted was part of a UK-Mexico Partnership to breed hardier wheat varieties in Sonora able to survive the threats of climate change.

Saudia Arabia

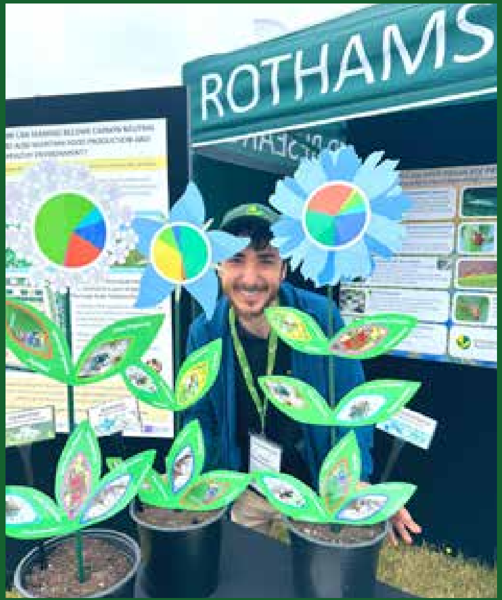
Rothamsted's Zainab Oyetunde-Usman and Khalid Mahmood, took part in the 1st International Forum and Exhibition For Sustainable Agriculture (IFESA) in Riyadh.

Malawi

Veronica Guwela, a joint Rothamsted PhD student with the University of Nottingham won the University's Edward Cocking Prize for best PhD thesis in Plant and Crop Sciences for her study on high zinc wheat for sub-Saharan Africa.

Public
and stakeholder engagement

Once again Rothamsted ran a full public and stakeholder engagement programme throughout 2023. Policy highlights included our first ever participation in the Sense About Science Parliamentary Evidence Week and a site visit by the parliamentary Science and Technology Committee as part of their inquiry into insect declines.



Clockwise from top left:

Journalist and broadcaster Tom Heap addressing an all-staff seminar

Our Intelligent Data Ecosystems team take part in the Sense About Science Parliamentary Evidence Week

New Scientist Live, London

The All Party Parliamentary Group researching insect declines visit the insect survey

School careers fair

Dr Kelly Jowett at Groundswell 2023

Fieldwork, North Wyke

Stand at Groundswell 2023

2023 in numbers

87,700 samples processed by **8** facilities

347 publications

4,101 Media mentions

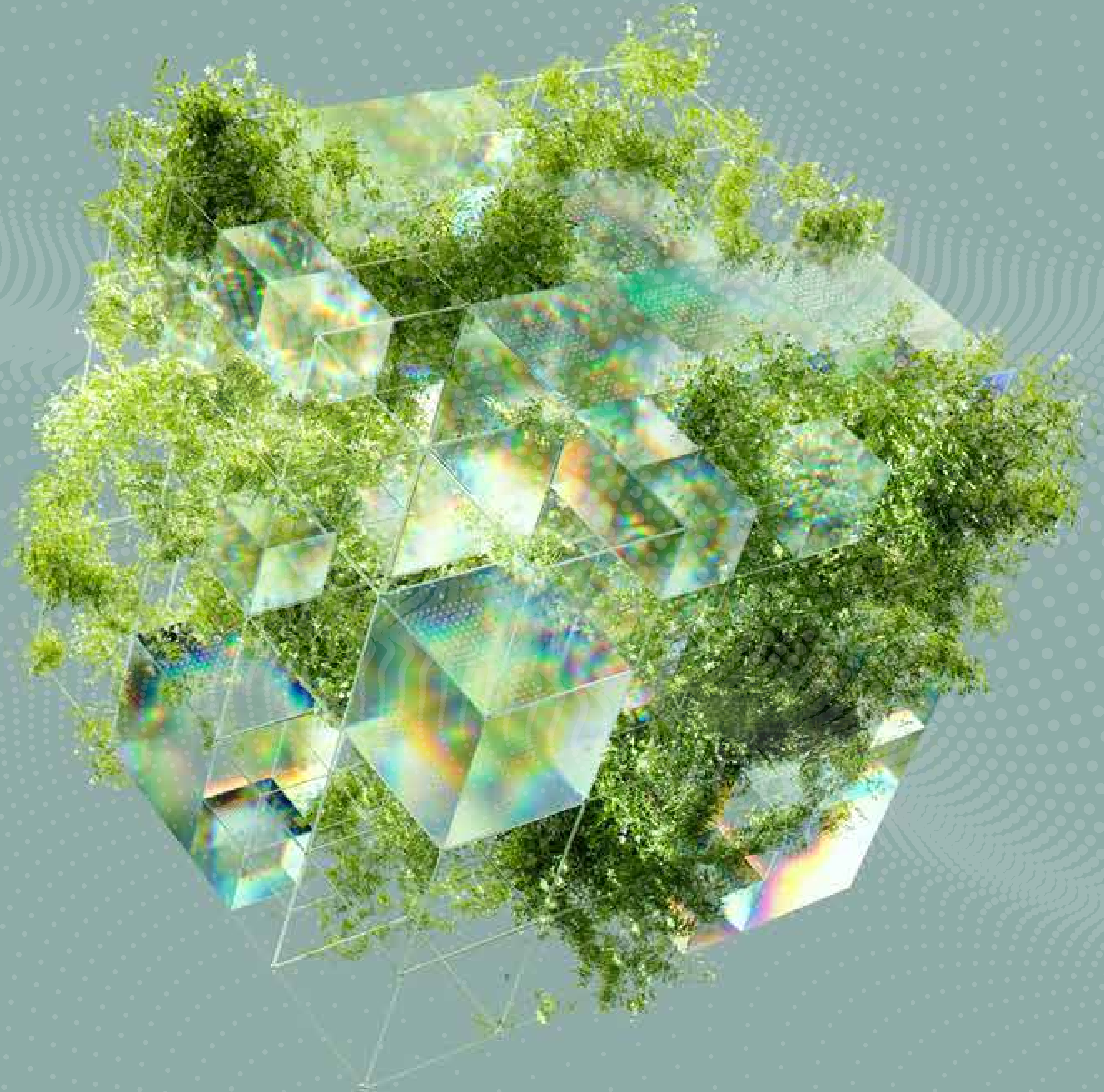
572k Social impressions

537 members of staff, from **51** countries

1k+ farmers engaged

158 farm trials grown

29 awards & recognition for **19** people across **18** BBSRC projects



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