

Institution: University of Hertfordshire
Unit of Assessment: 6 Agriculture, Food and Veterinary Sciences
<p>1. Unit context and structure, research and impact strategy</p> <p>Context and structure</p> <p>The Agriculture, Food and Veterinary Sciences (AFVS) Unit was established in 2011 within the School of Life and Medical Sciences (LMS). There are 23 staff (18.97 FTE) in the Unit which comprises 3 Professors, 4 Readers, 9 Lecturers, 6 independent Research Fellows and 1 Statistician. AFVS also provides leadership for Food, one of the University's six interdisciplinary research themes.</p> <p>Research strategy is developed within the Unit and approved by the LMS Research Executive Group (REG). AFVS is led by Fitt, who manages the Unit's research budget (which includes a devolved QR allocation) against an agreed University-level research delivery plan. Research deliverables, including targets for external grant applications, research income and high-quality research outputs, are monitored by the REG. The School is responsible for staff development and institutional infrastructure, while the LMS Associate Dean (Research) ensures that School research strategies align with those of the University.</p> <p>Unit highlights in comparison with REF2014 during this cycle include:</p> <ul style="list-style-type: none"> • 64% increase in submitted FTE staff • 126% increase in average annual doctoral awards • 82% overall satisfaction rate in 2019 Postgraduate Research Experience Survey • 19% increase in average annual income • Centre for Agriculture, Food and Environmental Management Research established in 2015 • Relocation to new £61.2M Science Building in 2016. <p>Strategy</p> <p>In REF 2014 the Unit identified the following strategic priorities which have been addressed during the current cycle:</p> <p>Build a critical mass of research-active staff through investing QR into research groups and generating external funding: There has been a 64% increase in the Unit FTE staff since REF 2014. This includes 8 new appointments at all levels from independent Research Fellow to Professor. The Unit also has recruited 13 Research Fellows, who are not independent researchers, attached to specific grant-funded projects.</p> <p>Researchers operate within 3 research groups that align to the Unit's core strengths.</p> <p>a) Crop Protection and Climate Change (CPCC): Barrero-Sicilia, Coutts, Davies, Fitt, Garcia-Cela, Hall, Huang, Malcolm, Mashanova, Qi, Richard, Stotz. Research focuses on sustainable, environmentally benign, strategies for control of crop pests, nematodes and diseases, under impacts of climate change, with applications to control some human diseases. New appointments in modelling impacts of climate change (Qi, Richard) and to support work on mycoviruses, strawberry pests/diseases and agro-ecology (Coutts, Hall, Mashanova), were made. CPCC publications during this REF cycle include work on plant biochemistry (Barrero-Sicilia), genomics of resistance to crop pathogens to enhance productivity (Stotz), and the modelling of impacts of climate change on grassland ecosystems (Qi) and willow growth (Richard) to inform adaptation policy. CPCC's work on use of mycoviruses for biocontrol (Coutts), biocontrol of nematodes (Davies), integrated control of strawberry pests and diseases (Hall), pathogen fungicide insensitivity (Huang) and the genomes of grass leaf blotch pathogens (Fitt) enhances sustainable crop production.</p>

Research on the spread of the Covid-19 virus in England (Mashanova) and control of malarial mosquitos (Malcolm) aims to guide control strategies. The group is strengthened by 3 post-doctoral Research Fellows.

- b) **Agriculture and Environmental Management (AEM):** Crook, Lewis, Pearce, Porter, Tzilivakis, Warner. AEM specialises in agri-environmental science, water resource management and climate change adaptation/mitigation to guide government and industry policy in the UK and overseas. Recent outputs include papers on adapting to climate change in agricultural ecosystems (Lewis, Tzilivakis and Warner), irrigation systems in India (Crook), impacts of climate change on glacial geomorphology (Pearce), and monitoring and modelling melting of Arctic and Himalayan ice loss to inform policy decisions (Porter). The group is strengthened by one Research Fellow.
- c) **Food Policy, Nutrition and Diet (FPND):** Barling, Fallaize, Kass, Madden, Vafeiadou. Work addresses food intake in relation to diet and its impact on disease, together with policy and governance impacts on the food system. FPND was supported with a targeted allocation of QR funding for a new research fellow post in nutrition (Fallaize), as well as PhD students in nutrition and diet (supervisor Madden). Research has been augmented with a Professorial appointment in food policy and security (Barling), generating externally funded research projects and further research fellows. FPND outputs include work on the estimation of energy expenditure in obese adults (Madden), precision nutrition and diet (Fallaize), food exchange modelling in free-living populations (Vafeiadou), dietary magnesium intake in hypertensives (Kass) and policy and governance interventions to enhance food sustainability (Barling). The group is strengthened by 3 Research Fellows.

Examples of substantial collaborative research between the groups include linking work on nutrition to expertise with primary crop and livestock production, and wider use of transcriptomics, genomics, and molecular and computational modelling to support research on microbiology and crop protection. There are joint PhD studentships on topics such as reduced tillage farming (Warner, AEM; Davies, CPCC).

All 3 research groups form the **Centre for Agriculture, Food and Environmental Management Research (CAFEM Research)**, led by Barling, which facilitates research across the University and with external institutional partners. CAFEM Research is institutionally located in LMS, and it is one of 13 designated Centres for Research across the University.

Develop a collaborative partnership with Rothamsted Research (Rothamsted) and the Royal Veterinary College (RVU) to make a substantial contribution to the research profile of the Unit. CAFEM Research provides the Unit with access to additional experimental facilities and new funding streams, along with quarterly meetings for members of all 3 groups to discuss research issues. It has significantly strengthened the Unit's research portfolio, notably through the development of successful externally funded research bids. The Centre delivers the Memorandum of Agreement between the University, Rothamsted and the RVC, to collaborate on research and education, operating since 2015. Collaborations with Rothamsted include a Newton-Bhabha project with partners in India and the UK (Stotz, Fitt), a BBSRC KTN PhD studentship (Stotz, Fitt) and a PhD project on light leaf spot (Stotz, Fitt). Three staff members from Rothamsted are Visiting Professors at the University; all collaborate in research projects and teaching. A Senior Research Fellow has been appointed jointly with RVC as part of a four-year project on sustainable British beef and sheep production and food systems in a changing environment, funded by the Cadogan charity.

In addition, in the REF period the Unit has partnered with Rothamsted in collaboration with several other institutions in three major innovation and research programmes *AgRIA: Agri-Tech Research Innovation Accelerator* funded by European Regional Development Fund (<https://www.rothamsted.ac.uk/agria>); *Ceres Agri-Tech Knowledge Exchange Partnership* funded by a Research England Connecting Capability Fund Award

(<https://www.ceresagritech.org>) and *Shake: Climate Change*, funded by Société Générale UK Foundation (<http://www.shakeclimate.org>).

Improve facilities and increase PhD awards: Unit research is now based in the new £61.2M Science Building which opened in November 2016. It includes bespoke facilities designed and equipped specifically for the Unit (see Section 3). Glasshouse facilities at the Bayfordbury Field Centre have also been refurbished. Since 2014, 25 new PhD and 5 new MPhil/MSc by research students have been enrolled within the Unit in comparison with 19 PhD research students enrolled during the REF 2014 research cycle. The number of doctoral awards has risen from 6 in the last REF cycle to 19, equating to an increase of 126% in average annual awards.

Interdisciplinary Research

AFVS's position within LMS has also facilitated close collaboration with researchers in other groups, notably biosciences staff submitted to Allied Health, with whom they share laboratory facilities in the Science Building. Joint projects include comparison of the role of microvesicles in plant and mammalian diseases (Stotz with Inal) modelling the interactions between pathogen effectors and plant resistance genes (Stotz, Fitt with Kukol), and joint research studentships on diet for pain management (Vafeiadou, Fallaize with Baines) and antibiotic resistance (Davies, with Baines).

The University established six interdisciplinary research themes to promote interdisciplinary collaborations and develop external funding applications across the University in 2016: Food; Global Economy; Health and Wellbeing; Heritage, Culture and Communities; Information and Security; Space. Barling is the University's Research Theme Champion for Food.

Four centrally funded University Early Career Research Fellowships supporting interdisciplinary research partnerships relevant to these themes were awarded to the Unit through an internal competitive process in 2016. These were all attached to the University Food Research Theme in partnerships with the Information and Security, Space and the Health and Wellbeing themes which are undertaken with partners from the Schools of Physics, Engineering and Computer Science or Health and Social Work. Two Fellows are also working in collaboration with Rothamsted.

Impact strategy

The Unit's strategy to achieve research impact is to deploy a range of mechanisms which include:

Encouraging applied research applications to agencies and funders primarily concerned with achieving positive outcomes for populations and communities. For example, Lewis, Warner and Tzilivakis were funded by the European Food Standards Agency (EFSA), the Joint Research Council (JRC) and European Regional Development Fund (ERDF), to undertake a research programme facilitating the impact case study on pesticide risk assessment (see below).

Ensuring funded applications with industry partners specify key impacts and continued liaison with end-users post-completion. This approach means that impact is embedded as a priority throughout the project life cycle. Successful grant applications with industry partners to Innovate UK, the Biotechnology and Biological Sciences Research Council (BBSRC), Agriculture and Horticulture Development Board (AHDB) and several charitable foundations include impact objectives. For example, during and after two Agri-Tech Innovate UK/BBSRC funded projects on phoma stem canker of oilseed rape (2015-20), industry partner Hutchinsons was able to disseminate new findings through its network of 200 agronomists to 13,000 farmers per year to influence their disease control practices.

Working with the University's Enterprise and Business Development Team to develop collaborative projects with impact. The Unit has established 6 Hertfordshire Knowledge Exchange Partnership (HKEP) 4-year Industrial PhD studentships with industry partners,

benefiting from the University's Hertfordshire Science Partnership scheme (see Institutional Statement). These studentships facilitate research that can influence the partners' business methodologies, thereby creating substantial impact. There are two studentships with RSK ADAS, and one each with companies, DryGro and Syngenta, and also the Letchworth Heritage Foundation. A further HKEP PhD student is hosted by K G Davies Ltd - a company providing nematode biocontrol solutions established by a Unit member – in collaboration with the Norwegian Institute of Bioeconomic Research (see section 4).

Requiring impact generation activities to be included in all internal funding applications

The Unit requires PhD studentships (e.g. QR funded PhDs; HKEP co-funded PhDs with industry partners), University early stage researcher grants and Santander research travel awards to include impact generation proposals.

Utilising University funds for impact development. The Unit successfully applied for 6 University small grants for impact development totalling £13,520 during the cycle. Funds supported a research assistant to collect evidence of impact of the pesticide database on government and industry policy in different countries (Lewis); travel to China to collate evidence of the impact of Unit research on arable crop diseases on government policy (Huang); a research assistant to collect evidence of impact of the Unit's work with UK industry partners and government policy (Fitt, Hall); and travel to India to work with policy-makers and water harvesters (Crook).

Public engagement events to share ideas with the general public through, for example, Café Scientifique engagement events organised by Madden that have been held on a regular basis, open to the general public at venues outside the University, enabling researchers to explore and discuss different themes in science and technology.

The two submitted case studies are illustrative of the Unit's approach. The first case study '*Benefits to UK and Chinese agriculture from new crop disease control strategies*' resulted from research on crop pests and diseases, mostly carried out in collaborative consortia with end-users and industry partners (crop breeders, distributors, farmers, agrochemical companies). It has led to global strategies for managing insensitivity to insecticides, and improvements in breeding for resistance to extracellular arable crop pathogens (such as those that cause oilseed rape phoma stem canker and light leaf spot and barley leaf blotch) and disease management by growers. It has also influenced Chinese government quarantine policy and led to capacity-building through the development of personnel in UK industry, and also skills development and knowledge transfer in China. The second case study '*Improving worldwide pesticide risk assessments for more effective international regulation and stronger protection of human and environmental health*' is the result of extensive externally funded research to improve pesticide risk assessments. This work has included the development of a database of risk assessment procedures which enable global agricultural regulators, policy makers, researchers and industry to undertake risk assessments more effectively and easily. The database has substantially improved knowledge regarding the safety of pesticides, provided evidence to support policy objectives and helped improve the accuracy and comparability of these risk assessment procedures.

Open Research Environment and Research Integrity

Data underpinning the Unit's research are published for the purposes of reuse and verification, and to maximise their impact and benefit to society. Unit staff make their outputs available in electronic formats that support searching, downloading, text and data-mining, and re-use of their content, subject to full and correct attribution. These are placed in the on-line University of Hertfordshire Research Archive (UHRA). The Unit also follows the University-wide open access publishing strategy protocols and operates in accordance with the Budapest Open Access Initiative. For example, results obtained in the Unit Newton-Bhabha and Newton-Mosharafa projects were openly shared and discussed with collaborators in India and Egypt, respectively.

Unit staff often take additional steps to share research data effectively. An example is the three agricultural-substance (pesticides, biopesticides and veterinary substances) databases. Access to these is provided free of all charges via the University website and they are used extensively globally, with the pesticide properties data typically receiving 5000+ hits daily. Other examples include the use of Mendeley Data for storing data associated with research publications or the Protein Model Database (PMDb) for storing specific research results.

The Unit follows the University policy to publish outputs in green open access (OA) format wherever practicable. The University also operates an annual Article Processing Charge (APC) Fund to support gold OA publication of research outputs, where this is beneficial for reputational enhancement or to facilitate access for specific discipline areas, when other funding is unavailable. The Unit has benefitted from University central funds for gold OA publication of many papers, including 5 papers in PLOS One (2014-2019), Scientific Reports (2017), Trends in Plant Science (2014) and Molecular Plant-Microbe Interactions (2020). In addition, the University has recently reached transformative agreements with several publishers facilitating publication with gold OA in their journals without individual charges.

All research carried out by the Unit is fully compliant with University protocols on research ethics and integrity. No projects involving human participants or animal subjects may be undertaken without prior University senior management and ethics committee approval. The University is a signatory to the Concordat to Support Research Integrity and provides mandatory training on research integrity for all researchers (staff and students) delivered through the Doctoral College Researcher Development Programme. Unit staff actively participate in the annual research ethics seminar and periodic update workshops organised by the University.

Future Strategy

The Unit aims to advance its agricultural, food, environmental and health research in order to transform lives, whilst addressing fundamental global and societal challenges, such as climate change. Specifically, it plans to:

- a) **Develop new sustainable global partnerships and strengthen existing collaborations with international/national partners** (see Section 4) through joint applications for further funding. For example, the Unit will apply for funds to develop international collaborative projects on phoma stem canker and to extend current Newton projects with India and Egypt together with previous GCRF QR funded work with India on biological control of nematode pests. The Unit will apply for funds with national partners (e.g. Rothamsted and RVC through CAFEM Research and Oxford University on food policy, Barling) and take advantage of funding opportunities, such as those provided by the Agri-Tech programme, Innovate UK, and UKRI for joint research projects with countries in sub-Saharan Africa (e.g. climate change programme at the University of KwaZulu-Natal South Africa).
- b) **Address societal and industrial priorities** through research with industry partners on projects that address societal challenges (e.g. impacts of climate change on agricultural crops). In particular, the Unit will continue to participate in the interdisciplinary research opportunities provided through the Food Research Theme, and collaborate with other colleagues in the newly designated University-wide Centre for Climate Change Research to form interdisciplinary teams to apply for funding for research addressing climate change impacts, adaptation and mitigation.
- c) **Improve the Unit's global research profile** by expanding the numbers of publications with international co-authors with whom Unit researchers have engaged in collaborative projects in high profile international journals (e.g. *PNAS*, *Scientific Reports*, *Plant Physiology*), as a basis for attracting invitations to give keynote presentations at major international conferences (e.g. International Congress of Plant Pathology, Lyon, 2023).
- d) **Encourage research outcomes that have external impact outside academia.** The Unit will expand its engagement in research projects which include end-users as partners - farmers, crop breeders, agricultural distributors - through applications to funders such as Innovate UK. It will obtain new industrial contacts through involvement in end-user networks such as the annual stakeholder meetings of the Oilseed RapE Genetic Improvement

Network, OREGIN. Furthermore, the Unit will expand participation in public engagement activities (e.g. Royal Society soirees, Café Scientifique, lectures to local groups such as University of the Third Age) to increase its profile among the general public.

- e) **Expand the community of research-engaged staff**, by growing the number of staff who have significant responsibility for research through the recruitment of new staff, investment of Unit QR resources (e.g. for Early Career Researchers (ECRs)) and providing time for academic staff (such as those returning from a break from academic life) to develop research programmes.
- f) **Grow the Unit's community of research students** in line with the University's target for a 35% increase in postgraduate research (PGR) students by 2025, taking advantage of the interdisciplinary opportunities offered for collaboration through the University Research Themes, and cross-disciplinary Research Centres, such as the two new University-designated Centres for Climate Change Research and Future Societies Research.

2. People

Staffing Strategy

As part of the strategy to strengthen agri-food research at the University, research in the Unit was focused into the 3 groups (CPCC, AEM, FPND), each now led by a professor. Fitt (CPCC) was appointed in 2011, Lewis (AEM) was promoted from Reader in 2014, Barling (FPND) was recruited as professor and Head of CAFEM in 2015. Eight new staff who have been submitted to REF2021 were appointed since 2014 in line with a strategy to build critical mass in these major research concentrations. The overall number of staff in the Unit has increased from 15 (11.60 FTE) in 2014 to 23 (18.97 FTE) in 2021; a 64% increase in FTE staff.

These new staff have expertise aligned with that of the main research groups and structures. Barling (FPND) was recruited to a professorship in Food Policy and Security and appointed University Research Theme Champion for Food in 2016. Malcolm (CPCC), Pearce (AEM) and Garcia-Cela (CPCC) were recruited to permanent Principal Lecturer, Senior Lecturer and Lecturer posts, respectively.

Four independent Research Fellows - Barrero-Sicilia, Qi, Richard (all CPCC), Fallaize (FPND) - were appointed on initial 5-year contracts with the expectation they will secure research funding and establish their own research areas during this period. In 2020, Fallaize and Barrero-Sicilia, both ECRs, progressed to permanent Lecturer posts in the Unit.

Two of these Research Fellows are engaged in interdisciplinary projects working in collaboration with other Units across the University. Richard studies the dispersion of airborne pathogens and implications for crops with colleagues from Rothamsted and the University's Centre for Atmospheric and Instrumentation Research (CAIR), as well as CAFEM Research. Barrero-Sicilia is researching Systems Biology for Food and Disease with support from colleagues in computer science. The Unit is also collaborating with two other UOAs in which two further ECRs are based: Food and Public Health across the Life Course (UOA3 Allied Health, with Barling); Airborne Pathogens and Disease Epidemics (UOA9 Physics, with Fitt).

Twelve of the thirteen additional Research Fellows noted above have been appointed on shorter-term contracts, as a result of successful external grant applications: for example, EU H2020 and Cadogan Trust and research consultancy grants to Barling, and Agri-Tech/BBSRC grants to Fitt and Huang, and a Newton Bhabha grant to Stotz. These Fellows are not currently independent researchers but will be supported to apply for independent research fellowships, research funding and academic posts in the future.

Staff development

The Unit places great importance on staff development, especially, though not exclusively, for ECRs. This is delivered through:

- Provision of bespoke in-house Unit training sessions, such as those on advanced statistics (led by Mashanova) and grant application training (delivered in collaboration with the University Research Office), to complement the extensive University Researcher Development Programme;
- Established mentoring and training schemes through which new staff, especially Research Fellows, can integrate into specialist areas and benefit from opportunities to develop into independent researchers, while maintaining an emphasis on teamwork. A Unit research fellow represents all Research Fellows on the LMS Research Executive Group and is a member of the University Researcher Development Group that monitors delivery of these programmes;
- The use of personal development plans (reviewed at annual appraisal and 6 month review) and staff development budgets to create time for research through workload management and provide financial support to attend conferences and networking events: e.g. Fallaize was funded to attend the 23rd European Nutrition Leadership Platform seminar, Luxembourg, 2017;
- Encouraging and supporting applications to competitive internally funded central University schemes. Barrero-Sicilia was awarded an Early Career Researcher Grant of £4,000 to study barley tolerance to abiotic stress and a £5,000 Santander Partnership Award to work on exploiting the potential of *Brachypodium* as model grass to improve breeding cereal crops in collaboration with Prof. Pilar Catalan, University of Zaragoza;
- Supporting staff to join supervisory teams for PhD students, initially alongside a more experienced supervisor. Mandatory training in PhD student supervision is delivered by the University Doctoral College. All Unit staff have participated in the supervision of one or more PhD students during this REF cycle;
- Enabling staff to maximise the output potential of their research by providing advice and mentoring on publication strategies delivered by staff with experience of publishing in high-impact journals;
- Supporting and facilitating staff to receive research sabbatical time to further their research and also to engage in academic/industrial exchanges both in the UK and overseas.

Appraisal and mentoring processes are designed to facilitate career progression by addressing development needs and agreeing on bespoke action plans which, together with performance targets, are monitored at annual appraisals with six-monthly reviews. The University has a rigorous annual academic promotion round which enables staff to seek elevation to Reader or Associate Professor (Research) and, with an appropriate track record, to Professor without the requirement for a specific vacancy to be available. There have been three promotions within the Unit from Senior Research Fellow to Reader (Tzilivakis, Huang, Stotz), and one from Reader to Professor (Lewis) in this REF period.

The Unit's research culture has substantially matured during this cycle in response to the increase in research staff and post-graduate student numbers. Staff and postdoctoral researchers are well integrated into Unit, University and disciplinary research culture through:

- Formal and informal AFVS meetings and discussion forums. These include regular bi-monthly meetings when staff discuss plans for high quality publications, external impact, funding opportunities, collaboration and research environment strategies;
- Fortnightly lunchtime research seminars, at which new staff are encouraged to give presentations and to which external speakers are also invited;
- Participation in networking and other events provided by the Food Research Theme which is led by Barling, as Theme Champion;
- Internal research conferences. These include large annual conferences specific to research in LMS (2014-20) and a series of biennial Researcher Development conferences that are University-wide and encourage cross-disciplinary research and other development activities;

- Funding attendance at national/international external research conferences (e.g. International Plant Pathology Congress, Boston, 2018).

Postgraduate research students

The Unit has continued its capacity building strategy of creating a vibrant research community by recruiting full-time PGR students with 25 new PhD students enrolled since 2014 (Table 1). There has been a 32% increase in enrolments and 217% increase in overall awards with a 126% increase in awards per annum over the current cycle.

Table 1: Comparison of Unit PhD enrolments and awards for REF 2014 and REF 2021 cycles.

	2008-13	2013-14	2014-16	2016-18	2018-20	Total
	REF2014 Total	REF2021				Total
Enrolments	19	4	7	5	9	25
Awards	6	3	5	6	5	19

The Unit was awarded 18 PhD studentships by external funding bodies during this REF cycle. These include a BBSRC Knowledge Transfer Network PhD studentship (Stotz, Fitt), Agricultural trust funded PhD studentships (Huang); and a studentship funded by the Salisbury Trust on minimum tillage agriculture (Davies, Warner). In addition, investment of QR funds has supported some studentships in strategic partnerships: for example, two dual award PhDs with the Hawkesbury Research Institute, University of Western Sydney, Australia on the topics of bioprospecting for fungal-based biocontrol agents (Coutts) and investigating pathogen-plant signalling during the switch from biotrophy to necrotrophy in hemibiotrophic interactions (Stotz).

Six industrial PhD studentships have been awarded to the Unit by the Hertfordshire Science Partnership (HSP) in the area of agricultural technologies. HSP was established by the University in partnership with the Hertfordshire Local Enterprise Partnership (LEP) with £6.0M in funding from the Department for Business, Energy and Industrial Strategy, the Department of Community and Local Government and the European Regional Development Fund. This was augmented with £0.9M industrial funding to establish Hertfordshire Knowledge Exchange Partnerships (HKEP) – innovative four-year PhD with Industry Experience doctoral studentships.

For the Unit the project partners, studentship grant values, and PhD student supervisors respectively are: Syngenta, £125,081 (Lewis); Letchworth Garden City Heritage Foundation, £103,631 (Barling); two with RSK ADAS and charitable trusts, £207,274 (Huang); DryGro, £109,431 (Barrero-Sicilia); KG Davies Ltd and Norwegian Institute of Bioeconomic Research, £143,000 (Davies).

Kass, a Unit member, gained a PhD through publications in 2018. There is also one part-time technician/PhD post in AFVS, where a technician is undertaking a part-time PhD on populations of amphibians and reptiles at the University's Bayfordbury Field Station. Such posts provide funded opportunities via technical/LMS budgets to expand the research culture, develop technical staff and contribute to research outputs.

Five successful PhD students have been appointed as Research Fellows in the Unit. Other destinations for students awarded PhDs in this cycle include research fellowships/lecturer posts at other HEIs or Research Institutes in the UK, Canada, Iran, Malaysia and Taiwan, and positions in the agricultural industry, healthcare product industry, environmental management, public relations and government.

PGR students are enrolled with the University Doctoral College which oversees their progress and progression through the online Research Student Management System with which both students and supervisors engage to record meetings, submit progress reports and record assessments. Research student training is delivered by the Doctoral College through an extensive Researcher Development Programme as well as an annual PGR student conference.

The University was ranked 4th for research culture, 15th for research supervision and 21st for overall student satisfaction from 103 participating HEIs in the 2019 Postgraduate Research Experience Survey (PRES). The participation rate was 62% compared to the 42% national average. The responses of AFVS PGR students reflect this positive outcome – 94% satisfaction for supervision, 92% for research skills, 82% overall satisfaction.

The Unit's supervisory process, overseen by the Doctoral College, requires an experienced team of at least two supervisors, with at least two successful supervisions between them, to be appointed for each research student. The outstanding supervision outcomes reported through 2019 PRES are facilitated by:

- quality assurance of the research expertise and experience of the supervisory team; potential new supervisors are also required to attend training courses provided by the Doctoral College before they can supervise students;
- supervisory time workload allocations, with more time given to staff who are principal supervisors;
- monitoring of the student's progress at several levels, including a 3-4 monthly progression report from each student discussed with supervisors, all meetings recorded on the online Research Student Management System, plus an annual monitoring or progression report, reviewed by the relevant School Research Tutor, and by the Doctoral College;
- PGR students participating in teaching undergraduate students through demonstrating in practical classes and running tutor groups across different subject areas;
- Funding from the Unit to ensure that each student attends at least one international scientific conference while they are studying for their doctoral degree. For example, six PhD students attended the International Congress of Plant Pathology in Boston, USA, in 2018.

Equality, diversity and inclusion

The Unit fully supports and adopts the University's equality, diversity and inclusion principles and processes. LMS has an Equality, Diversity and Inclusion Team (EDIT), which reviews EDI data, formulates action plans, evaluates the impact of Unit-level initiatives and feeds into School Research Executive Group meetings. EDIT membership includes diverse perspectives such as those of BAME PGR students and staff; staff with different contract types; and a mix of declared protected characteristics. There is an increasing emphasis on inter-sectionality and this is reflected in the Unit's support for priorities around charter marks such as Race Equality and Stonewall. LMS currently holds an Athena Swan Bronze and is making substantial progress towards a Silver application in November 2021.

Athena Swan principles have been embedded into all recruitment, promotion and leadership appointment activities with significant success so that 55% of Unit PhD students, over 80% of new Research Fellows and 48% of Unit staff are women. In addition, women have been promoted to both Professor (Lewis) and Reader (Huang) during this REF cycle.

The University's Women in STEMM Network is open to all women in science, technology, engineering, mathematics and medicine. It aims to support them in their career development, providing discussion forums, networking and mentoring opportunities. There is also an informal CoCo (conversations and communications for women researchers) network within LMS that offers tailored training and support sessions.

10.5% of the Unit FTE staff identify as BAME. During this REF cycle a BAME staff member was promoted to Reader and 3 BAME staff were appointed to Research Fellow positions. It is anticipated that these Research Fellows will progress to independent researcher status forming a pipeline for future lecturer appointments.

All staff are encouraged to engage with the University's independent staff networks coordinated by the Equality Office addressing BAME staff, Carers, Disability and Wellbeing, LGBTQ+, Women+ and Professors, Academic Women's Action Group, Working Parents, Men's Health, and Menopause, providing an opportunity to share experiences, discuss issues and offer peer support.

3. Income, infrastructure and facilities

Income

During the 7-year period from 1 August 2013 to 31 July 2020, the Unit generated £4.7M of external research income (Table 2). Annual average income was £666k, a 19.1% increase on annual average income in the REF 2014 cycle. The average annual income over the last three years of the current cycle has been 65% higher at £860k, reflecting increasing success in winning larger funding awards as a consequence of the investment in high performing research staff during the cycle. These figures suggest a continuing positive trajectory for Unit external research income generation.

Table 2: External research income 2014-2020.

Year	2013-14	2014-15	2015-16	2016-17	2017-18	2018-19	2019-20	Total
£k	666	370	424	624	821	804	954	4,663

Over the cycle 29% of the Unit's external research income came from URKI, 37% from other UK funders, and 34% from non-UK sources (Table 3).

Table 3: External research income sources 2014-2020.

Location	UK	UK	UK	UK	UK	EU	EU	Non-EU	Non-EU
Source	UKRI	Charity	Govt	Industry	Other	Govt	Industry	Govt	Other
£k	1,339	478	392	541	264	1,132	173	20	264

Funding Awards

All three groups within the Unit have won major funding awards during the REF period. These include:

- **CPCC:** British Council Newton-Mosharafa (£106,136; Fitt, Qi, Richard), various charitable trusts for work on biocontrol (£91,500; Coutts), BBSRC Newton-Bhabha (£165,699; Stotz, Fitt), AHDB (£119,389; Huang), BBSRC ERA-CAPS (£350,000, Fitt, Stotz) and two BBSRC/Innovate UK projects (£491,815, Huang, Fitt).
- **AEM:** European Food Safety Authority (£131,280; Lewis, Tzvilivakis, Warner); EU H2020 (£381,256; Lewis, Tzvilivakis, Warner).
- **FPND:** European Commission (£389,658; Barling); Cadogan Charity (£200,000; Barling)

Staff often pursue collaborative funding with industry partners. For example, a BBSRC LINK project on understanding resistance to decrease risk of severe phoma stem canker incorporated a consortium chaired by the AHDB that included nine oilseed rape breeders and two farmers. The project was part supported by industry in kind contributions of over £500,000, plus cash contributions from AHDB and agricultural charities of more than £200,000. Industry involvement also contributed to MSc research projects, which can then lead to PGR student support: for example, Affinity Water has supported water projects (Crook) and Syngenta plc projects on the fate of pesticides (Lewis). Other projects with industry partners include a Ceres Agri-Tech Knowledge Exchange Partnership on integrated control of strawberry pests and diseases (£211,000, Hall) that has resulted in a licence agreement with Agri-Tech Services. The Unit is also involved in three AgRia (Agri-Tech Research Innovation Accelerator) projects (value circa £150,000) with commercial partners, which are transferring knowledge and expertise from Unit staff to benefit SMEs.

Infrastructure and facilities

A new £61.2 M science building was opened on the University's College Lane campus in 2016 comprising 9000 square metres spread over 4 floors. The facility provides spacious, state of the art, naturally lit laboratories, notably Microbiology and Plant Pathology, Molecular, and Analytical Chemistry research laboratories, together with PGR student study areas and informal social spaces which create an environment conducive to multi-disciplinary research collaborations.

Equipment purchased for Unit research includes four new Aralab plant growth chambers and shared equipment costing £ 2.0M, including safety cabinets, centrifuges, - 80C freezers, plate readers, incubators, Western blot equipment and water baths for molecular biology work in crop protection and microbiology and animal/human diseases. A Matrix-Assisted Laser Desorption/Ionisation time-of-flight analyser, 3 UV Spectrophotometers, 2 qPCR machines, a Geldoc System (DNA and RNA), Fourier-Transform Infrared Spectrometer, Gas Chromatograph, and 2 High Performance Liquid Chromatography systems are available. In addition, 2 Nuclear Magnetic Resonance magnets (400Hz and 600Hz) are located in a separate suite with dedicated technician support. There is also a specific microscopy laboratory suite with both confocal and Raman facilities available for use by Unit staff.

Plant growth chambers provide accuracy, reliability and reproducibility with controlled environments to assess resistance to pathogens. The new safety cabinets are used for microbiology work, such as pathogen isolation and sub-culturing, and molecular work, such as PCR and qPCR. New centrifuges are routinely used for DNA extraction. The -80 C freezers are employed for long-term storage of fungal and bacterial pathogens. The microtiter plate readers are used for *in-vitro* fungicide sensitivity tests on fungal isolates and for bacterial susceptibility testing in multi-disciplinary collaborative research with external partners. The incubators are utilised for incubating microbial cultures and the water baths for undertaking molecular biology protocols such as DNA extraction.

The Science Building has a new geographical information systems (GIS) laboratory for aerial mapping, land survey, and biodiversity and crop monitoring in both the visible and infrared spectrums. Three drones with high specification cameras provide the capability for remote sensing, and aerial imaging.

Unit staff were involved in designing the recent refurbishment of the glasshouse/ controlled environment block on the main campus. Work has also commenced on the refurbishment of glasshouse facilities at the nearby Bayfordbury Field Station, where field/glasshouse-based ecology and plant pathology research is undertaken. Furthermore, an additional glasshouse/ controlled environment facility adjacent to the Science Building is planned.

The University Library and Computing Service (LCS) maintains subscriptions to 220 information databases of which circa 60 relate to the Unit. From the 50,575 journals held (an 81% increase since 2014), approximately 2100 are relevant to the Unit. It contains 543,000 ebooks of which circa 1540 are in relevant areas and there is a dedicated LCS Information Manager to support

the Unit. Also new transformative agreements (with Sage, Wiley, PLOS) are in place to facilitate gold OA publication without individual charges.

The Unit also makes use of University support structures to facilitate impact identification, administration and evidencing. The Research Impact Team, Research Grants Team, Enterprise and Business Development Team as well as the Development Office all offer staff support for developing research project proposals, including the identification of impact pathways and methods for impact evaluation. The Marketing and Communications Team are responsible for press releases and social media channel communications concerning research projects and findings to inform both industry and the public (e.g. through *The Conversation*) and offer expertise in producing promotional videos and other material for media dissemination.

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

Research Collaborations and User Partnerships

Developing strategic research partnerships is a major activity across all 3 groups within the Unit. As well as many national and international academic collaborations, the Unit actively collaborates with external NGO partners, and increasingly conducts funded research in direct collaboration with user partners in industry.

Examples include:

Crop Protection and Climate Change: collaborations with specialist centres include Hall's work on integrated pest management for strawberries with NIAB Innovation Farms, now licensed commercially; Coutts, Fitt and Stotz with the John Innes Centre, and Davies with the James Hutton Institute, now published. Richard, Qi and Fitt research the impacts of climate change on crop diseases with Mansoura University and the Agricultural Research Centre in Egypt; Barrero-Sicilia collaborates with Polytechnic University, Madrid, Spain on understanding seed germination, and Malcolm works on the control of malarial mosquitos with the University of Khartoum. Huang collaborates on improving resistance against pathogens with Limagrain and other oilseed rape breeding companies.

Other important partnerships for CPCC work include Cranfield University (Garcia-Cela, joint PhD studentship), Imperial College, London (Fitt), and international collaborations with partners in: Australia - Hawkesbury Research Institute, Western Sydney University (Coutts, Stotz, joint PhD studentships, publications); Brazil, UNESP (Stotz); Canada, Agri-Food Canada, Saskatchewan (Stotz), China, CAAS Oil Crops Research Institute, Wuhan (Huang, Stotz), Jiangsu Academy of Agricultural Sciences (Hall); France, INRA Rennes and Thiverval-Grignon (Fitt, Huang, Stotz); Germany, University of Göttingen (Fitt, Stotz); India, Indian Agricultural Research Institute (Davies); Japan, Niigata University (Stotz); Norway, Norwegian Institute of Bioeconomy Research (Davies), Russia, Institute of Plant and Animal Ecology, Urals, Ekaterinburg (Mashanova); South Africa, University of Kwazulu-Natal (Mashanova),

Agriculture and Environmental Management: in collaboration with the pesticide industry and Society of Environmental Toxicology and Chemistry (SETAC), the group has provided policy support to the European Food Safety Authority on exposure of bystanders and residents to agriculturally applied pesticides that has led to the revision of regulatory risk models. Lewis has led teams undertaking research funded by Premium Crops Ltd to investigate management of oilseed rape volunteer plants in subsequent oilseed rape crops and a Waitrose funded project to develop a pesticide risk assessment software package to support Waitrose growers worldwide to develop more sustainable crop protection strategies. Warner carried out a project in collaboration with Western Sugar USA to compare the environmental impacts of sugar beet and sugar cane, while Tzvilivakis led an interdisciplinary project in collaboration with Affinity Water AECOM Environmental Services and Reading Agricultural Consultants to reduce pesticide contamination of surface waters.

Other collaborative partners for the group include University of Aberystwyth (Porter); University of Nottingham (Lewis, Warner), University of Reading (Tzilivakis), Natural England (Warner); Norway, University Centre of Svalbard (Porter).

Food Policy, Nutrition and Diet: Madden collaborated with the British Dietetic Association on projects on patient's preferences for diet and nutrition-related outcomes in coeliac disease and a further project on weight management in collaboration with, and supported by the Department of Health, Health and Social Care Volunteering Fund. Barling leads the work package on policy, regulation and governance within the VALUMICS consortium funded by the EU Horizon 2020 framework, bringing together 19 European partners from 14 countries, plus a further 2 Asian partners. A 238-page report on Governance on European Food Value Chains was delivered in 2019.

Other collaborations include University of Aberystwyth (Fallaise), Addenbrooke's Hospital (Madden), University of Cambridge (Madden), City University of London (Barling), Oxford University (Barling), University of Reading (Fallaise, Vafeiadou). Internationally group members work with institutions in Belgium (International Life Sciences Institute Europe (Vafeiadou)); Iceland (University of Iceland (Barling)); Italy, (University of Pisa (Barling)); New Zealand, (University of Waikato (Barling)), Netherlands, (WUR (Barling)).

Many of these Unit collaborations have resulted in peer reviewed publications in major journals, as well as influencing policy and/or practice by end-users.

Contribution to economy and society

The Unit's research has made a substantial contribution to various economies and societies. It has both influenced and changed UK and EU government policies on pesticides, climate change mitigation and adaptation (Lewis, Qi), nutrition and food policy (Barling, Madden, Fallaise), irrigation systems in India (Crook) and preventing spread of the phoma stem canker pathogen *Leptosphaeria maculans* into China (Huang, Fitt).

Engagement with industry provides an excellent route for delivery of the Unit's research findings to end-users, augmenting its business-facing reputation. For example, outcomes and new developments from the 2011-2014 BBSRC LINK project were conveyed through AHDB, National Farmers Union, and oilseed rape breeders' open days, roadshows, workshops, trade events, conferences and topic sheets (Fitt, Huang). In addition, the distributor Hutchinsons has used its extensive network of agronomists to disseminate information about the outcomes of the two BBSRC/Innovate UK projects to more than 13000 farmers per year (Huang, Fitt). Similarly, the land carbon management research carried out by Warner for Natural England and the National Trust has been presented as best practice guidance and through several workshops.

Staff strengthened existing relationships with non-academic users/beneficiaries/audiences making contributions by:

- presenting work at industry meetings (e.g. 'Cereals' – the largest annual agricultural trade event in the UK - and Hutchinsons' open days, Huang, Fitt, Hall),
- joining professional groups (e.g. NIAB innovation farm platform, Hall),
- providing consultancy advice (e.g. to FAO Chile, Fitt)
- participating in policy-making groups (e.g. those convened by Defra to improve and implement agri-environment stewardship schemes, Lewis, Tzilivakis).

An important partnership has been formed with the International Union of Pure and Applied Chemistry (IUPAC) to facilitate access to the Pesticide Properties Database by a broader community, particularly in developing countries (Lewis, Tzilivakis, Warner). The Unit's membership of OREGIN with academic/industry partners also provides a means of disseminating research outputs to contribute to the wider agricultural industry.

The Unit's contributions to research in nutrition have been further developed through well-established partnerships with social enterprises, such as BeeZee Bodies, Henry, Hertfordshire Community Meals and the charitable sector, including Sustain, Caroline Walker Trust, The Salvation Army, Coeliac UK and Diabetes UK.

Davies has also founded a company for the biological control of nematode pests, K G Davies Ltd, building on his research carried out in the Unit, and supported by the University, into fecundity enhancing peptides in the mass production of entomopathogenic nematodes with the object of developing this technology to control insect pests in India in partnership with the Indian Agricultural Research Institute, New Delhi.

The Unit's commercial and innovation activities also benefit the economy and society, and support the Unit's growth and sustainability, generating £4.4M income over the cycle where £3.1M was derived from Biodet, a University company which undertakes microbiological analysis and investigation, whose profits are fed back into the Unit's research.

Contribution to Sustainability of the Discipline

Hall was awarded an MBE, made an honorary member of the British Society for Plant Pathology in 2016 and an honorary professor of the Inner Mongolia Academy of Agricultural Sciences, China, in recognition of her research on diseases of horticultural crops, and her contribution to research and teaching at the University. Other Unit members have been given awards and fellowships (see Table 4). There are 5 Fellows of the Royal Society of Biology (Coutts, Davies, Fitt, Huang, Stotz), 2 Fellows of the Royal Geographical Society (Crook, Porter), one Fellow of the Linnaean Society (Davies), one British Science Association Media Fellow (Porter) and one Fellow of the British Dietetic Association (Madden). Fallaize received a British Nutrition Society Award in 2017; Madden received two prizes from the British Dietetic Association (BDA) in 2018 and 2019 and delivered the BDA Elsie Widdowson Memorial Lecture in 2019. Davies is an honorary professor of the Norwegian Institute of Bioeconomy Research and Fitt is an honorary professor of the Oil Crops Research Institute in Wuhan, China.

Table: 4 Summary of Unit member contributions to the sustainability of the discipline

Awards and Fellowships/Honorary positions	22
Member international/ national/ grants committees	28
Editor journal etc.	20
Invited conference keynotes / chairs	73
Collaborative doctoral training	32
Refereeing activities:	
PhD examiner	29
Reviewer, grant proposal/ promotion	47
Reviewer, paper in international journal	946

Unit staff are editors or editorial board members of journals. These include *Archives of Virology* (Coutts), *Frontiers in Nutrition* (Fallaize), *Frontiers in Fungal Biology* (Garcia-Cela), *Canadian Journal of Plant Pathology* (Huang), *Journal of Human Nutrition and Dietetics* (Madden), *Fauna of the Urals* (Mashanova), *Outlooks in Pest Management* (Fitt), *Journal of Remote Sensing* (Pearce), *Agriculture and Human Values* (Barling), *Frontiers in Agronomy* (Stotz), *MDPI Agronomy* (Qi) and *MDPI Toxics and Climate* (Lewis, Tzilivakis and Warner). Barling co-edited Elsevier's annual book series *Advances in Food Security and Sustainability*, Volumes 1-4, 2016-2019.

Unit staff are also members of national/international committees, including grant-awarding committees. For example, Coutts is on the International Committee on Virus Taxonomy, Davies is on a Norway Association of Applied Biology committee and Fitt is a consultant to the FAO and, with Stotz, on the Global Council for Innovation in Rapeseed (GCIRC). Lewis is a consultant to the European Food Standards Agency (EFSA), and Pearce is on the Quaternary Research Association Committee. Vafeiadou is on the International Life Sciences Institute European Expert Group and Warner is on The Arable Group new farming systems committee.

Several Unit staff are also actively involved with the broader community and with non-academic bodies. Lewis serves on the IUPAC's Advisory Committee of Crop Protection Chemistry, Barling is a Trustee of Sustain (UK food and farming NGO alliance) and Fitt is a trustee of the Perry Foundation (agricultural charity). Madden is a Member of the British Dietetic Association's Higher Education Sub-Committee and General and Educational Trust and sits on the Steering Committee of the James Lind Alliance for Non-alcohol-related liver and gallbladder disorders.

Unit staff have given invited keynotes or chaired sessions at 73 international conferences in Australia (Fitt), Belgium (Davies, Garcia-Cela, Tzilivakis), Brazil (Barrero-Sicilia), Canada (Fitt), China (Davies), Chile (Fitt), Czech Republic (Warner), Egypt (Qi, Richard), Germany (Fitt, Garcia-Cela), Hungary (Malcolm), Italy (Tzilivakis), Japan (Coutts), Qatar (Malcolm), South Korea (Stotz), Thailand (Garcia-Cela), Denmark (Barling) and the USA (Barrero-Sicilia, Davies, Garcia-Cela). Unit members have also been actively involved in the public promotion of science to the general public; for example, in the local community (Madden) and at the Royal Society, London, BBC radio and TV and the National Geographic (Porter).

Since 2014, Unit staff have examined 29 PhD student theses, from Australia (Fitt, Huang), Canada (Fitt), Ireland (Davies), Spain (Barrero-Sicilia) and the UK (Barrero-Sicilia, Fitt, Huang, Lewis, Malcolm, Vafeiadou, Barling). They have reviewed more than 47 grant proposals/promotion proposals, for Australia (Fitt), Canada (Fitt, Stotz), China (Coutts), Czech Republic (Coutts), Israel (Coutts), Kuwait (Lewis), Poland (Coutts), South Africa (Madden), USA (Coutts, Davies, Pearce) and the UK, including the Research Councils (BBSRC, NERC, ESRC) and the Wellcome Trust (Barling, Crook, Coutts, Fallaize, Fitt, Lewis, Malcolm, Richard, Porter, Qi). They have also reviewed more than 946 papers submitted to international journals, including Plant Cell Reports, Journal of Experimental Botany, Fungal Genetics and Biology, PLOS One, Proceedings of the National Academy of Sciences of the USA, Frontiers in Microbiology, American Journal of Clinical Nutrition, Royal Society Journal of Open Science, Philosophical Transactions of the Royal Society B, Mycotoxin Journal, Theoretical and Applied Genetics, Scientific Reports, Geosciences, Global Environmental Change, BMC Plant Biology, Molecular Plant Pathology and Journal of Environmental Management, Food Policy, Food Security and Agriculture and Human Values.