Institution: Cranfield University

Unit of Assessment: 6

1. Unit context and structure, research and impact strategy

Context and Structure

Cranfield is an exclusively postgraduate university focused on technology and management. Our activities in agriculture and food sciences began when the National College of Agricultural Engineering joined Cranfield in 1975 and became Silsoe College. The Soil Survey and Land Research Centre for England and Wales was incorporated in 1985. In 2005, all activities relocated to the main Cranfield campus near Milton Keynes.

Our high-level academic organisational structure embeds interdisciplinarity through market sector focussed Themes, rather than Departments that are typical of a conventional, discipline-led university (REF5a). **Our agriculture and food science research is led by one of eight Themes: Environment & Agrifood,** within the School of Water, Energy and Environment (SWEE, www.cranfield.ac.uk/about/our-structure). The theme is centred around agricultural research, working to ensure that global food systems are resilient for the future and to protect and enhance natural capital. We work with global and domestic agriculture and food companies, regulators, and governments to ensure that our research benefits society.

Within agriculture and food, 40 staff (38.2 FTE) in SWEE are included in this UoA6 submission: 38 from Environment & Agrifood and 2 from the Water Theme. Of these, 9 are Professors, 4 independent researchers and 10 Early Career Researchers (ECRs). The staff from Water are experts in water management for agriculture and food, hence inclusion in UoA6.

Research strategy

Following REF2014 and development of the University's 415i Corporate Plan (www.cranfield.ac.uk/about/about) and institutional Research Strategy (REF5a), the UoA6 strategy was also reviewed. It was decided to significantly strengthen the role of basic research to better underpin the applied research strengths. The following objectives were set:

- Improve the quality of research and resulting outputs by increasing the UK Research and Innovation (UKRI) supported research while simultaneously increasing the academic quality of industry-supported research.
- Recruit senior academics to enhance academic leadership, encourage existing staff, and grow talented ECRs numbers through internal promotion and recruitment.
- Enhance doctoral training by strengthening industry networks and involvement in UKRI-funded initiatives.
- Invest further in near industrial-scale and new laboratory facilities to support these aims.

In parallel, an important objective was to develop an integrated research strategy ensuring interdisciplinary agricultural and food science research was underpinned with achieving environmental sustainability. This change was motivated by the increasing recognition of the significant role for agriculture and food production in achieving net zero carbon emissions, preventing air and water pollution, and protecting the broader environment. As a consequence, the Theme now operates through two Centres:

- **Cranfield Soil and Agrifood Institute (CSAFI)** (www.cranfield.ac.uk/centres/soil-and-agrifood-institute).
- **Centre for Environmental and Agricultural Informatics (CEAI)** (www.cranfield.ac.uk/centres/centre-for-environmental-and-agricultural-informatics).

The CSAFI and CEAI together have expertise in ecosystems, soil, plants, water and air, data science and decision-making. There are a number of research projects combining these centres of expertise, as well as the submitted outputs and impact case studies. The UKRI funding for this research comes principally from the Biotechnology and Biological Sciences Research Council (BBSRC) and the Natural Environment Research Council (NERC).

The **CSAFI** builds on Cranfield's heritage in agriculture and soil science, as exemplified by the Queen's Anniversary Prize for soil science in 2017 (https://www.cranfield.ac.uk/about/rankings-and-awards/queens-anniversary-prize) and hosting the British Society of Soil Science (https://soils.org.uk/). Research includes food safety and storage, plant science and bioinformatics. This research base is complemented by the investment in Cranfield-based facilities in two AgriTech Centres of Innovation (of the four created as a result of the UK Government's Agritech Strategy www.agritechcentres.com): Agricultural Engineering Precision Innovation (AgriEPI) and Crop Health and Protection (CHAP).

The **CEAI** focusses on measuring, monitoring, and managing agricultural systems and the natural environment, with remote sensing and local sensor systems and their link to larger, more complex datasets at the core. In combination with data science and the soils' datasets hosted at Cranfield, the Land Information System (LandIS, http://www.landis.org.uk) and World Soil Survey Archive and Collection (WOSSAC, www.wossac.com/), the potential for greatly enhanced understanding of how landscapes function and how they respond to stresses and pressures is being realised. Cranfield's combination of agriculture, environment, and data science reflects agriculture's critical role in achieving a sustainable environment and a safe and healthy food supply.

Research in this submission focusses on the two research areas **of resilient food systems** and **agricultural and environmental data sciences** to address sustainable agriculture. These areas cut across the Theme structure and bring together those with similar interests and technological requirements. Much of our research is collaborative and involves scientists from across these research areas as well as from elsewhere within and beyond Cranfield.

In this way, the research on agriculture and environment helps deliver the University's mission '*to create leaders through our education and research in technology and management'* (REF5a). Based on our fundamental science, our approach aims to provide food security, help create a low carbon and growing green economy, enhance natural capital and support the UK Industrial Strategy.

Individuals have strengths in soil science, plant science, soil-plant systems, agricultural water management, agricultural engineering, agricultural systems modelling, agroforestry, postharvest biology and technology, food safety, bioinformatics, environmental informatics, natural capital, ecological restoration, atmospheric and climate science, and risk management and decision-making. These diverse research interests combine to develop the integrated view of agriculture and the environment required for current and future societal needs.

Our multi-disciplinary research into **resilient food systems** is led by CSAFI and is conducted at spatial scales from genes to agro-ecological systems and involves bioinformaticians and remote sensing experts to lead analysis of complex datasets and development of software tools.

The research in soil science spans basic soil physics, chemistry, and biology; soil management and conservation; and soil informatics and resource evaluation. Our expertise in the biogeochemistry (**Kirk**), biophysics (**Otten**) and biology (**JHarris**) of soil systems was consolidated with the appointment in 2020 of a plant and soil ecologist (**Girkin**). Specialisms include plant root-soil interactions in the rhizosphere (**Kirk, Otten, Girkin**), non-invasive

techniques to characterise soil microhabitats (**Otten, JHarris**), crop-plant adaptations to mineral deficiencies and toxicities (**Kirk, Otten**), the biogeochemistry of submerged soils and wetlands (**Kirk, Girkin**), whole-system carbon balances and greenhouse gas fluxes (**Kirk, Girkin**).

More-applied soil and land management research focuses on soil protection and degradation, ecosystem restoration, sustainable land management and soil policy formulation. Our core expertise includes quantifying the cost of erosion at national level and defining the mechanisms underlying soil degradation (**Rickson, Deeks, JHarris, Kirk**); understanding soil functions and their role in the delivery of water regulation, agricultural production and carbon storage (**Simmons, Rickson**); assessing and improving soil fertility, health and biodiversity through the use of novel fertilisers and active management practices (**Sakrabani, Pawlett, Johnston**); and the application of novel ecological perspectives to resilience and ecosystem management (**JHarris**). **Graves, Rickson, Deeks** assess the current state of soil resources and the multiple ecosystem goods and services delivered to society. This research quantifies the pressures / threats acting on this finite national asset as well as the cost-effectiveness and feasibility of implementing soil protection policies and practices.

The UK is committed to reducing food losses and waste by half by 2030 (UN Sustainable Development Goal 12.3), therefore scientific human capital needs to maintain quality and reduce food loss of horticultural and durable products. In UoA6, new collaborations have been developed between Cranfield researchers and users of research such as businesses and policy makers. Five new academic appointments have been made since 2013.

Food loss research in the Plant Science Laboratory is led by **Terry**, working with **Alamar**, **Anastasiadi** and **Falagan**. It uses advanced controlled atmosphere facilities to research technologies for extending storage and shelf-life of fresh produce. **Anastasiadi** specializes in metabolomic and transcriptomic data analysis (e.g., bioactives in fruit), and **Alamar** and **Falagan** in manipulating biological mechanisms through innovative postharvest technologies to reduce food loss. Research encompasses fundamental biological processes of dormancy (e.g., onion, potato), postharvest senescence, ripening and nutrition with input from molecular plant scientists (**Thompson, Kevei**) and bioinformaticians (**Mohareb, Anastasiadi**). This mechanistic work intersects that on food safety by the Applied Mycology Group, with mycologists **Magan** and **Medina** researching methods to reduce fungal-derived mycotoxin accumulation during commodity, e.g. grains, nuts, storage to reduce losses and improve food safety. **Kourmpetli**, with expertise in the fundamentals of grain development, undertakes research with seed technologists to improve longevity of stored vegetable seeds.

Sustainable crop production is addressed through molecular genetics of root development (**Thompson, Kevei**) and above-ground plant architecture in horticultural crops. The current focus is on defining genetic control of root vigour, adventitious rooting and drought resistance, using AgriTech Centre facilities for plant growth, phenotyping and genomic analysis led by **Mohareb**. New appointee **Rezwan** transfers bioinformatics expertise gained in medical studies to the rhizosphere microbiome and epigenetic variation in crop traits and disease.

Application of sensor technology, coupled with informatics and data science, has led other industrial sectors to a rapid transformation of massive-scale data acquisition to formulate and rationalise management decisions and systems. This transformation has yet to be fully realised in the agricultural sector. Recognising this gap, UoA6 staff (**Otten, Rickson, Waine, Simms, Khouakhi, Kourmpetli, Girkin**) support the new CHAP and AgriEPI Centres. The facilities include a unique platform for assessing pilot scale crop-soil systems and sensor development, integrated with existing soil management and postharvest facilities.

Within digital agriculture, Earth Observation data provide a unique perspective on natural and anthropogenic processes. The remote sensing team (**Waine, Rivas-Casado, Brewer, Simms, Khouakhi**) develop state-of-the-art approaches, integrating remote sensing and ancillary data through model-data fusion, to provide reliable information for a breadth of applications including agriculture, deforestation, drought and food security.

Water, agriculture, and the environment are inextricably linked. Understanding interactions and the relationship with policy and practice is critical for sustainable, resilient land and water management. Core strengths in UoA6 lie in development of integrated modelling platforms to evaluate climate impacts and adaptation responses for catchment-scale land and water management (**Hess, Knox**), the development of biophysical models to support national and regional agricultural water demand forecasting (**Knox, Hess**), water valuations for agriculture under conditions of drought and water scarcity, including governance links to the water-environment-food nexus (**Knox**) and the application of water footprinting to evaluate water-related risks to agriculture, food production and diets (**Hess, Williams**). New research is focusing on understanding resilience pathways to climate and water risks in international horticultural supply chains in the context of livelihoods and food security (**Hess, Knox**).

'Crop water use' research is multidisciplinary with **Thompson** (plant water relations) working with **Knox** and **Hess** (agricultural water management) on models and control systems for irrigation. **Kirk and Simmons** are experts in biogeochemistry and modelling of root-soil interactions in nutrient and toxicant uptake. **Kevei** studies biophysics of soil-root interactions with DNA-based assays for quantifying mixed root systems. **Burgess** uses agroforestry to demonstrate benefits of integrated agricultural systems to sustainability, drawing on crop modelling expertise and collaboration with **Graves** on bio-economic evaluation.

Our multi-disciplinary research into **agricultural and environmental data sciences** is led by CEAI, strengthening the scientific base for informing land use and environmental policy. The soil informatics team (**Hannam, Hallett, Corstanje, Keay**, **Johnston**) work with the remote sensing experts to integrate spatial statistical models, remotely sensed data and the LandIS and WOSSAC databases to include plant soil and water interactions across spatial scales. **Corstanje** and **Hallett** lead harnessing digital sciences to environmental research through the CINITDIEN project - Championing INnovation In The DIgital Environment (£1.27M, NERC, NE/S016287/1). Broader research on land use includes natural capital assessment and modelling across the land-use spectrum (**Corstanje, Burgess, Graves, JHarris, Leinster**), ecological restoration (**JHarris, Pawlett**), flood risk (**Rivas-Casado, Leinster**) and crop, forestry, and agricultural modelling (**Burgess, Corstanje, Graves, Waine**). This is complemented by the decision science group assessing risks in natural and human systems (**Garnett, Graves, Hallett**).

The importance of the interaction of soil, plant and water systems with the atmosphere has been recognised with four new appointments since 2013 which together provide expertise on air quality and climate change. A core strength is the use of measurements based on existing and custom-built sensors (**NHarris, Mead, Girkin**), used to study trace gas emissions from woodlands, agriculture, waste and the built environment. Lower cost instruments are used in networks (**Mead, NHarris**) and hard-to-access locations (**NHarris**). Understanding interactions of rural and built environments is central to this work, including the air quality component in the Urban Observatory.

This observational work is complemented by research on policy implications for food supply, air quality and climate change (**Williams, Cain, Leinster, NHarris**). This includes life cycle analysis

and the potential for soils to sequester CO_2 (**Williams**), as well as new metrics to assess the relative importance of the climate impact of CH_4 and other greenhouse gases (**Cain**).

Stimulating interdisciplinary research, the Cranfield Urban Observatory provides the networking and sensing infrastructure in the Living Laboratory (**JHarris, NHarris, Mead**). Inspired by research in the NERC Biodiversity & Ecosystem Service Sustainability programme, it focusses on sustainability and resilience of the agricultural, natural, and built environments across the Oxford-Cambridge Arc development region. Researchers interested in environmental and social issues encompassing agriculture, wildlife, air quality and water, are co-operating and integrating with data scientists (**Corstanje, Hallett**).

The structure and research culture that has been developed to be able to deliver the UoA6 **research objectives over the next five years** is aligned with global challenges and the UK agenda on agriculture linked to food security and environment. The UK's 25-year Environment Plan, nascent National Food Strategy, Agriculture Act 2020, and Environment Bill centre around achieving a sustainable environment whilst ensuring a resilient food and water supply. Achieving this requires development of new technologies based on digital agriculture and data science, as well as further development of qualitative and quantitative understanding of existing areas such as soil quality, waste reduction, biodiversity and decision-making. Therefore, Cranfield's fundamental agricultural research will aim to enhance environmental research across the university and beyond in the context of regional and global initiatives.

The underpinning elements of research objectives over the next five years are to:

- Appoint talented scientists, provide the best research infrastructure and flexible environment so they flourish. Addition of high-quality researchers will continue through recruitment and internal promotion.
- Realise full potential of current and emerging talent by ensuring equality, diversity, and inclusion (ED&I) in staff and research students. Building on our positive experience in promoting ED&I, UoA6 will identify and action where extra support is most beneficial, raise awareness in Theme meetings and employee engagement through satisfaction surveys.
- Work even more closely with industry and government to ensure that our research results are translatable to the real world. Consolidation of existing strategic industry partnerships, e.g., Unilever, PepsiCo, is a priority alongside new ones.
- Develop the next generation of researchers. Engaging and training PhD students is central to this strategy and industrially funded partnerships will be complemented by involvement in new multi-university Doctoral Training Partnerships (DTPs) supported by UKRI and industry.

Environment and Agrifood is Cranfield's principal recipient of NERC, BBSRC and Global Challenges Research Fund (GCRF). Fundamental research forms the foundation of current and future activities.

The underpinning **research areas for the next 5 years** are:

- Soil Science: Fundamental and applied understanding of physical, chemical, and biological processes mediating soil-crop and natural systems, exploring interaction between plants and microbes in the rhizosphere

- Food quality: Linking agronomic traits to genes to accelerate plant breeding for food security, water use efficiency and nutrition using molecular genetics, advanced phenotyping, and bioinformatics
- Food loss and safety: Elucidating fundamental mechanisms governing ripening, senescence, and dormancy to improve quality and safety, reducing food loss.
- Catchment science: reconciling multi-scale trade-offs between agricultural, environmental, and other human needs for water quantity and quality within complex socio-ecological water resources systems
- Digital environment: Exploiting novel instrumentation and informatics techniques in a digital environment to enhance natural capital, gaining new insights addressing complex environmental and agricultural challenges
- Decision science: development of approaches to identify pathways to sustainable food and water supply, quantifying the impact of environmental change in planning for and managing vulnerability, risk, and resilience in the natural environment.

These areas will inform decision-making towards meeting several United Nations Sustainable Development Goals (UNSDGs), especially zero hunger, clean water and sanitation, sustainable cities and communities, responsible consumption and production, climate action and life on land.

Interdisciplinary research

Cranfield's Theme-led structure embeds interdisciplinarity, further supported through four Grand Challenges (GCs) linked to the UNSDGs (www.cranfield.ac.uk/research/why-cranfield/grand-challenges, REF5a) that brings together researchers across all Cranfield Themes. Staff from UoA6 have leadership roles in several:

- The **Connected Resilience** GC aims to advance resilience research across socio-economic silos (**JHarris**).
- The **Sustainable Security** GC focuses on synergies between security and sustainable development to advance research improving human health and well-being, including food and water security (**Burgess**).
- The nascent pan-university Grand Challenge on the **Green Economic Recovery** (**Terry**) nurtures research to ensure an environmentally sustainable recovery from Covid-19, including focused initiatives on agriculture and environment.

Our expertise in futures analysis, strategic risk assessment and stakeholder engagement (**Garnett, Graves, Leinster**) is used in collaboration with external partners, e.g., UK utilities, Department for Food and Rural Affairs (Defra), Directorate-General for Environment, and Syngenta, on issues such as the green economy, critical infrastructure planning, flood preparation, and improving participatory decision-making in adaptation planning.

Impact strategy

Impact is central to the Unit's research strategy, reflecting Cranfield's Mission of unlocking the potential of people and organisations by partnering with business and governments (REF5a). The four submitted Impact Case Studies on agricultural issues are exemplars of this approach: two (CROPS and SOILS) address governmental actions and policy; and two (ETHYLENE and WATER) focus on agri-food business (Table 1). The Impact Case Studies, and other examples

cited below and in Section 4, are outcomes of ensuring academic staff are business-focussed in their day-to-day roles, nurturing strategic partnerships with key clients in agriculture and food, and supporting researchers through Cranfield's Research and Innovation Office (RIO). These are three key objectives in our commended Higher Education Impact Fund (HEIF) Strategy that covers the REF period. (https://webarchive.nationalarchives.gov.uk/20180405122213/http://www.hefce.ac.uk/ke/heif/strategies/).

Table 1. Impact Case Studies.

Impact Case Study	Summary
CROPS – Improved crop monitoring with applied remote sensing	Cranfield's development of refined remote sensing approaches became the basis for the United Nations Office on Drugs and Crime (UNODC) and Government of Afghanistan campaign of poppy eradication: increasing accuracy of estimates of crop production; saving lives by reducing the need for field surveys; exposing misreporting of eradication; informing international drug policy decisions.
ETHYLENE – Reducing food waste by controlling Ethylene	Cranfield co-developed and helped commercialise a novel technology for an active compound to remove ethylene in the packaging of fresh produce, suppressing ripening and reducing food loss. Annual sales and exports of the technology licensed to It's Fresh! Ltd total over £23M in global supply chains, with a Return on Investment of 300%.
SOILS - Improved national soil policies and local soil management based on geospatial data and modelling	Cranfield's work on large-scale soil and environmental data has driven policy debates on the protection of national soil resources, culminating in a Parliamentary inquiry and inclusion of soil protection measures in Defra's 25 Year Environment Plan which underpins the new Agriculture Act and Environment Bill. Research into spatial soil data and information systems has saved the Welsh Government an estimated £100 million, and 10 to 20 years of resources.
WATER – Supporting sustainable water management for agriculture and food production	A new framework for understanding current and future water demands in agriculture has directly informed policy and management reforms by the Defra and the Environment Agency. Cranfield research has been used across the agri-food sector - including horticultural and fresh produce retail businesses - to develop sustainable water plans and build resilience, whilst meeting growing global demand for fresh fruit and vegetables.

All staff are encouraged to take part in pan-University impact programmes and to integrate impact activities into the research culture. Academic staff in UoA6 are delivering impact from their research through involvement in national and international societies, programmes, and assessments (Section 4). Experience and leadership in impact for UoA6 is provided by **NHarris**, winner of NERC's 2015 International Impact and Overall Impact Awards. The importance of planning for maximising the impact gained from our research is mentioned at most UoA6 local meetings.

UoA6 has a leading national role in delivering impact through NERC's Constructing a Digital Environment Strategic Priorities Fund, in partnership with the Engineering & Physical Sciences Research Council (EPSRC) and Defra. **Corstanje** and **Hallett** were appointed as NERC's Digital Environment Champions who oversee the programme and a network of environmental and informatics experts to identify research ideas, develop funded feasibility studies and demonstrators.

One of our data holdings, LandIS (www.landis.org.uk), is the National Reference Centre for Soils for England and Wales (Section 3). Research in UoA6 helps develop the accessibility and use of this data resource. Impact is created through products marketed by Cranfield. CatchIS (Catchment Information System) is a software decision support system for the management of water quality at the catchment scale (www.catchis.com/), widely by water utilities and the Environment Agency for the fate and behaviour of diffuse agricultural compounds such as pesticides. The National Perils Directory uses soils data for subsidence and flood predictions used by the insurance industry, water utilities and national and local governments (www.landis.org.uk/npd_insurance).

In 2017, Cranfield received the Queen's Anniversary Prize for its impact in large-scale soil and environmental data for sustainable use of natural resources in the UK and worldwide: the first that such an award has been given for soil science. The Prize recognises outstanding work that shows quality and innovation, delivering real benefit to the wider world.

We view our close links with industry as important for our impact. Two key examples are:

- Cranfield is involved in two, AgriEPI and CHAP, of the four UK Agri-Tech Centres, working with farmers and businesses across the agrifood value chain to support greater efficiency, resilience, and profitability (www.agritechcentres.com). The centres support the development, evaluation and delivery of technology and data-driven solutions to the challenges faced by the agricultural industry.
- Cranfield and Produce World were awarded the KTP Research Base Impact Award in 2015 for the development of the Soil-for-Life management system developed to allow Produce World to optimise soil fertility, match crops to soil type, and improve marketable yield of vegetables and the sustainability of its farming business (www.cranfield.ac.uk/case-studies/research-case-studies/produce-world-ktp).

Further examples of industry collaboration and impact are given in Section 4.

Research integrity and open research environment

Cranfield is committed to research integrity based on the 2012 (and 2019 update) Concordat to Support Research with a comprehensive suite of integrity and ethics policies and processes (REF5a, www.cranfield.ac.uk/about/research-integrity). All research in UoA6 complies with the Joint Code of Practice for Research (JCoPR): UoA6 members on the JCoPR working group took the lead in embedding processes for improved quality assurance and compliance across the university. Research within UoA6 maintained 100% compliance with our Research Ethics Policy that requires all research, including 'nil' returns, to be logged through our online system CURES (www.cranfield.ac.uk/about/governance-and-policies/policies-and-regulations).

Cranfield has a full suite of policies and processes to work towards a more open research environment and ensure compliance with the Concordat on Open Research (REF5a, www.cranfield.ac.uk/about/governance-and-policies/policies-and-regulations). Within UoA6, open access publishing is strongly encouraged with all outputs submitted to REF2021 being

eligible. Between 2016 and 2020 89 UoA6 datasets were deposited on Cranfield Open Research Data (CORD), the university's data repository for use when no other suitable ones are available (REF5a, https://cord.cranfield.ac.uk). Over the 12 months to February 2021 there were ~49,000 views and 19,000 downloads. The most viewed data (3359 views) is from the HEFCE Carbon Brainprint project on quantifying the impact of universities on carbon footprint reduction. Other initiatives within UoA6 to support open research include:

- All measurements from the Cranfield Urban Observatory will be fully open;
- We staged environmentally themed Digital Sprints tackling the effects of Covid-19 in 2020.
- Where practicable, the approach to Open Source extends to software tools and GitHub is used to share code.
- Researchers 'blog' their work to encourage access to data.

2. People

Staffing strategy

Cranfield is committed to supporting staff through the schemes described in REF5a. UoA6 is fully committed to these and ensures their full implementation, aiming to generate a supportive, inclusive culture and to trial new initiatives.

Of the 40 staff (38.2 FTE) included in UoA6, 37 (92.5%) are on open-ended contracts and 3 (7.5%) on fixed term contracts:16 staff have been retained since 2014 (63% retention). Of staff who have left during the REF2021 period, other than retirement and redeployment, three moved to chairs at leading Universities and one to a senior research role at the Centre for Environment, Fisheries and Aquaculture Science (CEFAS) and several to the private sector.

Personal development and increasing the diversity of staff is an essential part of the overall Unit research strategy. For existing staff, the importance of personal development and working in a supportive working environment is a standing item at Theme and other team meetings. Training, regular appraisals, personal mentoring opportunities, open communication and being involved in research are all central to achieving this and so help motivate staff to achieve their full potential.

To complement development of existing staff, 6 new lecturers (**Cain, Girkin, Johnson, Khouakhi, Mead, Rezwan**) have been recruited in the REF2021 period to bring in new expertise, develop future leaders and to ensure that UoA6's research portfolio is cutting edge and future-proofed. These actions have been enhanced through recruitment to newly established professorial positions in strategic areas (**NHarris, Leinster, Otten**).

Staff development and support

Staff development at Cranfield is underpinned by a long-established annual Performance and Development Review (P&DR) (REF5a): participation for UoA6 is excellent with 100% completion of 2020 annual P&DRS. These P&DRs are supplemented by regular ad hoc meetings with line managers. Peer advice is enhanced in many projects undertaken by people in UoA6 where a team approach is taken to delivering the research. This provides practical opportunities for people to learn in a collegiate manner about all aspects of research from project design and proposal writing, through the research phase to interpreting and presenting results. The importance of staff development is emphasised through regular meetings held at Theme and Centre level to report on progress and opportunities, and to celebrate successes by all staff. These include PhD vivas, promotions, publications, patents, prizes and outreach activities.

In the last 3 years, all UoA6 staff have attended a variety of workshops/online Learning and Development, including Building Personal Resilience; Dyslexia Awareness; Introduction to Bid Writing; Writing the Perfect Bid; Time Management; Improving Social Media Presence; Writing Research Proposals; Promoting Wellbeing in the Workplace; Business Development Skills and Opportunities to Leverage Private and Public Funding. LinkedIn Learning provides access to over 13,000 on-demand courses to all staff for personal career development: 46% of UoA6 staff are users. All staff in the Unit have completed mandatory online learning that includes ED&I, General Data Protection Regulation and information security awareness.

All staff have the flexibility to work from home and are encouraged to achieve a healthy work-life balance. In UoA6 we continue to focus on flexible working and homeworking, for example by promoting the recently revised Flexible Working and Homeworking policies especially to those returning from family leave (REF5a). Of the 40 UoA6 staff, five have formal flexible working arrangements in place, working either part-time or annualised hours (12.5% of the unit headcount: one woman, four men). In addition, policy changes banning out of hours emails (unless business-critical or caused by time zone differences if travelling) are enforced, and a half-day per week has been set aside for 'scholarship' to encourage academics to develop new ideas and prioritise preparation of outputs. Maternity and paternity meetings are held in advance of the leave with regular Keep In Touch (KIT) days and potential options to work flexibly on return. Since 2013, 2 UoA6 academics and 3 Research Fellows (RFs) took maternity leave and 3 took paternity leave and/or worked flexibly.

Support for academics in developing proposals has increased since 2014 with the formation of the Research & Innovation Office (RIO) (REF5a, www.cranfield.ac.uk/research/rio). Improvements in UoA6 have included:

- More formalised evaluation of research opportunities involving mentoring (particularly for ECRs), early internal review panels and mock interview panels for UKRI proposals.
- Greater consideration of external collaboration needs to enhance the research quality.
- A new working group developing NERC Highlight topics and other large funding proposals involving senior, mid-career and ECR academics.
- Stronger emphasis on prompt publication of research outputs, complemented by support on preparation of potentially high impact outputs, to enhance track record.

At Cranfield, Post-doctoral Research Assistants who are **early career researchers (ECRs) are called Research Fellows (RFs)**, who we aspire to develop to become Cranfield academics to meet our distinctive business needs (REF5a). As a signatory to the Concordat to Support the Career Development of Researchers, support for research careers from ECRs is implemented through actions aligned with our HR Excellence in Research (HREiR) plan (www.cranfield.ac.uk/about/rankings-and-awards).

Exceptionally talented RFs have the opportunity to be appointed as Academic Fellows (AFs) on a 5-year contract, with the expectation of promotion to Lecturer: Five of the staff submitted in UoA6 are AFs. Six early career lecturers (67% female) have benefited from this route in the assessment period, following in the footsteps of five others prior to 2014. In the REF period 16 people (19%) have advanced their careers to lecturer equivalent or above through the University promotion scheme. Through these supportive initiatives, combined with an ECR population that is 50% female, we aim to steadily increase the gender balance of staff in senior academic roles.

Cranfield's has a £6M 75th Anniversary Fellowship Scheme (www.timeshighereducation.com/hub/p/cranfield-universitys-fellowship-scheme-tackling-problems-future) to support up to 30 exceptional RFs from September 2020: one of the first

three appointments was to UoA6 (https://www.cranfield.ac.uk/people/dr-daniel-evans-28309587).

Research Fellows are integral to the research environment of UoA6, examples of this include:

- The regular UoA6 Theme and Centre meetings are used to promote these opportunities, to celebrate their successes, and to encourage open discussions with academic staff.
- Use of independent mentors is strongly encouraged in addition to advice available from immediate colleagues.
- All RFs are included in the University's P&DRs. These focus on career development with opportunities to take on responsibilities to develop skills and experience.
- RFs can submit small proposals (e.g., the University's HEIF and GCRF schemes) with support from an established academic and assist in the preparation of other proposals. Such contributions are formally recorded.
- Opportunities to teach are offered to RFs.

We offer all RFs the opportunity to register for the Postgraduate Certificate in Academic Practice (PgCAP), which includes research supervision skills to enhance their academic career prospects. As of July 31st, 2020, 8 of 17 UoA6 RFs had registered for the PgCAP, with 2 already achieving HEA recognition (AFHEA or FHEA).

Technical staff are essential to the success of our research and individuals are integrated into UoA6 projects in many ways, e.g., sample/data analysis, proposal preparation, and project management and delivery. Technicians who run the laboratory facilities are responsible for development, training on and troubleshooting of analytical instrumentation. UoA6 actively supports the Technician Commitment As a signatory to the Science Council's Technician Commitment (REF5a, www.cranfield.ac.uk/about/working-at-cranfield/technician-commitment), implementing the following measures for the University action plan:

- Provide ongoing support and funding for technical staff development.
- included on papers where a contribution is made
- Support technical staff to become professionally registered, achieving a target an initial target of 10% of technicians professionally registered by June 2020.
- Ensure technician input is sought for strategic plans and proposals.
- Nominate technical staff for awards as appropriate.

Additionally, UoA6 supports the Midlands Innovation (MI) TALENT Research England RED fund project which leads, and influences change to advance status and opportunity for technical staff. TALENT is led by Midlands Innovation, a consortium of eight Midlands universities, along with industry partners (www.mitalent.ac.uk/Home). Within this project, UoA6 has identified new opportunities for technicians to engage with colleagues across the consortium, attend shared training, share best practice, and learn new skills through a placement scheme. Two technicians (***Dawson, Cowley***) benefited from placements at Nottingham University to gain more experience with analytical techniques and operating research glasshouses.

Equality, Diversity, and Inclusion (ED&I)

Increasing the diversity of staff is an essential part of the overall Unit research strategy. Cranfield has taken action to embed ED&I practices across the university, e.g., achieving an institutional-level Athena SWAN Bronze Award in 2017 and a further 5 years from 2020, joining Stonewall, member of Working Families (REF5a). All staff undertake online ED&I training, including training on unconscious bias. Unconscious bias and ED&I awareness training was run for the UoA6 REF

team, led by the Head of Diversity and Inclusion, to ensure compliance with our Code of Practice (REF5a, www.cranfield.ac.uk/research/why-cranfield/research-excellence-framework)

In 2014 there were 27 staff in UoA6, 5 women and 22 men, and a conscious decision was made to redress this gender imbalance. There are currently 40 UoA6 staff, 12 women and 28 men, i.e., females comprise 54% of the increase in staff numbers. The percentage of women increased from 19% of headcount in 2014 to 30% in 2020.

We encourage and support women staff to join development programmes and networks:

- Advanced HE's Aurora programme to encourages women in academic and professional roles to develop leadership skills, and to help institutions maximise the potential of women. Since 2013, three women in UoA6 (20% of UoA6 females) have taken part in Aurora and subsequently acted as role models. Places on Aurora are limited, but we aim for other women in UoA6 to be involved in future.
- The Women as Leaders programme provides the opportunity to mix with other female leaders at Lecturer to Professor grades and to develop strategic leadership skills. Since 2013, two women in UoA6 (13%) have attended the workshop.
- Cranfield's own Step Up network was launched in 2017 and provides an inclusive network to support and create career development opportunities for women at Cranfield, in line with the wider University ED&I Strategy and helps to address the gender pay gap by seeking to improve the female representation at senior levels. Three UoA6 female staff (25%) are Step Up members.
- We encourage participation in Soapbox Science that promotes women scientists to the public (Section 4).

In 2014 11% of UoA6 academics shared their ethnicity as BAME: this has increased to 22% in 2020. One person in UoA6 has shared they have a disability. Reasonable adjustments are made to provide support for this colleague. The small numbers in UoA6 limit the analysis that can be presented on ethnicity and LGBT. While the signs are positive, this remains a topic for ongoing awareness and action.

Recruitment processes are continually reviewed to make them more inclusive and free from unconscious bias. In the most recent recruitment campaign, SWEE advertised several positions around the theme of 'Green Economy', with four vacancies in UoA6. The selection criteria were designed to avoid women feeling they did not meet all the essential criteria and self-selecting out of recruitment processes. The overall requirements were broad and aligned to SWEE's priorities, but the specific subject matter was left open within that. The level was flexible and advertised for Lecturer/Senior Lecturer. Gender neutral language was used in the advertising material and job description, using a text decoding app. Statements were included which encouraged underrepresented groups to apply. Finally, emphasis was placed on our values of 'community' and 'respect' and the flexible working and career progression support that staff at Cranfield have access to. This was specifically aimed at encouraging women to apply, as they are underrepresented in our STEM subjects in Cranfield. Final selections were made on meeting the selection criteria and this resulted in four appointments, two male and two female (Table 2.)

Table 2. Recruitment statistics for academic posts in UoA6.

	Applicants	**Short-listed**	**Offers**	**Hired**
Female	12 (24%)	6 (35%)	3 (50%)	2 (50%)
Male	37 (76%)	11 (65%)	3 (50%)	2 (50%)

Research students

An increase in the PhD cohort was an explicit aim of the drive to increase scholarship in UoA6. It was achieved with an average of 25.6 PhD research degrees awarded annually in the REF2021 period compared to 13.7 in REF2014. This equates to an average of 4.70 degrees awarded per submitted staff FTE for the period. In 2019/20, there were 76 full-time or part-time research students (73 FTE) in the Environment and Agrifood theme. The students are 49% UK, 14% EU and 37% RoW, with 92% full-time and 8% part-time, and 54% male and 46% female. 11% had a recorded disability.

Students receive support from a variety of sources including UKRI, usually through DTPs or equivalent; business and government; charitable trusts; and self-funding. The Cranfield Industrial Partnership PhD Scholarships, with 50% funding from Cranfield, encourages business co-operation. Additionally, students may receive Cranfield scholarships; about half of all recruited by UoA6 received support. In 2016, the Sue White Fund for Africa was established to provide scholarships for up to 3 PhD students a year in UoA6 on topics related to catchment processes and water management in Africa (www.cranfield.ac.uk/themes/water/sue-white-fund/about).

UoA6 was involved in 6 UKRI PhD Training Consortia during the assessment period:

- DREAM CDT (NERC, www.dream-cdt.ac.uk). Data, Risk and Environmental Analytical Methods consortium led by Cranfield with Birmingham, Cambridge, and Newcastle.
- CENTA2 (NERC, https://centa.ac.uk). Central England NERC Training Alliance led by Birmingham with Cranfield, Leicester, Loughborough, Open and Warwick with the British Geological Survey (BGS) and Centre for Ecology and Hydrology (CEH).
- STARS (BBSRC, NERC, http://www.starsoil.org.uk/). Soils Training and Research Studentships led by Lancaster with Bangor, Cranfield, and Nottingham with BGS, CEH, James Hutton Institute and Rothampsted Research.
- AFTP (BBSRC, www.aftp.co.uk/) Advanced Agrifood Training Partnership led by Reading with Aberystwyth, Cranfield, and Harper Adams. Support for part-time PhDs at Cranfield is available.
- FoodBioSystems DTP (BBSRC, https://research.reading.ac.uk/foodbiosystems/). FoodBioSystems Doctoral Training Partnership (DTP) directed by Reading, co-directed by Cranfield, with Aberystwyth, Brunel, Queen's University Belfast and Surrey; and 54 partner organisations.
- CTP-FCR (BBSRC, Agricultural and Horticultural Development Board (ADHB), https://www.ctp-fcr.org/) Collaborative Training Partnership for Fruit Crop Research led by Berry Garden Growers Ltd and NIAB-EMR with Cranfield, Essex, Harper Adams, Lincoln, Nottingham, and Reading.

The OCP Group, a phosphate fertilizer producer, sponsors a DTP in UoA6, delivered in co-operation with Rothampsted Research, supporting the development of the next generation of Moroccan agricultural scientists and engineers (www.cranfield.ac.uk/press/news-2019/building-africas-resilient-agricultural-future-uk-morocco-partnership-announced).

All PhD students join the pan-University Cranfield Doctoral Network (CDN), through which they are offered training in the Doctoral Researcher Core Development (DRCD) programme (REF5a, www.cranfield.ac.uk/research/research-degrees/cranfield-doctoral-network). In UoA6, PhD students join the Thematic Doctoral Network (TDN) for Environment & AgriFood, one of eight at Cranfield (REF5a). Led by a senior academic (**Sakrabani**), the TDN aims to build a sense of community and belonging for all doctoral students across the Theme through provision of

focussed activities, many of which are also offered pan-University to encourage inter-disciplinary understanding. Specific to those in UoA 6 are:

- Monthly research forums, seminars and discussions among staff and students that include bioinformatics and plant genetics; crop, soil and water systems; modelling; postharvest and mycology.
- Leading the student response to COP26 for the CDN.
- Encouragement to apply for and accept placements to gain broad experience for career development. Organisations accepting placement students include Defra, Natural England, NIAB-EMF, Parliamentary Office for Science and Technology, Syngenta and Unilever.
- Research students from UoA6 have leading roles in Silsoe Aid for Appropriate Development (SAFAD), a British charity managed by Cranfield students (https://safadcharity.org). The students gain practical experience and insight into how charities operate to raise money. The funds from SAFAD are then used to send Cranfield graduates to Low Income Countries to work with local organisations in providing technical assistance and expertise on agricultural related issues, gaining field experience in return. SAFAD has sent over 340 volunteers to 40 countries.

Student representation is embedded in the governance structure of Cranfield (REF5a) with membership of key decision-making bodies (REF5a). The Postgraduate Research Experience Survey (PRES) is used an important component of student feedback, used to inform the delivery of individuals' research programmes and the research culture engendered locally by UoA6 staff and the Environment and AgriFood TDN.

Recent alumni have made successful starts to their career based on their PhD research experience with employers including PepsiCo, Severn Trent, Department for Business, Energy and Industrial Strategy (BEIS), Defra, Deloitte Ventures, Unilever and Mondelez International.

3. Income, infrastructure and facilities

Research income

The overall research income grew with a total of £23.0M compared to £14.6M in REF2014. This was driven by UKRI income growth, increasing from 12% to 41% of total. The growth was principally from BBSRC and NERC due to the increased emphasis on delivering fundamental research. As planned, this translated into increased support from industry, growing to 35% (27%). Income from charities is 4% (2%). EU government income was stable at 10% (12%). These changes offset reduction in support from UK government, mainly Defra, due to changes in funding policies (10% vs 47%).

Selected major UKRI grants include:

Metal contamination in rice (£1.45M, BBSRC, BB/P02274X/1, BB/R020388/1 **Kirk, Corstanje, Simmons**)
Greenhouse abatement in soils (£790K, NERC, NE/P019668/1, NE/P019498/1, **Williams**)
Grassland management (£200K, NERC/BBSRC, NE/R017387/1, **Burgess**)
Innovation in the digital environment (£1.27M, NERC, **Corstanje, Hallett**)
Enhancing nutrient use from biosolids for crops (£110K, NERC/BBSRC, NE/M012794/1, **Sakrabani**)
UKCRIC Urban Observatory (£1.05M, EPSRC, EP/R017727/1, **Harris, Jude**)

Implementing novel, sustainable potato storage (£525K, BBSRC, **Terry**)
Soils and irrigation in Senegal (£160K, InnovateUK, 47259, **Simmons**)
Fine bean growers in Kenya (£150K, InnovateUK, 105658, **Simmons**)
Aflatoxins in Ethiopian peanuts (£380K, InnovateUK, 105663, **Medina Vaya**)

Strategic management of the overall income mix successfully ensured the financial sustainability of UoA6 by providing strong basic research. Contact with government and industry continually challenges the relevance of our work and helps us work across a wide range of technology readiness levels. Underlying trends include a shift toward multi-institutional projects, more joint UKRI-funded academic/industry projects, and the development of longer-term relationships with specific companies (Section 4).

Research infrastructure and facilities

Cranfield has a range of unique research facilities, often at or near industrial-scale, to deliver the mission of transformational research that meets the needs of business, government and wider society (REF5a). Within UoA6 this includes access to real-world conditions on Silsoe Farm where crops are trialled. Other established facilities include the Soil Management Facility and Wolfson Field Laboratory (www.cranfield.ac.uk/facilities). These facilities are complemented by 20 commercial farms associated with Agri-EPI. As noted in Section 1, investment in new facilities was a major component of the plan to improve the research environment in UoA6.

A total of £13M was secured from Innovate-UK for two of the four new **UK Agritech Centres** (www.agritechcentres.com) with facilities and staff at Cranfield. Cranfield hosts the Agri-EPI's Crop Technology Southern Innovation Hub (https://agri-epicentre.com/solutions/soil-crop-technology/southern-innovation-hub). CHAP is designed to make sure that the knowledge from the UK's science base is translated into benefits for farmers and the food industry. Academia and industry work together to improve crop productivity and provide environmentally friendly solutions to a range of challenges (e.g., soil health, plant and soil-borne diseases).

A £3.5M **Plant Growth Facility** (https://www.cranfield.ac.uk/facilities/plant-growth-facility) for plant phenotyping and soil health was opened in 2018 by Indra Nooyi (CEO and Chairman of PepsiCo). This is the world's first phenotyping glasshouse facility designed to trial crop-soil systems under a multi-sensor gantry operating at a scale large enough to simulate controlled field conditions (1-24 m^2). Incorporated is a 45m long, 5m wide soil lane designed to accommodate field scale operations, such as cultivation and drilling, in a controlled manner. Uniquely, the facilities can operate over multiple cropping cycles allowing insights into legacy effects of previous cropping practices on future crop production. The LemnaTec overhead multi-sensor phenotyping platform is used to monitor crop health, develop new sensors and sensor protocols in controlled soil-crop systems. Data is used to research the optimum data collection and analysis routines to direct farm management. Facilities include a sensor laboratory and sensors deployed on associated commercial farms.

The **Soil Management Facility** (www.cranfield.ac.uk/facilities/soil-management-facility) comprises full-scale facilities for studying the dynamics of soil-machine-crop-water interactions, unique in Europe; full scale rigs for studying soil erosion, including simulation of different rainfall intensities and storm return periods; and a gravity-fed 'rain tower' allowing precise control of precipitation form and intensity for detailed studies of soil erosion processes. The soil and plant laboratory provides a full range of equipment and processes for soil and plant characterisation with comprehensive equipment for soil physical and hydrological measurements. These are complemented by the soil microbiology laboratory for measuring genotypic, phenotypic, and functional community level traits. The Wolfson Field Laboratory is an array of 24 large lysimeters

with contrasting, intact soil monoliths and real time sampling of emitted gases via automated closure systems connected to greenhouse gas measurement systems.

A new £3.2M **Agri-informatics Building** was completed in February 2020 funded by Innovate-UK, the Wolfson Foundation, Agri-EPI and Cranfield (www.cranfield.ac.uk/press/news-2018/construction-begins-on--new-agri-informatics-facility--at-cranfield). It will provide the UK with a centre of excellence in data science related to precision agriculture and house the National Soils Collection and Reference Centre. Cranfield and its partners will use the facility to increase data quantity and quality, while using innovative informatics to support novel business, management, and policy approaches in the agricultural sector. Agri-EPI will focus on agri-tech research and innovation.

The **Environmental Analytical Facility** (EAF) underwent a £1.2M Cranfield funded refurbishment in 2016. It comprises a series of shared laboratories for the analysis of surrogate parameters, trace contaminants and emerging pollutants in all media as well as experimental rooms for bench top and longer-term experiments (www.cranfield.ac.uk/facilities/environmental-analytical-facility). The facility is central to many PhD and academic research projects with more than 200 registered users a year. Staff have recently improved data quality and governance.

The **Plant Science Laboratory** comprising full analytical capability for volatile and non-volatile, targeted and non-targeted metabolomics, and labs for molecular biology and plant genetic transformation supported by a 270 m^2 research glasshouse (www.cranfield.ac.uk/centres/soil-and-agrifood-institute/research-groups/plant-science-laboratory). It has access to a full suite of HPLC MS, and GC devices equipped with a wide range of detectors. UoA6 has invested heavily in upgraded capabilities which now include a UPLC-qTOF-MS and LC MS/MS for metabolomics and compound discovery. New instruments are significantly improving our capability for high throughput mycology and bacteriology experiments as well as in elemental analysis and gas chromatography. Associated facilities include four environmental walk-in growth chambers and cold storage rooms with controlled atmosphere facilities.

The **Postharvest Research Facility** enables fresh produce storage and ripening research by simulating and further evaluating industrial postharvest scenarios by controlling/modifying the temperature, relative humidity, and the surrounding atmospheric environment (CO_2 and O_2, and ethylene levels) of fresh produce during storage. This is complemented by 6 mini-pods which imitate controlled commercial stores and three respirometers (one 16-channel and two 24-channel) and allow real time monitoring of CO_2, ethylene production and O_2 consumption in packaging, storage, and controlled atmosphere conditions.

In 2016 a £3.1M new building to support the Cranfield-based **Facility for Airborne Atmospheric Measurement (FAAM)** was opened with co-funding from NERC (www.cranfield.ac.uk/press/news-2017/universities-minister-jo-johnson-opens-new-multiagency-research-hub). It houses CEAI atmospheric sciences academics researchers and the NERC FAAM research aircraft team. This has secured the future of the FAAM facility at Cranfield with strong links to the atmospheric scientists and related academics in UoA6. The building also houses the outdoor air quality station, a key component of the Living Lab.

Cranfield is one of six universities in UKCRIC (UK Collaboratorium for Research on Infrastructure and Cities) establishing urban observatories as platforms for research. **Cranfield Urban Observatory** is a major part of the University's Living Laboratory providing a £1M campus-wide sensor network. Cranfield's semi-rural, peri-urban location at the centre of the Oxford-Cambridge Arc provides unparalleled research and learning opportunities to investigate how agriculture can develop within a complex natural and built environment. The network harnesses the latest sensor technology and includes environmental and infrastructure sensors to

monitor factors such as air, water, and wildlife. Data, analytics, and visualisation are used to investigate infrastructure performance, quality of life and wellbeing, allowing studies of healthy and sustainable environments and the effects of planned change. Cranfield provides a unique infrastructure, including the global research airport and other large facilities, such as the wastewater treatment works, all controlled by the University.

Data holdings

LandIS (www.landis.org.uk). Cranfield is recognised by Defra as providing the National Reference Centre for Soils. This comprises the entire data derived from the former Soil Survey of England and Wales, which is now integrated into a searchable vector data system. The 5-year LandIS soil contract was renewed by Defra in 2018. Since 2017, LandiS data has supported over 90 projects for Defra, associated governmental departments (e.g., Ministry of Defence, MOD), agencies (e.g., Committee on Climate Change, Environment Agency), charitable trusts (e.g., The National Trust) and UKRI research (NERC, BBSRC). These core archives have been developed to produce the National Perils Directory (flooding and subsidence), CatchIS (a software tool for the management of water quality at catchment level), and Soil-Net (an online soil science resource). The datasets holdings underpin many research projects, including those with outcomes used by government to formulate and implement policy e.g., Agricultural Land Classification (Welsh Government).

WOSSAC (www.wossac.com). Cranfield is the custodian of more than 20,000 soil survey reports, maps, imagery, and photographs produced over the last 80 years from 372 territories worldwide. This unique global resource covers a large part of the terrestrial surface of the planet.

4. Collaboration and contribution to the research base, economy and society

Research collaborations, networks, and partnerships

Developing collaborations with national and international partners and funders has been central to UoA6's research strategy. This has been achieved by raising the quality of academic research (Section 1), increasing participation in doctoral partnerships and enhancing scholarship through recruitment and promotion (Section 2). The working group for preparing NERC Highlight Topics and strategic proposals is specifically aimed at promoting research collaborations. Overall research income has risen with increases from several sources – this has been coupled with our hosting an increased number of national facilities which engender collaboration (Section 3).

Consortium projects comprise an increasing proportion of the UKRI research budget and UoA6 academics are participating in many of these, including with 18 UK universities in several DTPs or equivalent (Section 3). In 2020 we joined 10 other UK universities and the Science and Technology Facilities Council (STFC) Rutherford Appleton Laboratory as a member of the National Centre for Atmospheric Science (NCAS) (https://ncas.ac.uk/about/site-locations/). The NERC funded FAAM aircraft is based at Cranfield (Section 3) that facilitates NCAS research. We collaborate with 8 universities in Agr-EPI (https://agri-epicentre.com/membership/network/) and 2 in CHAP (https://chap-solutions.co.uk/our-network/).

Academics are proactively setting the agenda for government research and innovation strategies, e.g., leading the preparation of two successful NERC Highlight Topics ideas related to land use and ecology. They contributed to the BBSRC/UKRI National Plant Science Strategy 2021 with the Impact Case Study ETHYLENE (Table 1.) used an exemplar for converting

research to impact (www.ukri.org/about-us/what-we-do/strategies-and-reviews/uk-plant-science-research-strategy/).

UoA6 staff led international-facing projects including EU projects on agroforestry and on biofuels (**Burgess, Graves**), NERC and GCRF projects on metal pollution of soils (**Kirk**), and EU and BBSRC projects on plant genetics in horticultural crops and potatoes (**Kevei, Thompson, Mohareb, Terry**). In the UK, projects include the Global Food Security's Resilience of the UK Food System Programme (**Hess**); the UKRI/BBSRC Horticultural Quality and Food Loss Network (**Terry**) and BBSRC FoodBiosystems DTP (Co-Director) (**Terry**); a MOD project seeking ways to use its estate to contribute to the UK Government target of net zero carbon emissions by 2050 (**Burgess, Corstanje, Hannam, Rickson, Williams, Hallett**); 3 NERC consortium projects on ecosystem resilience at the rural/urban interface **(JHarris, Corstanje**); and, for the UK governments, the evidence base on the state of soil resources and soil protection policy has been assembled and assessed (**Hannam, Deeks, Burgess, Holman, Graves, Rickson**).

Two projects were funded under the UKRI Covid-19 Urgency call; one a rapid assessment of the spatial consequences on the environment of pandemic responses and opportunities, using our food systems and soils capability (**Burgess, JHarris, Williams**) in co-operation with the James Hutton Institute; the other on the response of pollution levels in the Oxford-Cambridge Arc (**NHarris**).

Industry collaboration

Cranfield particularly values industry partnerships and has 14 strategic industrial research partnerships (REF5a). Two of those are led by UoA6: with Unilever (2011-to date) and PepsiCo (2013-to date). This major emphasis on the development of long-term partnerships with industry allows kick-starting of new ideas, developing impact from existing research and helping to develop future thought-leaders. Other significant examples of our successful collaboration with industry include:

- Hosting key components of the Agricultural Engineering Precision Innovation (Agri-EPI) UK Agritech Centre (https://agri-epicentre.com). The centre engages with industry to encourage the adoption of precision agriculture and engineering technologies to boost productivity across the whole agrifood chain by using next generation technologies such as sensing, imaging and robotics.
- Providing key soils data and expertise for the Crop Health and Protection (CHAP) UK Agritech Centre (https://chap-solutions.co.uk). Industry partners include Bayer, Liberty Produce and Tesco.
- Helping entrepreneurs and start-ups who are combating climate change with science and technology-based ideas in the areas of agriculture and food production as a partner in the SHAKE Climate Change programme, funded by Societe Generale UK Foundation (www.shakeclimate.org).
- Improving Produce World Group's Soil-for-Life® Soil Management Information System to help improve its use of soils and marketable yields.
- Co-creating and leading the Johnson Matthey Agritech Partnership Programme offering small companies and start-ups from across the world intensive advice and funding for market translation of high impact innovations in Agritech (www.cranfield.ac.uk/business/develop-your-technology-and-products/johnson-matthey-agritech-partnership-programme).

- Partnering with OCP Group (£14M, 2019-23) to boost agricultural productivity in Africa with partners Rothampsted Research and Mohammed VI Polytechnic University, Morocco. In addition to the DTP (Section 2),

Contributions to research base

Individual UoA6 academics are involved in many learned societies, Research Council assessments and journal editorships (Table 3.). Many UoA6 academics are members of research council equivalent organisation panels in other countries, including Canada, Republic of Ireland, The Netherlands, New Zealand, Poland, Russia and USA.

Table 3. Cranfield staff contributions to wider research activities.

Indicator	Number
Fellowships of learned societies	25
Committee members for learned societies, professional bodies	30
Research Council Committee roles	14
Grant reviewers for Research Councils	20
Grant reviewers for charities, Royal Society and non-UK bodies	32
Journal editor roles	38
Keynote and Invited Lectures	52
Conference Chairs and Organising Committees	22

Staff have undertaken major roles in a number of national and international societies, programmes, and assessments:

- President (2018-20) Institution of Agricultural Engineers, first female since established in 1938 (**Rickson**)
- Member representative, Agricultural Universities Council UK (**Terry**)
- Non-Executive Director, AgriEPI and CHAP (**Terry**)
- President (2017-18) British Society of Soil Science (BSSS) (**Otten**)
- President elect (2020-21), British Society of Soil Science*;* Division Vice-Chair (2018-22), International Union of Soil Science (**Hannam**)
- Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES) Lead Author and UK delegation, BioDiversa, UN and World Commission on Protected Areas (WCPA) programmes (**JHarris**)
- Vice-chair, Food and Agriculture Organisation Advisory Committee on methane (**Cain**)
- Co-chair (2014-present) Stratosphere–troposphere Processes And their Role in Climate (SPARC), a core project of the World Climate Research Programme (**NHarris**)
- UNEP Ozone Layer Science support: Scientific Assessment Lead author (2014), Review Editor (2018;) Advisory Group, Unreported CFC-11 Emissions report (2021) (**NHarris**)
- Chair, Oxford—Cambridge Arc Local Natural Capital Plan Partnership Group (**Leinster**)
- Member, Global Food Security Programme Tipping Points Working Group (**JHarris**)
- Advisor to Defra Chief Scientist on Living Laboratories and the Soil Microbiome (**JHarris**)
- National Digital Champions for Constructing a Digital Environment (**Corstanje, Hallett)**

Notable awards and prizes include:

- Queen's Anniversary Prize (2017) in recognition of education and research in large-scale soil and environmental data for the sustainable use of natural resources in the UK and worldwide.(**Rickson, Hallett, Hannam, Terry**)

- RCUK Research Base Impact Award (2015) for Soil-for-Life system KTP (**Simmons, Corstanje, Hallett**)
- Women Leaders UK winner (2019), Outstanding Contribution and Engineering, Science & Maths awards (**Rickson**)
- Society of Chemical Industry's Sydney Andrew Medal (2021) for encouraging the application of science for public benefit (**Rickson**)
- IAgrE President Award (2018) for outstanding contribution to development of sustainable soil management solutions (**Simmons**)
- Berkeley Award (2020), British Mycological Society (**Medina-Vaya**)
- NERC International Impact and Overall Impact Awards (2015) for role in the development of the Montreal Protocol on Substances that Deplete the Ozone Layer. (**NHarris**)
- Highly Commended Papin Prizes (2019) and Times Higher Education Awards, Outstanding Technician category (2020) for senior technician (***Hubble***).

Outreach

Nearly all UoA6 academics are involved in outreach in some way, whether through contributions on TV or radio, writing blogs, giving talks to schools, the public, farming groups, etc. A total of 118 press releases were issued by UoA6, with one on the perfect avocado reaching an audience of 399 million and generating 50 news articles (www.cranfield.ac.uk/press/news-2020/new-test-could-guarantee-the-perfect-avocado). Four events exemplify UoA6's commitment:

- Researchers from Cranfield University and the Open University are responsible for Soil-Net (http://www.soil-net.com), a free, online soil science resource for school pupils (KS1-4) and teachers which has been used by >1.5 million people in >200 countries worldwide. It aims to remedy the historic under-representation of soil in the school curriculum.
- Soapbox Science is a unique platform that promotes women in science by organising events in public spaces to reach people normally not attending scientific activities. The event showcases women in STEMM and their research. **Hannam** was founder of the event in Milton Keynes in 2015. It has provided public engagement training to ~60 Cranfield academics and PhD students who annually engage with >1000 members of the public. It supported promotion cases and UKRI proposals to demonstrate impact and engagement of their research and developed a regional network of women in science.
- The Digital Champions (**Corstanje, Hallett**) in UoA6 organised the UKRI NERC-funded Digital Sprints in June 2020. They brought together environmental researchers, health and social science experts and data specialists to work together or individually to draw from NERC digital assets and datasets to consider the environmental impacts and consequences of Covid-19 and create a wealth of open, digital, environmental solutions to the pandemic. The four topics were air quality; recovery; ecosystem services; and visualising risk.
- Lockdown Lettuce Beds stimulated lettuce growing in Bedfordshire through an oversubscribed citizen science experiment set up in response to Covid-19 (**Kourmpetli, Falagan**).