Institution: University of the West of England, Bristol

Unit of Assessment: 6 - Agriculture, Veterinary and Food Science

a. Overview

This submission is based on the research of a collaborative group of 14 (13.9 FTE) staff who are core members of the Agri-Food, Plant and Environment research theme within the Centre for Research in Biosciences (CRIB, **Doran**, Director). Research in the interdisciplinary group of staff includes fundamental and applied research focussed on plant, crop, food, soil and water science within the Agriculture and Food component of this UOA. The group have strong links with staff returned to UOAs 3 and 15 as well as the University Institute of Biosensing Technology (IBST, **Luxton**, Co-Director), which supports collaborations with industry and other research users. Submitted members of staff are identified in **bold**.

b. Research strategy

b1. Achievement of strategic aims

1.1. The core element of the REF2008 strategy was to *enhance multi-disciplinary research through collaboration, which would enable the Unit to align its activities with funding body priorities and attract funding from a range of diverse sources.* This has been achieved through:

(i) Strategic restructuring of research across the Faculty in 2011 which resulted in the establishment of the multidisciplinary Centre for Research in Biosciences (CRIB, **Doran**, Director). Agri-Food, Plant and Environment research forms one of the 3 research themes of CRIB.

(ii) Expansion of research facilities and the research portfolio of the Unit from mainly Plant (**Arnold, Hancock, Wilson**) with some Environment (**Willey**) research in 2008 to include food quality in relation to human health (**Ames, Doran**), soil geochemistry (**Maxfield**), the effect of agriculture on ecology and natural communities (**Ellwood, Steer**) and development of novel effective technologies for rapid analysis of food and water quality **(Doran, Hart, Hill, Luxton, Reynolds)**.

These developments were achieved via Faculty investment in research facilities (section d ii), 7 new strategic appointments and 5 promotions (section c i). This has resulted in 14 staff being returned in this REF, compared to 6 in RAE 2008. The cross-disciplinary approach and expansion of the research portfolio of the Unit broadened the funding base. £2.31m funding won from the UK Research Councils includes a BBSRC grant on plant antimicrobial hot zones (**Arnold**); BBSRC Pathfinder grant on novel technologies for food quality (**Doran** and **Hart**); BBSRC/Biosciences KTN/Pfizer CASE PhD on biomarkers for fat deposition in cattle (**Doran**); NERC/Chelsea Technologies Group PhD on sensors for ecological health of freshwater systems (**Reynolds**); NERC Radioactivity in the Terrestrial Environment programme grant (**Willey**). Building expertise in bio-sensors development in the Unit has led to industry funding via direct contracts. These include Pfizer (Effects of immunocastration on fatty acid composition in pigs, **Doran),** and three Technology Strategy Board (TSB) awards (i.e. electrochemical sensor for metal toxicity, **Hart**; development of endolysin-bound paramagnetic particle assay platform as a rapid diagnostic tool, **Luxton**; preservation and protection of fresh produce using aerosolised biocides, **Reynolds**). Charity funding (Woodland Heritage) was awarded for research on taxonomy of bacteria causing Acute Oak Decline (**Arnold)**. Excellence of the Unit's research is evidenced by high quality papers in high-ranking international journals including *PLOS ONE* (**Allainguillaume, Doran, Hancock**), *New Phytologist* (**Allainguillaume**), *Current Biology* (**Arnold**), *Ecology Letters* (**Ellwood**) and *Proceedings of the Royal Society B* (**Allainguillaume**).

1.2. The REF 2008 strategy placed a strong emphasis on *increasing national and international collaborations and extending the contribution to international scientific communities.*

This was achieved by *responding to the EU and UK international initiatives and developing collaborative research and knowledge exchange grants*. In response to the BBSRC international partnership initiative**,** the Unit successfully developed a BBSRC-funded UK/China partnership on novel technologies for food quality and safety (**Doran**). In response to European legislation banning surgical castration of piglets, **Hart** and **Doran** participated in 2 successful EU tenders on the development of novel technologies as alternatives to castration to prevent the meat quality defect, boar taint. This led to the award of a BBSRC Pathfinder grant for evaluation of the commercial potential of the technology (**Doran** and **Hart**), involving 12 European and UK

academic/industry partners and expansion of the international network of the Unit. In response to the UKRC's strategy to enhance cross-disciplinary research and collaboration with industry, **Arnold** developed a collaboration with Imperial College, Oxford and Reading to investigate the evolution of bacterial pathogens and host resistance. The research demonstrated that a pathogenicity island carried by the bacterial plant pathogen *Pseudomonas syringae* pv. *phaseolicola* can be transferred between bacterial strains by a process of natural transformation. The study led to (i) further BBSRC funding to **Arnold** to study the relationship between plants antimicrobial "hot zones" and accelerated pathogen evolution and (ii) developing collaborations with the Public University of Navarra, University of Catania and University of Malaga via PhD student exchanges. Cross-disciplinary research with the University of Adelaide and National Botanical Garden of Wales, led by **Allainguillaume**, generated ground-breaking DNA barcoding for all the native flowering plants in Wales. This in turn led to (i) collaborations with industry (Cocoa Research UK and Mars) which funded an epidemiological study of Cacao Swollen Shoot Virus (**Allainguillaume**) and (ii) a collaboration with West Africa on a strain-independent DNA-based detection system for better monitoring and eradication of this virus in cocoa plantations. Collaboration with Queen's University Belfast (**Ames**) allowed the development of an accurate method for detecting the advanced glycation endproduct, N-epsilon-(carboxymethyl)lysine (CML) in different food matrices, and was used to estimate potential consumer intake of CML in Northern Ireland. Work with the Institute for Animal Research (FBN) in Germany resulted in a new approach for detection of isomers of conjugated linoleic acid (**Doran**) which contributed to the development of strategies for improving the healthiness of beef.
The Unit has been involved in several collaborations with industry via TSB schemes (section b1.1 above). It has also provided extensive multidisciplinary training to visiting researchers and PhD students from the Institute for Food Research (IRTA, Spain), Ukrainian Institute for Pig Breeding, China Academy of Agricultural Sciences, and other organisations (section c2). The visits are integral to our EU Marie Curie International Research Staff Exchange Scheme and BBSRC UK/China Partnership (led by **Doran**).

1.3. *The RAE 2008 strategy emphasised the importance of enhancing Knowledge Exchange (KE) and research impact.* This was achieved as follows: KE plans have been incorporated into research bidding strategy of the Unit as evidenced by grants in collaboration with industry funded by BBSRC, EPSRC, NERC, British Pig Executive, Department of Trade and Industry, Environment Agency, Esmee Fairbairn Foundation, European Commission, Great Western Research, Home Office, TSB, Royal Society, and Woodland Heritage (section b1.1.). Close links with the Bioscience Knowledge Transfer Network (KTN) resulted in (i) a successful "SPARK" award to address industry needs in novel approaches to decontamination of soil and water (**Reynolds**) and (ii) a Pfizer International Operations co-funded CASE PhD to identify biomarkers for regulation of fat partitioning in pigs (**Doran and Luxton**). The Unit has close links with IBST (Co-Director **Luxton**), a strategic cross-Faculty KE initiative which links academia and industry. The Unit benefited from the £1.5m EC-funded IBST-led Innovation Network which provided opportunities for pilot studies with industry on novel technologies for environmental monitoring (**Hart** and **Reynolds**). An outstanding achievement of the Unit is the inclusion of **Doran** and **Hart's** work on biomarkers for food quality in the RCUK 2011 Report 'Big Ideas for the Future'. The appointment of external members (from the Biosciences KTN, Environment Agency, Gwent Electronic Materials Ltd and North Bristol NHS Trust) and **Luxton** to the CRIB Advisory Board ensures close links with end-users and their input in the development of CRIB and Unit strategy. The CRIB Director (**Doran**) is a member of the IBST Advisory Board.

b2. Future strategic aims and goals

The Unit's aim is to undertake excellent research, based on innovation and partnership, to successfully address real-world challenges and enhance its international reputation. This will be mediated by internally funded pilot projects and sustainable external income generation from a variety of sources.
This is fully aligned with CRIB, Faculty and University strategy for the next 5 years. The Unit will build on the main areas of expertise: *plants, environment, and food quality, complemented by strong expertise in technology development*. These will be taken forward in an integrated and cross-disciplinary manner. They address funder strategic priorities including: BBSRC: Food Security (e.g. Healthy and Safe Foods, Crop Science, Animal Health, Soil Science and Agri-

Systems) and Technology Development for the Biosciences; NERC: Biodiversity, Sustainable Use of Natural Resources, Environment, Pollution and Human Health; Cross-Research Council: Global Uncertainties; TSB: Food (e.g. Crop Productivity, Sustainable Livestock Production), Bioscience (Biosensors, Diagnostic Platforms).

2.1 Plant research and technology development. BBSRC-funded research on the role of antimicrobial "hot zones" in accelerating pathogen evolution (**Arnold**) will generate new knowledge on evolution of plant pathogenic bacteria. The future focus will be on investigation of Integron-like elements and their prevalence and emergence from environmental bacteria. This research, complemented by the expertise of **Hancock** and **Wilson** on molecular mechanisms of plant responses to stress, will form the basis for multidisciplinary study on understanding of environmental effects on plants. Mechanisms for supporting this research include follow-on bidding to BBSRC (e.g. Ecology and Evolution of Infectious Diseases calls), annual rounds of internal funding for research projects and PhD studentships. Another strategically important direction of **Arnold's** research is investigation into acute oak decline funded by Woodland Heritage. The new appointment of **Allainguillaume** opens up new opportunities for applying a DNA barcoding approach to monitoring and understanding the acute oak decline process. Faculty funding has recently been awarded to **Arnold** in collaboration with the University of Bangor, Forest Research and Woodland Heritage to undertake a pilot study on the role of pathogenecity of bacteria in acute oak decline. Development of this area will be further supported by collaboration with a new appointment, **Steer**, and his close links with Somerset Wildlife Trust, bringing ecological and environmental aspects to support the fundamental research.

The Unit will build on the innovative research of **Willey** on the use of plants as indicators of environmental contamination (collaborative NERC grant) combined with expertise in bio-sensors (**Hart**) to develop a cutting-edge technology for the use of plants for *in-situ* prediction of metal concentrations. Faculty proof-of-concept funding was awarded to **Hart** and **Willey** in 2012.

2.2 Food quality research and technology development. Molecular biomarkers for food quality and technology development for food quality traits have been identified among the 100 "Big Ideas for the Future" Research Council UK Report 2011 as areas which will have a profound effect on our future. Success has been achieved via a cross-disciplinary approach (food quality, **Doran**, and technology development, **Hart**) and close collaboration with industry (Pfizer International Operations, British Pig Executives, BPEX). Future strategy is to build on partnerships with instrumentation companies (Uniscan) and UK Pig Industry (JSR Genetics and BPEX) to validate the new technology, evaluate its commercial potential, and take it to market. This will be achieved via financial support from the Faculty (awarded to **Hart** in 2013), a BPEX/JSR Genetics PhD studentship (awarded in November 2013, **Doran, Hart**) and targeting specific BBSRC schemes (Follow-on-Funds Scheme), TSB competitions and EU Horizon 2020 Research for Benefit of SMEs schemes. The appointment of **Ames** brings food chemistry expertise to the Unit, as well as a strong track record of industry collaboration. It is anticipated that collaborative projects (funded by TSB and industry) with **Hart, Luxton** and **Reynolds** will lead to novel technologies for rapid detection in food of chemical components of nutritional or safety significance. Food safety expertise of the Unit will be extended by **Reynolds** who will apply research on the use of electrochemically activated solutions to the development of novel approaches for the microbial management of fresh produce in collaboration with industry partners (TSB award 2013). This work complements **Hart's** plans to develop new technologies for ensuring the purity of drinking water for intensively reared animals (with TSB as the target funder). **Luxton's** recent TSB award will lead to the development of new magnetic immunoassay technologies for detection of endemic diseases in animals destined for human consumption.

2.3 Environment research and technology development. The Unit will maintain and expand expertise in ecological health of freshwater systems (**Reynolds**) funded by NERC. It is anticipated that this research will lead to deeper understanding of relationships between microbial processes underpinning ecological health of aquatic systems and the fluorescent properties of water, leading to the development of better sensors providing refined information. Combined with the expertise of **Luxton** (magnetic immunosensors) and **Hart** (electrochemical sensors), this research has the potential to be applied to the assessment of soil and air. Such work will be facilitated by a new appointment, **Maxfield,** with expertise in soil bio-geochemistry. A further new appointment, **Hill,**

specialising in mathematical modelling, contributes to understanding of interactions between bio-sensors and fluid flow through soil, thus facilitating the development of novel bio-sensors for environmental applications. New appointments (**Steer** and **Ellwood**) form the basis for developing new directions in environmental and ecological research. This includes investigating the scale of landscape responses to changing environments (**Steer** and **Reynolds**) and understanding the phylogenetic basis of species co-existence (**Ellwood**). Faculty investment funds have been awarded to **Allainguillaume, Ellwood, Hart, Hill, Maxfield, Reynolds, Steer** and **Willey** to pursue their multidisciplinary research, generate high quality outputs, enhance collaboration with end-users and generate data for applications to external funding bodies, especially NERC.

Additional mechanisms to facilitate future research in all the above mentioned areas include an EU Marie Curie International Staff Exchange Scheme and BBSRC UK/China Partnering Award (both led by **Doran**). These form the basis for cross-disciplinary research networks and international consortia for bidding to the European Commission and accessing a wider range of funding bodies (British Council, Research Councils in China and European Countries, specific BBSRC and Royal Society Initiatives for shared-cost grants with countries experiencing high economic growth, such as China and India).

c. People, including:

c1. Staffing strategy and staff development. Strategy has been to increase the number and range of Unit staff to broaden expertise, ensure sustainability and enhance vitality. New appointments are: **Allainguillaume** (from Aberystwyth University) maintains expertise in plant molecular biology; **Maxfield** (Bristol) brings expertise in soil bio-geochemistry; **Ames** (Northumbria) and **Doran** (Bristol) enhance food research; **Ellwood** (Cambridge) and **Steer** (0.1 FTE, Somerset Wildlife Trust, 0.9 FTE, UWE) develop ecological and environmental impact capability; **Hill** (appointed from Nottingham) specialises in mathematical modelling of flow over surfaces and through substrates, of direct relevance to the interaction of solutes and gases with sensor surfaces and with fluid flow through soils. In 2008, **Hart** and **Luxton** were submitted to UOA 12 (Other Studies and Professions Allied to Medicine) and **Reynolds** to UOA 32 (Geography and Environmental Studies) but have re-aligned their research to UOA 6, strengthening the application of sensing to water quality and food safety, related to the impact of agriculture on environment and health.

Newly appointed Unit members include established independent researchers (**Allainguillaume, Ames, Doran, Hill**) and newly independent researchers (**Maxfield, Steer**) currently mentored by more experienced staff. Pump-priming of research, especially that of ECRs, includes initial funding and allocation of PhD studentships and undergraduate vacation bursaries. The latter scheme, launched in 2011 involves selected UG students applying for funding from organisations, e.g. British Society for Plant Pathology, to enable them to gain research experience through pilot projects before and during their final year project. Some have developed into excellent PhD students.

All staff have an annual Personal Development Review to review work and support career development. This effective system has led to promotion of **Wilson** from Senior Research Fellow to Senior Lecturer; **Reynolds** to Associate Professor then Professor; **Willey** to UWE Graduate School Director; and **Arnold**, **Doran** and **Luxton** to Professor.

The University Strategic Research Development Fund invests £1.5m in competitive ECR Awards. These target priority areas, such as agri-food, to help staff establish their independent research career. A senior staff member mentors the award holder, who is also provided with support to bid for external funds. CRIB has received £108k to support 7 new staff since 2008. For example, Research Fellow Dr Huda Al-Kateb (working with **Doran**) was funded to develop flavour research.

A range of University initiatives promote the career development of researchers, including: Researchers' Forum to provide a network and voice for Research Staff (Research Associates, Research Fellows and Senior Research Fellows) to share good practice and common issues across the institution, and to run development events specifically for research staff in support of their career aspirations; the Women in Research Mentoring Scheme promotes equality and facilitates the professional development of women at all levels (**Ames** and **Arnold**, mentors); the Research, Business and Innovation (RBI) department provides a programme of staff development workshops in research, innovation and knowledge exchange, closely allied to the four domains of

the Vitae Researcher Development Framework. A staff development budget specifically supports attendance at conferences and courses.

The commitment of UWE to the Concordat to Support the Career Development of Researchers was recognised by the European Commission through the HR Excellence in Research Award granted in January 2012. This identifies 'providers and supporters of a stimulating and favourable working environment for researchers' and 'recognises the University's outstanding work in developing and supporting its research staff'. High priority is given to equality and diversity, and this is reflected by UWE being the third highest ranked UK University in the Stonewall Workplace Equality Index Top 100 (2013) at 45th place, having risen 30 places since 2012. UWE is also a member of the Athena SWAN Charter, with commitment to address gender inequalities, advance women's careers in science, and promote best practice in recruitment, retention and promotion of high quality staff - recognised by a Bronze award to both the University and CRIB's parent Department.

c2. Research students. PGR students supervised across the census period have increased from 29 in RAE 2008 to 44 with 21 completions in REF 2014. CRIB was awarded the only BBSRC Doctoral Training Account in a post-1992 University (2006-2012), with the first student supervised by **Arnold** and the second by **Wilson**. The arrangement for academic staff from the Faculty of Agriculture, University of Tripoli (formerly Al-Fateh University, Libya) to undertake PhD training within CRIB (as noted in RAE2008), has continued with 2 completions since RAE2008 and 1 currently enrolled. Other PhD students have been funded by BBSRC, Biosciences KTN, EPSRC, Environment Agency, Great Western Research, NERC, Malaysian and Thai Governments, and industry (AstraZeneca/Waters, Gwent Electronic Materials Ltd, Pfizer).

Each PGR student has a supervisory team comprising a Director of Studies plus one or more Supervisors (often from industry or another HEI, e.g. Bristol, Oxford, Reading). PGR students are also supported by the Faculty Director of Postgraduate Research Studies. The UWE Code of Practice for Postgraduate Research Study is closely aligned to the QAA Code of Practice. Procedures include the requirement for annual progress reports from student and supervisory team, and a progression report and viva at the end of the first year of study. All students are members of CRIB and required to attend the programme of seminars given by external speakers. Students present their work as internal speakers at the Annual Postgraduate Forum, as part of a 60-credit Research Training and Professional Development element of PhD training. They have dedicated laboratory bench space and individual work-stations in designated postgraduate rooms, working alongside post-doctoral researchers. All are members of the UWE Graduate School (**Willey**, Director) launched in 2012 to replace Faculty-based Graduate Schools. It provides a supportive environment from application through to graduation, offering a range of bespoke services to meet individual needs. This includes a training and development programme for students and supervisors mapped to the Vitae Researcher Development Framework. The Graduate School also provides networking events and access to regional and national support. PhD students also have opportunities to gain experience in research laboratories abroad via the UK/China Partnership and a Marie Curie International Staff Exchange Scheme (both managed by **Doran**). This has included visits to the Food Research Institute (Spain), China Academy of Agricultural Sciences, University of Bologna (Italy), National Pig Breeding Institute (Ukraine). International PhD students are provided with ongoing English Language support within the University Centre for English Language and Academic Skills.

The UG vacation bursary scheme also provides opportunities for PGR students to develop supervision skills, which complement other opportunities to teach small groups, supervise practical classes and deliver lectures. As part of the University Graduate School's support for PGR students, the Researcher Skills Development Programme provides a range of workshops aiming to help them develop vital transferable skills towards their future career. PGR students are encouraged to apply for external awards and take part in competitions; for example, Helen Neale (nee Lovell; BBSRC-funded PhD student with **Arnold**) was awarded the 2011 Best Student Paper Prize by the journal, *Molecular Plant Pathology*.

d. Income, infrastructure and facilities

d1. Income. External research grant funding (£2.3 million in the REF period) has included

Research Councils (BBSRC, EPSRC, NERC), British Pig Executive, Department of Trade and Industry, Esmee Fairbairn Foundation, European Commission, Great Western Research, Home Office, Technology Strategy Board, Royal Society, Woodland Heritage and industry, and has supported 14 contract researchers since RAE2008. Further external funding has supported 18 research studentships and international collaborations, particularly with China (BBSRC funded), Croatia, Portugal, Brazil (Science without Borders initiative), Ukraine, Spain, Italy, Belgium (EU Marie Curie), Libya and the Czech Republic, ensuring a sustainable and international research environment. Significant ongoing grants are noted in section b.

d2. Infrastructure and facilities. Of particular relevance to CRIB is the £3.5m invested by the University to refurbish all science laboratories since 2008, building on a £3.6m programme of refurbishment and consolidation of Faculty research laboratories prior to 2008. Investment in post-genomic technologies underpins research outputs of **Allainguillaume**, **Arnold**, **Doran**, **Hancock**, **Willey**, and **Wilson**. Recent laboratory investment by the University included work to convert general laboratory space into a dedicated Sensor Suite (supporting the research of **Hart**, **Luxton**, and **Reynolds**). This includes specialist equipment accessed from a large central Bio-Analytical Laboratory housing extensive electroanalytical instrumentation. Dedicated preparation and dark rooms are complemented by water- and organic solvent-based screen printing facilities for sensor manufacture, a clean room with filtered positive pressure for inkjet precision printing of pico-litre droplets, a Graphtec cutter for fabrication of micro-fluidic devices, a Biodot liquid-dispensing system (precision delivery of nano-litre droplets of biological solutions and suspensions), and a combined Atomic Force/Scanning Electrochemical/Scanning Tunnelling Microscope for characterising electrochemical surfaces. An adjacent Conference Room and offices for academic staff and PhD students completes the new facility. The Sensor Suite is used for research and development of chemical sensors, biosensors and diagnostic devices. It enables application of novel electroactive materials (nanostructured conducting polymers and electrocatalysts) to electrochemical sensors and biosensors, while also making these amenable to low cost mass production by screen and inkjet printing, and polymer Micro-Electrical Mechanical Systems (MEMS) fabrication. The laboratory allows integration of these sensors into functional devices and systems, for example for crop and animal disease diagnostics, and food and water quality assessment.

New investment complements existing infrastructure including: research grade glasshouse and extensive plant growth-cabinet facilities; a specialist nuclear science suite; electron microscopy unit with environmental scanning and transmission electron microscopes; cell biology suite with confocal microscopes and fluorescence activated cell sorting (FACS) facilities; post-genomics laboratories with DIGE-proteomics and micro-array equipment.

The investment strategy and allocation of University funds has been undertaken in tandem with the appointment of new staff, and investment in research infrastructure. For example, the University has funded 14 PhD students to be supervised by the Unit's academic staff since 2008.

d3. Research governance. Internal peer review is used to scrutinise research council grant applications and research ethics applications, under the auspices of the Faculty Research Ethics Committee. Recent attention has focused on reviewing and updating data protection policies as they relate to research, and developing a strategy for data management through the work of a JISC-funded project. A new Research Governance Manager has been appointed to support delivery of good practice.

e. Collaboration or contribution to the discipline or research base

The Unit has a strong focus on collaboration and partnership. It brings together complementary expertise to enhance both competitiveness of research grants and quality of outputs.

e1. Collaborations within academia. The Unit has extensive links and collaboration with UK and international universities. The international aspect is described in detail below (section e3). National collaborations include (i) a BBSRC research project with Oxford University, Imperial College and University of Reading on plants signalling (**Arnold**); (ii) with Nottingham University, **Hancock** has advanced understanding of how different signal transduction pathways may influence crop quality, (iii) with Bristol University, new appointment **Steer** is studying the mechanisms for restoring ecosystem function in agricultural systems; (iv) with University of Exeter

and Osijek University in Croatia, **Hancock** and **Wilson** have improved understanding of plant cell signalling and stress responses; (v) with the University of Cambridge, **Ellwood** has revealed the role of chance in structuring the arthropod communities of tropical rainforests; (vi) with Portsmouth University, **Willey** has established the use of phylogenetic effects to predict the environmental behaviour of contaminant radionuclides.

e2. Collaborations with stakeholders beyond academia. A key strength of the Unit is the combination of fundamental and applied research expertise. The Unit has vast experience of collaborating with industry via TSB grants, CASE studentships, directly funded industrial contracts, EU grants and SPARK awards. This is evidenced by (i) Cocoa Research UK and Mars funding for an epidemiological study of Cacao Swollen Shoot Virus (**Allainguillaume**); (ii) a South West Water grant for carbon sequestration and fresh water provision (**Reynolds**); (iii) **Hart** and **Luxton,** in collaboration with a range of industrial partners, have developed novel water-based screen printing inks for use in biosensors for environmental monitoring and agri-food analysis. A £1.6M collaborative SensaCelltox project (Micro- and Nanotechnology Manufacturing Initiative) involved Uniscan, Gwent Electronic Materials (GEM), QinetiQ, Himedica, Cardiff University, NPL and AstraZeneca, integrated novel screen-printed sensors with a bespoke instrument (**Hart**); (iv) **Maxfield's** collaboration with IGER and Rothamsted has linked nitrogenous fertilisation to CO_2 respired by soil.

e3. International collaborations. The Unit has well-established collaborations with international universities, research institutes, and commercial organisations e.g. University of Lleida (Spain), University of Lisbon (Portugal), Agricultural University of Uppsala (Sweden), Food research institute (IRTA, Spain), Chinese Academy of Agricultural Sciences, Ukrainian Institute for Animal Breeding, Croatian Government, University of Bologna (Italy), Food Research Institute NOFIMA (Norway), University of Malaya (Malaysia), Zhetusy State University (Kazakhstan). Collaborations have been supported by, for example, EU Tender funding and EU Mobility grants, an ERASMUS programme, Brazilian Science without Borders initiative, Portuguese Government, and the British Council. Outcomes include: (i) new insights into the mathematical modelling of porous materials to describe linear and nonlinear stability analysis and vertical through-flow (**Hill** with University of Federico II, Naples); (ii) a new approach to modelling effects of soil-plant transfer phylogenetic effects on uptake of radionuclides by fish (**Willey** with the International Atomic Energy Agency, Vienna), Saskatchewan Research Council (Canada), Swedish Radiation Safety Authority, University of Salford and the NERC Centre for Ecology and Hydrology, Lancaster).

e4. Contribution to the discipline via scholarly activities. This includes: (a) *Membership of Editorial Boards*: **Ames**, *Journal of Agricultural and Food Chemistry*; **Arnold**, *PLOS ONE*, *Frontiers in Plant-Microbe Interactions, Molecular Plant Pathology*; **Hancock**, *Plant, Cell and Environment*; **Hart**, *International Journal of Environmental Analytical Chemistry*. (b) *Involvement in the governance of scientific societies, membership of advisory boards, conference organising committees*: **Ames**: President, International Maillard Reaction Society (2008-09); **Doran**: Chair, European Association for Animal Production Working Group (2008-10); Member, Management Board of EU Directorate General for Health Tender ALCASDE (2009); Member, Expert Panel of the European Food Standards Agency (since 2009); Member, Research Committee, Animal Science and Food Research Institute, Portugal. **Hancock**: Scientific Committee Member, 3rd International Plant NO Club Conference (2010, Olomouc, Czech Republic). **Hart**: Honorary Secretary, Electroanalytical Sensing Systems Group, Analytical Division, Royal Society of Chemistry (RSC). **Luxton**: Initiator, Conference Organiser and Chair of the Scientific Committee for the first three international conferences on Bio-sensing Technology (2009, 2011 and 2013). **Steer,** Member, Somerset Levels and Moors Nature Delivery Group. **Willey**: Committee Member, UK Coordinating Group for Environmental Radioactivity (COGER).