Institution: University of Nottingham

Unit of Assessment: 6; Agriculture, Veterinary and Food Science REDACTED FOR PUBLICATION

a. Overview

The strategic emphasis of the University of Nottingham (UoN) for Agriculture Veterinary and Food (AgVFd) since RAE08 has been the provision of a dynamic, sustainable and supportive environment, which fosters the development of our staff and students, and promotes world-leading research. Accomplishments since RAE08 stem from world-class facilities, innovative researchers and a multidisciplinary environment, all of which together ensure an outstanding contribution to research throughout AgVFd. UoN was recognised for this through the award of a Queen's Anniversary Prize for Higher and Further Education (2012), for work on Global Food Security based in this unit. The 2006 establishment of the first new vet School in the UK for 50 years has continued to be a stimulus for growth and, against national trends, our unit has benefited from levels of capital spending that are unprecedented for the AgVFd sector. Institutional investment coupled with success in competition for external funds has driven the creation of national and international centres of excellence (e.g. MRC-Arthritis Research UK Centre for Musculoskeletal Ageing Research, MRC/ARUK; Bioenergy and Biofuels Centre, BiBiC; Lallemand Research Centre for Monogastric Research, LMRC; EPSRC Centre for Intelligent Food Assembly, CIFA).

University investment in a unique infrastructure and world-leading research staff, spanning the AgVFd area, has enabled the delivery of outstanding research and generated critical mass for continued excellence. Highlights in the diverse UoN portfolio include; a novel integrative systems biology programme focused on plant-soil interactions (Bennett, Mooney and Hodgman); genomics of crop species (King and Holdsworth), reproductive technologies and nuclear reprogramming (Sinclair, Alberio, Allegrucci, Sweetman and the late Keith Cambell); cattle reproduction and health (Green, Leigh, Huxley and Garnsworthy) and control of food-borne pathogens (Connerton, Barrow and Dodd).

Organisation: Research in AgVFd at UoN focuses on the Schools of Biosciences (SBS) and Veterinary Medicine and Science (SVMS) on the Sutton Bonington Campus. Researchers collaborate across the two Schools and the UoN Faculties of Science, Medicine, Engineering and Social Science.

Research priorities: Our mission is the discovery and application of new knowledge relevant to AgVFd in the context of contemporary requirements for improving human and animal nutrition and health, environmental sustainability and economic efficiency. This is addressed through many integrated themes. Global Food Security research is a flagship activity, which assimilates the full range of interests across plant, crop, environment, animal and health research.

Research themes: Cross-cutting research themes are a major strength, providing platforms that allow for development of inter- and multidisciplinary collaborations. The themes, which are supported by world-class facilities (see section d), focus on clinical, basic science and applied aspects of AgVFd:

- *Population Health and Welfare*: Research of international significance, centred around established groups in cattle medicine, uses epidemiological methods to study farm, companion, laboratory, wild and zoo/exotic animals, furthering understanding and promotion of health and welfare. A focus on important endemic diseases of dairy cattle, sheep and horses (mastitis, lameness, reproduction, infectious disease and nutrition in dairy cows, footrot in sheep, lameness and colic in horses) underpins national and international intervention programmes.
- *Comparative Medicine*: Research in this emerging area focuses upon spontaneous or induced disease in companion animals or relevant animal models, explores similarities or differences between veterinary and human medicine ("One Medicine"). Whole animal approaches (e.g. systems physiology and behaviour) are combined with post-genomic technologies (DNA/RNA-seq, epigenomics), to focus on comparative aspects of cancer

pathogenesis, cardiovascular disease, musculoskeletal disorders, systems biology and healthy ageing.

- *Infection and Immunity:* Research focuses on host-pathogen interactions and their exploitation to develop vaccines and other novel approaches to disease and infection control. UoN are established world-leaders in studies of bacterial food-borne pathogens, embracing *Campylobacter* and *Salmonella* colonisation of livestock, innate immune responses to infection, malignant catarrhal fever, novel applications for infection control and food borne zoonoses.
- *Reproduction*: Reproductive biology is a long-established strength of UoN. Cutting-edge research on pluripotency and nuclear reprogramming is complemented by studies encompassing embryology and early development, ovarian function, reproductive health and reproductive development.
- *Food Science, Nutrition and Animal Science:* The largest of the UoN AgVFd themes comprises research that covers aspects of food production ranging from the quality of food raw materials from the farm, to processing. This integrates with nutritional sciences (human diet and health, metabolism and disease), animal science (animal nutrition, meat, dairy and egg production, and the environmental impact of animal systems) and food microbiology.
- *Integrative systems biology*: Building upon success in plant and crop sciences, innovative approaches to modelling and mining of data are used to further understanding of interactions occurring in biological processes. This work is based upon analysis of high-throughput (transcriptomic, metabolomic) and high-content (2D and 3D image time-series) data, which is integrated with models at cell, tissue and organ level.
- *Plant and Crop Science*: A renowned centre of excellence for internationally acclaimed researchers, accommodates one of the largest communities of plant and crop scientists in the UK. Research utilizes genomic and epigenomic-level studies in crop and model species to provide novel understanding of biological mechanisms underpinning plant developmental processes and physiology, relevant to Global Food Security.
- *Agriculture*: Agricultural systems and management research of international significance integrates with applied research across the unit and beyond. A firm emphasis on issues affecting food, fuel, land and water use is coupled with understanding of farm business strategies, farm risk management, consumer behaviour and economics of the agri-food chain.
- *Environmental Science*: An emerging portfolio of world-leading work on soil biophysics, plant-soil interactions and soil-management strategies closely aligns with *Agriculture* and *Plant and Crop Science* research. *Environmental Science* researchers also lead on biogeochemical modelling and predicting the transport and fate of environmental contaminants.
- *Industrial Biotechnology and Brewing:* Novel multidisciplinary biofuels research addresses the challenges of biofuel production without compromising food supply, work is focused on identification of improved wheat varieties that can be more easily broken down into sugars, and yeasts which efficiently produce biofuel. A centre of excellence for brewing research is directed at development of new processes and technologies and yeast biology.

Key developments (2008-13): The unit has attracted significant funding to support research programmes in areas highlighted as our priorities in RAE2008: brewing and biofuels and integrative biology (~£25M funding). There has been major funding from BBSRC, EPSRC, ERC, ERDF, FP7, SRIF and industry for food science, systems biology and plant phenotyping. New infrastructure arising from this funding includes a Food and Biofuel Innovation Centre (FBIC, 2011), extensive glasshouse developments and a Rhizosphere facility (2013) integrating plant, soil and computer sciences expertise to image roots in soil and develop novel crop varieties. Strategic relocation of environmental science to the Sutton Bonington campus (2011) created interdisciplinary research opportunities that are stimulating new work in agriculture, plant and crop science.

Income: Despite a challenging climate for UK science funding, the Schools have attracted significant income (£47.3M compared to £40.8M RAE08). A 2008 goal to increase income from ~£6M per annum to £9M, has been achieved (£9.5M per annum). There has been greater

emphasis on larger awards (EU FP7, ERC and BBSRC sLoLa grants) that have provided significant income.

International excellence: UoN researchers generate productive international partnerships, with a strong focus on the EU and ASEAN-China region, and publish outputs of international significance across the AgVFd sector. UoN has a strong commitment to developing global reach having established international campuses in China (UNNC) and Malaysia (UNMC). This was recognised by the 2013 Guardian University Award for international strategy. SBS is present at UNMC where a training centre for 24 PGR provides a close research link to the Crops for the Future Research Centre (CFFRC). Both Schools are actively involved in partnerships with China (section c).

b. Research strategy

Vision: Our aim is to strengthen our position as an international centre of excellence for AgVFd research, with internationally recognised expertise based upon strong multidisciplinary networks and strategic, external partnerships.

Objectives: An underpinning philosophy based upon fundamental knowledge discovery and application, supports 5 top-level objectives that are firmly integrated with UoN strategic plans.

- *Capacity*- To prioritise investment in core capabilities, whilst investing to develop new research groups with critical mass, that have potential for expansion and collaboration across UoN. To enhance research through targeted investment in infrastructure.
- *Partnerships*- To foster a vital, entrepreneurial culture in which researchers appreciate the importance of Impact. Innovative delivery and dissemination of the rationale and significance of research broadens the potential range of academic and end-user partnerships.
- *Integrated multidisciplinary themes*- To develop cross-cutting multidisciplinary teams which enable innovative responses to national and international funding opportunities, strategic priorities of funders and which facilitate engagement with other UoN Schools.
- *Awards*- To increase research income from all sources, with a focus on large strategic projects.
- *Research students*- To increase PGR:staff ratios, recruiting high quality HEU and overseas students for world-class training in discipline-specific centres of excellence.

Progress towards objectives:

- *Capacity:* Targeted appointments and promotions in both Schools advanced greater capacity for research in *Industrial Biotechnology and Brewing*, *Population Health and Welfare* and *Infection and Immunity*. A period of growth for SVMS has enabled recruitment in key areas. Attracting world-leading expertise in bacteriophages and infection control has enabled development of international networks with industrial, clinical and academic partners. In SBS redevelopment of infrastructure for food processing-based research has complemented new buildings to support research in plants (glasshouses) [text removed from publication] and the Centre for Brewing and Bioenergy (see section d).
- *Partnerships:* UoN is one of just nine institutions holding a strategic partnership with BBSRC. This enables SBS and SVMS researchers to contribute to high-level, two-way dialogue regarding research strategy. Staff also interact with industry and the Sutton Bonington campus benefits from the presence of spin-out companies (Flavometrix Ltd, Eminate) and incubation facilities for small businesses within the food processing facility. Since opening in 2011, FBIC has provided support for over 100 small businesses. The global food company, McCain, maintains an office at the campus to facilitate interaction with researchers in *Food, Nutrition and Animal Science*. SBS plays a lead role in the Food and Drink Innovation Network, which was established in 2008 to co-ordinate specialist support to stimulate innovation and competitive advantage in the food and drink industry. Developments in musculo-skeletal biology and cancer biology provide links to the Schools of Life Sciences and Medicine and to the MRC-ARUK Centre (£3M, 2012-17). The latter is a partnership with the University of Birmingham and investigators from both SBS and SVMS are developing [text removed from publication] musculoskeletal ageing. Our

successful BBSRC Agrifood Advanced Training Partnership (AATP, £4M, 2010-15) offers research update days to disseminate key information to industry. The Schools have established links with institutions in China where joint postgraduate courses are being developed leading to closer research ties. SVMS involvement in key threads (Health and Wellbeing, Sustainable Futures) of the UoN Impact Campaign, which seeks to raise £150M to support research activity having a positive and lasting influence on society, will develop a centre for research on livestock and food-borne diseases, funded largely from industry.

- *Multidisciplinary themes:* A number of new priority areas were identified in RAE08 and most have been highly successful in attracting substantial funding, producing significant research outputs and distinct research strands (see section a). *Climate Change* was the platform for current research on biofuels and work examining methane production by dairy herds. *Integrative systems biology* associated with our highly successful Centre for Plant Integrative Biology (CPIB) now underpins fundamental biological research across both Schools. Since opening (2007) the CPIB remit expanded from *Arabidopsis* roots to crop species and other plant organs, and has attracted ~£24M (2008-13). The Rhizosphere group, an extension of CPIB has attracted ~£5M since 2011. Brewing research has developed from a relatively low base to provide a centre of excellence (~£1.8M external funding).
- *Awards:* In addition to responsive mode bids, a primary element of our strategy has been to focus upon large integrated projects in response to national and international strategic priorities, and many of these have directly arisen from our multidisciplinary research themes (see section d). Examples are Global Food Security (see above) and establishment of the BiBiC, which hosts the Lignocellulosic Conversion to Ethanol project (LACE, BBSRC £5.5M, 2009-14), an interdisciplinary element of UoN's bioenergy programme aiming to develop innovative solutions to problems of climate change and food waste reduction. UoN is one of 12 universities and institutes which comprise the BBSRC Sustainable Bioenergy Centre (BSBEC). This is a £24M investment to increase UK bioenergy research capacity by creating a network of expertise and specialist resources spanning the bioenergy pipeline from growing biomass to fermentation for biofuels. Whilst some large projects have arisen from UoN networks (e.g. BBSRC sLoLa, *GASCHEM*-£3.7M, 2012-17), most are in collaboration with other institutions and industry: EU grants (e.g. *Wildtech*: *novel surveillance techniques for wildlife diseases*-€8.4M, 2009-13); DEFRA and Dairyco projects on environmental impact of dairy cows (£2.8M, 2011-16). Multicentre projects include the EPSRC Centre for Intelligent Food Assembly (a collaboration with industry and universities of Birmingham and Loughborough. *Manufacturing complex, multifunctional short shelf-life products*; £4.5M, 2013-18). A collaboration of SBS researchers with institutions in India and Australia aims to develop crops that thrive in harsh environments and resist pests (£2.2M, 2012 BBSRC, Gates Foundation, Indian Dept. Biotechnology).
- *Research students:* There are 365 research postgraduates (PhD and MRes) registered in the two Schools. Student:staff ratio has increased in SBS since 2008 (2.2 to 2.65), whilst SVMS has increased substantially (0.8 to 1.45) as per strategic targets (see section c). SBS played a key role in securing a 4-year integrated BBSRC Doctoral Training Programme (£5.7M, 2012-15) jointly with Rothamsted Research (Rres) that provides students with a world-class training programme focused on Global Food Security, industrial biotechnology and bioenergy and, molecules, cells and organisms.

Strategic management: Research strategies are aligned with the overall UoN strategy, which the two Schools inform at the level of Faculty Deans and PVCs. An inter-School research strategy group considers collective approaches for facilities and resource management, infrastructure development and integration across research themes. The Schools work together in strategic planning of staff appointments. Schools report to the UoN Research and Knowledge Transfer Executive, ensuring co-ordination of strategy between Schools and a flexible approach to the identification of opportunities, which are taken forward when they complement our overall mission. A Science Research Faculty forum coordinates bids for large doctoral training grants, major equipment and facilities.

UoN has established Research and Knowledge Transfer Priority Groups to deliver excellence in research and knowledge transfer in key areas. Both Schools are actively engaged as instigators

and contributors to these. *Global Food Security* (managing waste, societal impact, governance and policy, food distribution and production, climate change) was grown from a key priority in the AgVFd strategy outlined for RAE08. The *Energy, Sustainable Chemical and Biological Manufacturing*, A*dvanced Manufacturing* and *Science Technology and Society* priorities also complement SBS activities. Active engagement with the Priority Groups enables integration with a broader UoN critical mass to more effectively recognise and respond to national and international opportunities and priorities. Global Food Security is an excellent example of an activity that was not a stand-alone unit priority in 2008, but has developed into a flagship theme, pump-primed by the UoN Research and Knowledge Transfer Board. It is sustained by partnerships with other UK (UoN/Rres Norman Borlaug Institute for Global Food Security) and international institutions (CFFRC).

Achievement of top-level objectives is highly dependent upon our ability to develop ***partnerships*** and success in ***capacity*** building. The latter objective is driven by extensive investment in infrastructure (section d) and commitment to recruitment and retention of excellent staff (section c). ***Integrated multidisciplinary research themes*** are products of the interactions between research staff and collaborators both within and external to UoN (section e). The themes described in section a) have soft boundaries and research innovation occurs across them. The community is active in generating regular research discussion forums, seminar series (internal and external speakers), annual postgraduate student symposia, research lab meetings and journal clubs, advanced techniques workshops, research newsletters and Summer Schools. Targeted cross-discipline initiatives, workshops and seminars enhance this strategy, promoting ***partnerships*** with different disciplines across UoN and beyond. These links are exemplified by workshops (SVMS and Physics workshop, 2011, Mathematics in the Plant Sciences Strategy Group, Animal Sciences-Maths interaction), and joint appointments between Schools (Dr Band between SBS/School of Mathematics, Dr French SBS/Computer Science, Dr Puleston SVMS/Clinical Science).

Links with industry and other end-users are driven through expertise generated by research themes. Farming groups and commercial agencies are strategic allies in the development of veterinary products and services. Multinational corporations such as SABMiller, Pfizer and Novartis have contributed to research capacity and infrastructure. The Centre for Evidence Based Veterinary Medicine (Novartis £3.6M, 2006-11) established methods to supply evidence for rational interventions in veterinary medicine and to provide continued underpinning for important research in evidence-based medicine. DairyCo funded a five year research programme on cow health, welfare and nutrition (£2.5M,2011-16) and a project in which UoN provides the academic lead for the national mastitis control scheme (£317K, 2012-16). SVMS works with the Pirbright Laboratory in monitoring the epidemiology of the Bluetongue virus across Europe.

Strategy for 2014-2019: Our aims are to further enhance research productivity, PGR:staff ratios; consolidate our international reputation in Global Food Security research by building on success in CPIB, and interactions with CFFRC at UNMC; extend our capacity and capability in horticulture research (£1.2M BBSRC stand-alone LINK grant with Royal Holloway, University of London and Syngenta) and enhance research activity in *Industrial Biotechnology and Brewing* by exploiting the success of BSBEC and encouraging increased inter-disciplinary research with Engineering and Chemistry. A wheat improvement sLoLa grant (SBS/John Innes Centre, £1.7M, 2012), is at the centre of an internationally excellent wheat research programme that is expected to deliver major outcomes in the short- to mid-term. The Schools will be major contributors to future BBSRC Doctoral Training Partnerships and will continue to receive support through the scholarships schemes available to UoN. Doctoral student recruitment from MRes degrees will be targeted and further international partnerships, especially with China and Malaysia, explored. Most work is likely to be funded through short term, 3-5 year, responsive mode or sLoLa grants. Strategic academic appointments to new posts will facilitate the further development of critical mass in these areas.

A key aim is to consolidate current collaborations with industrial and clinical partners, developing an existing strong reputation for strategic external collaboration. Traditionally collaborations have focussed within specific targeted areas. These activities are being extended with industrial collaboration into additional disciplines (e.g. environmental science, nutritional sciences). Research priorities will determine the targeting of infrastructure developments and capital equipment investments. The Rhizosphere building (autumn 2013) will comprise a £2.8M facility to house new

CT scanners with accompanying greenhouse capacity, which will initially support the ERC Futureroots project (€3.5M).

c. People, including:

i. Staffing strategy and staff development

Staff profile: The academic staff profile of the unit comprises 48 (35% women) staff at Lecturer, 34 (26% women) at Associate Professor/Associate Professor and Reader and 30 (13% women) at Professor. This ensures scope for medium to long-term succession planning with training and promotion used as a primary vehicle for developing and sustaining future researcher leadership. Some clinically active vets (e.g. Breen/Bradley) are employed part-time and this inclusion of clinical staff into research groups brings a valuable perspective to biological research. Clinical research strengths include dairy cow welfare, herd health and production (Green, Bradley, Huxley, Breen and Hudson), equine gastro-intestinal disease and cardiology (Burford, Bowen, Hallowell), reproduction (England, Freeman) and biomechanics, gait analysis and musculoskeletal disease (Freeman, Corr).

In addition to research active academics and clinical specialists, both Schools have high quality administrative and technical support for research. The unit has ~100 technical staff who support specialist facilities (histology, CT scanning, genomics, proteomics and metabolomics facilities, glasshouse management). The technical pool includes ~65 core UoN-funded permanent staff, which enables managed technical staff turnover, ensuring replacement of skills is structured. Technical input has contributed to important campus developments; allocation of core staff to the area of X-ray CT analysis of biomaterials was a key step in developing and expanding applications of the technology, which has been rewarded with significant research investment. ~65 administrative staff are employed in support roles which include research support (administration of grant finances, contract management, business engagement), working closely with UoN Research and Graduate Services, who support the development and delivery of research and knowledge transfer strategy, and contribute support on research governance, research operations and research policy. Interactions of academic staff with UoN Business Engagement and Innovation Services (BEIS) enable access to expertise and guidance in relation to technology transfer and commercialisation of research. BEIS lead on licensing of research and launching of spin-out companies.

Recruitment: The priority for new appointments is alignment of academic research interests to School strategic priorities and match with UoN Research and Knowledge Transfer Priority areas. This enables sustainable fit of incoming staff with research areas that are fundable and meet the needs of end-users. SBS are well-placed to contribute to UoN Priority Areas in Global Food Security and Energy and a number of appointments and promotions have aligned to this strategy (Prof. Azam-Ali promoted to Professor of Global Food Security, 2011 is now Director of CFFRC, Dr Ray, appointed *Plant and Crop Science* 2008). Since 2008 there have been ~50 new appointments to academic positions across the unit. Careful planning has ensured the strong balance of staff at different career stages across all research themes and provided leadership for new or developing initiatives. Succession planning for leadership posts is based around strategic new appointments and the training and promotion of staff (see below). Prof. Ian King (2010) brought an established wheat research programme and funding to SBS and other individuals with demonstrable research potential were appointed. For example, a molecular embryologist (Sweetman) was newly appointed to study developmental aspects of muscle in the chick embryo; an appointment in epigenetics (Stöger) further strengthened our interests in this rapidly developing area. New joint appointments with Computer Science and Mathematics (section b) have facilitated multiscale modelling and imaging associated with CPIB. There has been significant capacity building around established staff: *Infection and Immunity* (Daly, Dunham, Flynn), *Comparative Medicine* (Mostyn, Brower, Mongan, Rutland), *Reproduction* (Perry, Rutland, Stevenson, Stoger, Sweetman, Watkins, Welham). In 2011 UoN established the Strategic Development Fund enabling Schools to develop cases for significant funding to establish and attract professorial level staff, develop new centres of excellence and invest in capital infrastructure. The Advanced Data Analysis Centre (ADAC; £492K, 2013-18) is one such development and supports research and discovery by assisting in research grant applications and analysis of complex data sets. The key researchers leading ADAC are based in SVMS, SBS and Computer Science.

Staff development: We have a dynamic, collegiate and supportive working environment that values staff at all stages of their careers. UoN was awarded the European Commission's 'HR Excellence in Research' badge (2011) in recognition of commitment to supporting research staff and implementing the Concordat to support the career development of researchers. Only by ensuring equality of opportunity can UoN be confident that it is recruiting from the widest available pool of talented individuals and as such we are fully committed to providing a supportive and non-discriminatory environment for staff and students. ~80% of research staff participated in targeted awareness communication and training for equality and diversity in 2012. Commitment in this area is exemplified by the University Women in Science, Engineering and Technology group and promotions of women to senior posts (Prof. Katherine Smart was HoS SBS 2011-12; Professor Joanne Hort, Head of Brewing Science, 2013). SBS success in attaining an Athena Swan Silver award in 2009 (renewal 2013) preceded the UoN institutional Athena Silver award in 2013. The Schools fully implement UoN flexible working policies for parents and individuals with other carer commitments. UoN is a Stonewall Diversity Champion.

The recent development of SVMS and expansion of SBS means the Schools have ~20 ECR (15 returned for this assessment). UoN offers schemes to support their research career development. Researchers holding a permanent academic position are supported in applying for Early Career Research and Knowledge Transfer awards, targeted at scholars who have not been principal investigators on a research award. This scheme provides up to 12 months of funding for high-quality research anticipated to lead to external grant applications, or generate high-impact publications or other significant outcomes. Successful applicants (13) have received matched funding from the Schools (up to ~£50k, £0.5M total 2008-2013) to maximise these opportunities. Nottingham Research Fellowships (NRF) are targeted at exceptional postdoctoral researchers and provide three years of independent funding alongside participation in a mentoring and career advice scheme. The Anne McLaren (AM) Fellowship is similar, targeting at excellent women scientists and engineers. From 2013, both schemes will provide an established academic post at the end of three years and the current NRF recipient, Dr Bottley, will benefit from this change. SBS has hosted 10% of the NRF and AM awarded by UoN since 2008. The vitality of the unit ensures that research Fellows thrive and develop as independent researchers. Past fellows have gone on to academic posts at UoN and elsewhere (Alberio, Band, Fray, Gardner and Welham are all past fellows in our unit; AM Fellow Mowles is now in the School of Biology).

ECRs particularly benefit from individual mentoring schemes that provide support to staff at all career stages, with allocation of academic mentors and more formal grant mentoring committees that provide pre-submission and development advice. Applications for support from RCUK or charities are referred to suitable mentors and applicants may present grant ideas as seminars to colleagues. In SBS, ECRs have a reduced teaching and administrative load providing the opportunity to establish laboratories, appoint postgraduate research students, develop funding strategies and to take advantage of the multi- and interdisciplinary networking and collaborative opportunities both at UoN and Asian campuses.

UoN Research Committee operates a research leave scheme and the Schools have a policy of providing opportunities and funding to relieve staff of teaching and administrative duties for up to six months. ~20 academics have taken sabbatical leave since 2008, facilitating successful grant bids (e.g. Brameld, £977K Pfizer-BBSRC funding 2011-15) and publications.

Management of staff: Clear and effective line management of staff is achieved through taking responsibility for staff development activities and accessing training opportunities at School, Faculty and Institutional levels. Balancing workloads is a management priority, facilitating internationally competitive research alongside an excellent and supportive teaching and learning environment. SBS piloted a new workload model (2011) ahead of a UoN-wide scheme (summer 2013), designed to guarantee equitable and transparent allocation of work, promoting fair working practices, preventing individual work overload, improving work culture and staff satisfaction. The UoN Personal Development and Performance Review process evaluates academic achievements and sets goals, to assess and optimise loads and identify training or mentoring requirements. UoN Staff Education and Development Unit offers a broad portfolio of courses covering research environment and funding, leadership and management and career management. Staff are actively encouraged to access these opportunities.

UoN operates an annual merit-based promotions cycle. Staff promotions are managed, both locally and through UoN's central processes. Promotion is open to all R&T staff, ensuring that promotion opportunities accommodate individual career profiles and pathways, recognise achievement in research and scholarship, teaching and learning activity, and university and academic service. SBS offers development mentors for staff preparing applications for promotion. Since 2008 there have been 10 promotions to Chair (Azam-Ali, Broadley, Dickinson, Garnsworthy, S Hill, Hort, Huxley, Mooney, Sinclair, Z Wilson), 8 to Associate Professor and Reader (Broadley, Foster, Hardy, Lea, Mann, Mayes, Mooney, Parr, Scott, Z Wilson), and 13 to Associate Professor (Alcocer, Brameld, Broadley, Foulkes, Fray, Gardner, Gough, Hallowell, McCullough, Scott, Sjogersten, Sparkes, West). UoN launched the Nottingham Research Leaders Programme (2013) for senior academics to support and advance key individuals in strategic leadership and development through individual mentoring and training in large grant management, developing networks and collaborations (participants- Foster, Hort, Loughna).

International mobility: As described in section a), UoN is committed to furthering global reach and embeds its internationalisation programme into research developments. It provides opportunities for PGR and early career research staff to travel for conferences or visits to international collaborators (Graduate School research staff travel prizes). Staff have opportunities to participate in events to develop international research partnerships and increase exposure to international commercialisation opportunities. The presence of UoN in Asia promotes staff mobility and development of links to researchers in Malaysia (e.g. CFFRC programmes) and China. Many collaborations exist between individual research groups at the Sutton Bonington campus and in Chinese HE establishments and these are being expanded. Staff working on bacterial enterics and avian influenza, have strong links with colleagues at the China and Huazhong Agricultural Universities in Beijing and Wuhan. The close relationship with CAU was strengthened in October 2011 with the signing of an MOU with Nottingham, which involves jointly funded PhD students and PGR exchanges (£200k from Chinese Ministry of Science & Technology). UoN researchers have extensive collaborative networks in Europe (exemplified by involvement in large EU consortia, see section d), Africa (where UoN research is being translated into crop, soil and nutrition programmes) and North America (exemplified by United States Department of Agriculture projects that have funded postgraduate studentships with US partners).

ii. Research students

As outlined in section a), we have a large, dynamic, international (~40% of PhD registrants are non-HEU) PGR community, including students registered for MRes and PhD programmes. PGR have access to all research facilities, as part of their research, providing training in the use of state-of-the-art equipment. They are highly integrated into our research activities and, as members of world-class research groups, have the opportunity to work alongside postdoctoral RAs and interact freely with senior staff.

Capacity building and recruitment: ~90 research students (PhD/MPhil/MRes) are currently recruited to SBS and SVMS each year. Average doctoral completions (~50/year, 2008/09 to 2012/13; increased from 43 2008/09 to 61 2011/12) do not yet reflect recent expansion and lag behind current recruitment. The unit has seen a 37% increase in PGR recruitment between 2008/09 and 2012/13, with a shift towards greater overseas recruitment (41% of PGR were overseas in 2008/09, 53% in 2012/13). MRes has been a major capacity building feature since 2008 (annual MRes intake ~20). Students register for either a general MRes Biosciences, or for specific programmes (e.g. Sustainable Bioenergy). High quality students graduating from our own undergraduate, PGT and MRes programmes and external candidates benefit from sustainable doctoral training programmes. Since 2008, the Schools have received £1.25M in doctoral training grants from BBSRC (doctoral training grants, DTG, and Targeted Priority studentships) and EPSRC (DTG). SBS played a lead role in securing a UoN-wide BBSRC Doctoral Training Partnership award (£5.7M, 2012-15). Between 2008 and 2011, the Schools received 3 EPSRC Industrial Case studentships and 24 BBSRC Case Quota, Industrial Case and Industrial Case Partnership awards. Other funding streams for PGR include ~£8M in internally part-funded studentships, overseas scholarships (Libya, Iraqi, Saudi, Malaysian governments), charities and industrial partners. SBS has benefited from CFFRC programmes providing PGR sponsorship

(equiv. 300 yrs support, 2012-2015).

Support and generic training: Support for PGR students is provided through the UoN Graduate School and the Sutton Bonington Campus benefits from a dedicated Graduate School centre (2008). PGR access Graduate School generic training, currently comprising ~80 individual courses covering all aspects of researcher development. The courses are mapped against RCUK requirements, as defined in the Researcher Development Framework set out in the UoN Quality Manual. The central programme exists to complement the discipline-specific research training offered to research students by the Schools. The research themes run seminar programmes where postdoctoral and outside speakers present their work, and PGR contribution is mandatory.

Partnerships: Students are actively involved in interdisciplinary projects, networks and partnerships across Schools, UoN and external partners. The Doctor of Veterinary Medicine (Wellcome Trust £1.1M), established by UoN and Oxford is the only course of its kind in the UK, providing a programme comprising a taught component in combination with clinical research projects. The Schools have extensive links with industry, international institutions and research institutes and students are encouraged to take advantage of these links, attend formal and informal meetings and help to develop new interactions (e.g. Krystal Hemmings 1 month at INRA, Clermont-Ferrand, 2009; Dave Brown 6 months at Pfizer Animal Health Michigan, USA, 2012-13). PGR are encouraged to attend and participate at national and international conferences and many are recipients of Graduate School travel awards, which receive matched-funding from the Schools.

Student achievements: PGR are active contributors to publications, with ~ 40% of REF outputs including PGR authors. PGR are regular recipients of national and international prizes and scholarships (Lindau Nobel Laureate meeting 2011, Nutrition Society Postgraduate Symposium 2010), take up prominent roles in learned societies (e.g. Louise Lloyd of SVMS was member of Young Endocrinologists Committee; Society for Endocrinology) and present their work to influential non-academic audiences (e.g. SET for Britain, Houses of Parliament, 2010). 85-95% of PGR graduates achieve graduate level employment within 6 months of completion, with typical first destinations including postdoctoral research posts, research fellowships and consultancies and lectureship positions in UK and overseas universities (e.g. Dr Gkatzionis, graduated 2010, lecturer at University of Birmingham; Dr Chaosap, graduated 2010, lecturer at King Mongkut's Institute of Technology Ladkrabang, Thailand).

d. Income, infrastructure and facilities

Overview: The established strategy of the Schools has been to develop physical infrastructure around the scientific and intellectual resources of the staff and PGR student community. Planning of buildings and major items of equipment ensures critical mass and co-location of different disciplines, thereby enabling the flow of ideas and technologies. This is typified by the new Gateway development (£7M, 2011), which integrates *Environmental Science* with *Integrative Systems Biology* and veterinary researchers, and is intended to generate new interdisciplinary research opportunities. Additionally, there is a broad range of specialised facilities to support work across all research themes. Successful bids to BBSRC, ERDF and industry have enabled investment in FBIC in SBS (£6.3M, 2011). Other research accommodation is focused on the five main laboratory buildings that comprise SBS, the SVMS complex and shared areas [text removed from publication]. In addition there is access to core UoN facilities such as MRI scanning (used by sensory scientists in *Food Science, Nutrition and Animal Science*), next generation sequencing (accessed across *Reproduction*, *Comparative Medicine*, *Food, Nutrition and Animal Science*, *Integrative Systems Biology*, *Infection and Immunity* and *Plant and Crop Science* themes), electron microscopy, high-performance computing (used by *Integrative Systems Biology* researchers) and libraries.

Income: For 2008-2014 was £47.3M, derived from a diverse overall portfolio of funding. Grant awards comprised a mixture of UK and EU government grants (49% from UK research councils, 14.2% from central government bodies and 9% from the EU). 19.9% of income came from industrial partners (Syngenta, Pfizer, Novartis) and levy boards (DairyCo, HGCA, BPEX). In addition staff have secured 6.5% of total income from UK and international charities. There has

been a strong focus on larger awards such as sLoLa (e.g. wheat improvement programme; section b) and EUFP7 impacted significantly on our funding profile.

Infrastructure: Expansion and extension of research activities has necessitated major new building developments and refurbishments since 2008. The Gateway building houses world-leading facilities for analysis of in situ soil and root interaction and X-ray CT visualisation that are being further extended (£1M building housing a further £1.3M investment in new instruments, 2013). The new facility housing three X-ray CT instruments in one centre, is the world's largest dedicated facility for 3D visualisation of biomaterials. FBIC opened in 2011 accommodating three interconnected centres with pilot and incubation facilities for entrepreneurs and start-ups requiring development laboratories to trial new products and innovations. Within FBIC the unique Bioenergy and Biofuels Centre supports LACE research into the development and adoption of novel technologies in the processing of food-agri residues and development of energy conversion technologies and solutions. The Centre for Brewing Technology and Innovation, incorporating the global research brewery of SABMiller (£3.2M), provides research facilities and backing for businesses, with access to a micro-pilot brewery to support innovative technology production and testing, life cycle analysis and development of novel technologies and solution. The Food Processing Facility supports research into food and starch processing techniques and new product development. The facility includes pilot scale processing equipment, a food QA/QC laboratory, development kitchen and sensory booths.

- *[text removed from publication]*
- *Microbiology and Food Safety*: The *Infection and Immunity* and *Food, Nutrition and Animal Science* researchers have access to world-class CL2 and CL3 pathogen and GM 2 containment facilities. Tissue culture facilities with en-suite access to an environmentally-controlled fluorescence microscope equipped with a micromanipulator and micro-injector, enable the delivery of probes to study host-pathogen interactions in living cells. Density gradient and pulse field gel electrophoresis and analysis software are used for molecular characterisation of bacterial populations. A Biolog system enables microbial metabolomics studies.
- *Analysis of Food Systems*: *Food Science, Nutrition and Animal Science* researchers utilize a comprehensive array of instrumental techniques determine the physical properties of food systems: NMR instruments, low and wide angle X-ray diffraction, reflectance FT-IR, Bohlin rheometers TAXT2 texture analysers analytical ultracentrifugation, SEC-MALLS and field flow fractionation. Facilities to perform chemical analyses focus primarily on protein purification and sequencing. Flavour volatiles are detected through innovative GCMS systems and on line monitoring of volatile compounds using the APCI-MS system developed at UoN and a PTR-TOF-MS.
- *Post-genomic technologies*: Genomics, proteomics, and metabolomics, which form a central platform for most of our research themes are supported by conventional analyses (GC- and HPLC-MS) and novel on-line MS techniques providing rapid, high throughput analyses of complex mixtures of metabolites. Imaging facilities include provision of two confocal microscopes; one is dual photon allowing imaging of live cells. These resources are complemented by semi-automated facilities for microarray printing, hybridisation equipment and real-time quantitative PCR machines for high throughput expression profiling of mRNA concentrations. A specific facility runs protein microarrays.
- *Plant Research Facilities*: UoN provides unrivalled facilities to support research in *Plant and Crop Science*. The controlled environment glasshouses and growth rooms are suitable for temperate and tropical crops (most allowing ACGM containment). There is experimental glasshouse space (3279m^2) for large plant populations and the innovative 'Futurecrop' glasshouses (£1M, 2011) were designed for the analysis of entire crop stands to study field properties, and bridge the gap between plant and crop science. Temperature, humidity, light and soil water can be controlled with GM containment. *Plant and Crop Science* researchers utilize the 400 ha University farm, 20 ha of which is managed organically, has substantial trial plots and 20ha dedicated to field research. A transgenic glasshouse complex (880m2) supports the Arabidopsis Stock Centre. A new glasshouse (410m²) and seed store (22m²; £0.4M, 2011-12) was constructed to provide capacity for the wheat/alien introgression programme.

- *Environmental Analysis Facilities*: A newly built suite provides access to ICPMS, GF/F-AAS, IC, HPLC, GC, DOC/DON analysers, a CNS analyser and associated sample preparation facilities. The soil physics programme of *Agriculture*, *Environmental Science* and *Plant and Crop Science* researchers is supported by a state-of-the-art image analysis suite and the X-ray micro Computed Tomography (CT). A unique artificial soil gassing and response detection facility simulates CO2 leaks from carbon capture and storage sites under field conditions supporting *Environmental Sciences* work on climate change.

Collaborative access to infrastructure: Research groups are actively engaged in international collaborative activities (see section e) providing access to facilities for UK HEIs and global research partners. Two ERA-NET Plant Genomics projects (vSEED and TomQML, €3.24M, 2008-11) provided access to the software and hardware infrastructure of what is now ACAD, for consortium members. Involvement in sharing of facilities is exemplified by the European Plant Phenotyping Network (EPPN, a consortium of 14 participants in the UK, Europe and Australia). UoN offers access to 23 experimental plant phenotyping installations, at 7 different institutions, in 5 countries across Europe. EPPN gives free access for eligible user groups to research infrastructure, on-site logistic support and access to expertise. MicroCT equipment is accessed by multiple users in Europe and China. NASC provides seed and information resources to the international research community, providing global access to infrastructure, Affymetrix array facilities, genomics and bioinformatics resources (AtEnsembl and NASC Arrays), germplasm storage and glasshouses. Clinical equipment is accessed by other HEIs and non-academic users, e.g. [text removed from publication] image analysis equipment is used by Archimedes Pharma and the Guide Dogs for the Blind Association.

Policies and practice in relation to research governance: UoN Research and Graduate Services have a research governance team providing contract advice to researchers and ensuring compliance with legislation, regulation and best research practice. UoN has a comprehensive range of policies on research ethics, clinical trials, work with humans and human tissues and issues researchers with a research code of practice (last revised April 2013). This has robust policies on data storage, intellectual property, conflicts of interest, research integrity and research misconduct. The two Schools have their own ethical committees and additional policies to extend the UoN Research Code of Practice to include project planning, personnel competence and training logs, record keeping, quality control and upkeep of facilities and equipment.

e. Collaboration or contribution to the discipline or research base

Research success and delivery of innovative solutions appropriate for the industries we support, depends on groups of talented researchers working collaboratively. UoN shares facilities, processes, infrastructure and expertise with partners within and beyond the HEI sector to best exploit available research opportunities.

Engagement with UK and international HEIs: Our research strategy is founded on the principle of seeking large scale, often multi-centre funding including national and international networks of excellence (e.g. EPPN). As described in section b), researchers in the unit collaborate across the UoN Faculties. Engagement with non-UoN collaborators is evidenced by our profile of funding and outputs. Researchers have been involved as both principal and co-investigators on international projects (EU FP6 and 7 projects *The Early Nutrition Programming Project*, EPPN, ERA-NET *Plant Genomics*, ERA-NET *Healthy Gut, WildTech*, *Reproductive Effects of Environmental Chemicals*; United States Department of Agriculture *Milk fat-derived bioactive fatty acids and atherosclerosis*) and collaborative grants with UK partners (RCUK and UK charities). A high percentage (~60%) of our research outputs have been published with collaborators from outside UoN. SBS and Scottish Rural College (SRuC) developed a joint PhD studentship scheme based on a common strategy to apply fundamental and applied research to the development of sustainable, and efficient farming systems (2013).

Research interests are necessarily diverse, helping to develop interdisciplinary approaches to many problems. This is typified by CPIB, initially established to develop a multi-scale model of a plant root based on *Arabidopsis thaliana*. The cross-discipline opportunities provided by CPIB have resulted in additional integrative biology projects beyond that of the “virtual root”; tomato ripening

networks; virtual seed; modelling networks in pollen development; photosynthesis canopy modelling. Increasingly researchers are involved with modelling projects (including collaborators from other disciplines within UoN and externally), and next generation sequencing projects which utilize international collaborations with bioinformaticians to assist with analyses. CPIB is one of several centres of excellence within the Schools; others are: BiBiC; Centre for Brewing Technology and Innovation and LMRC. These centres enable key roles in collaborative networks, participation in core developments in our fields, engagement with industrial and government partners and a profile that can shape national and international research priorities (e.g. Global Food Security). Internationally recognised groups at the forefront of their research fields (cell biology and biomarkers; bacterial enterics; bovine disease epidemiology; bacteriophage applications) provide a focus for funded collaborative network development.

Essential resources (e.g. NASC as described in section d) are provided for the wider international communities within all our fields. SVMS supplies microarrays for wild animal disease surveillance across an EU consortium. The Fudan-Shanghai Jiatong University-Nottingham Plant Biotechnology Research and Development Centre (2001) is a joint venture established to facilitate closer collaboration and progress in plant biotechnology.

Networking events: Researchers develop national and international networks of collaboration with colleagues. Specific UoN events promote development of new networks fostering interdisciplinarity (e.g. SBS research day 2012). SBS and SVMS regularly host meetings of national and international importance (e.g. annual Cattle Fertility conference in association with the British Cattle Veterinary Association; annual Feed, Cattle Lameness conference). Researchers participate in EU COST Actions (e.g. Epigenetics and Periconception Environment). Colleagues are regularly invited join the scientific organising committees and to be keynote speakers at prestigious international meetings (e.g. Annual Symposium for Plant Biology 2011, Eurosoil 2011, Molecular Aspects of Plant Development 2010, Experimental Biology 2009/2011, Royal Statistical Society, World Congress of Reproductive Biology 2008/2010, Oskar Kellner Symposium 2011, World Poultry Science Congress 2012).

Peer review*:* The Schools are well represented on UK and international grant panels including BBSRC (Crout, Mobasheri, Seymour), BBSRC KTN Board (Seymour), BBSRC Training Awards Committee (Tucker), National Science Foundation (Broadley), DEFRA (Garnsworthy), Scottish Government (RESAS- Garnsworthy, RERAD- Langley-Evans, Salter, P.Wilson), Scottish Crop Institute Plant Products and Food Quality Programme and Syngenta Strategic Advisory Board panels (Seymour), NERC Peer Review Panel (Crout, Shaw, Bailey), NERC Technologies Review Panel (Mooney), MRC College of Experts (Langley-Evans), BBSRC Strategy Pool of Experts (Coffey, P Wilson). Researchers are actively involved in all aspects of grant peer-review, contributing expertise to major UK and international funding bodies. This provides a route to shape funding agendas, in parallel to the key UoN-BBSRC strategic partnership (section b) and extends to international influence e.g. representation on Portuguese Research Council (Chang), Luxembourg ATTRACT Panel (Langley-Evans). Researchers are actively involved in all aspects of grant peer-review, contributing expertise to UK (BBSRC, MRC, NERC, SEERAD, Wellcome Trust and medical charities) and international funding bodies (e.g. Agence Recherche France, ASTaR (Singapore), Canada Foundation for Innovation, European Union FP7, Marsden Fund (NZ), National Science Foundation, USDA (USA), NSERC Canada).

Researchers engage fully in peer review of publication (including *Nature*, *Science* and *PNAS*), and have extensive commitments to editorial boards of journals across the full range of disciplines that we represent, with a number holding editor-in-chief/senior editor (n=13, e.g. *Plant Pathology, Reproduction, Journal of Human Nutrition and Dietetics*), associate editor (n=36, e.g. *Food and Function, Frontiers in Bioinformatics and Computational Biology, International Journal of Obesity*) or editorial board positions (n=85 e.g. *Allergy*; *Bacteriophage; Developmental Cell; Plant Physiology, PLOSOne, Veterinary Journal, Veterinary Immunology and Immunopathology*).

Fellowships and prizes: The Schools hosted a number of prestigious external fellows, including twelve Marie Curie, two Wellcome, two RCUK, two Royal Society, two Commonwealth and one Leverhulme Fellow), along with ~40 visiting fellows from Europe, Africa, China, Brazil and Japan.

The esteem of our researchers is demonstrated by a number of notable awards and fellowships. Professor Bennett was a recipient of a BBSRC Professorial Fellowship (2009-14), Professor Green held a Wellcome Fellowship (2006-10), Dr Bishopp was awarded a Royal Society Fellowship (2013-2018) and Dr de Smet received a David Phillips Fellowship (2011-15). The late Professor Keith Campbell (d.2012) shared a Shaw Prize (2008) for his ground-breaking work on reprogramming of stem cells. Dr Tim Foster received the Institute of Chemical Engineering award for Innovation and Excellence (2009). Other awards include Dr de Smet (Society for Experimental Biology Cell Biology Medal, 2012); Dr Gardner (Nutrition Society Silver Medal, 2011); Dr Asher, (Scopus Young Researcher of the Year 2011, and UFAW Young Animal Welfare Scientist of the Year, 2011). Professor Steve Harding was made a Knight of the 1st Class of the Royal Norwegian Order of Merit in 2012 for genetic studies tracing Viking heritage in England. Professors Sinclair, Black and Langley-Evans all received DSc. awards from the University (2012-13).

Engagement outside the university sector: UoN works with UK government agencies and levy boards and includes commercial partners on specific projects, (TSB- *bovine production efficiency*; Food and Environment Research Agency- *in-field disease diagnostics*; *GREENPIG* Defra sustainable livestock LINK project - *home-grown plant proteins*, DairyCo- *Health, Welfare and Nutrition of dairy cows*). Outcomes of these programmes benefit the wider agri-food industry and provide invaluable research and development support for small and large businesses. Many of these projects draw on established links to UK HEIs and are collaborations with other universities and research institutes (e.g. Cranfield, Harper Adams University College, the Royal Veterinary College, Bristol University, John Innes Centre, Rres, SRuC and the University of Aberystwyth). There are numerous shared PhD studentships between UoN and the institutes, as described in section c (e.g. BBSRC DTP with Rres).

Co-localization at the Sutton Bonington campus with UoN spin-off and subsidiary companies (Flavometrix, Eminate) and external businesses (e.g. New Food Innovation Ltd, McCain) contributes to the pipeline between research and the food industry. This provides industrial investment for the Schools and allows businesses to share infrastructure and in-kind access to instrumentation. UoN is a member of the National Technology Platform for Food 'post-farm gate sector' (Food and Drink Federation, Campden BRI, IFR, Two Sisters) which provides a forum to bring together stakeholders aiming to drive forward innovation in the food sector, particularly in terms of education and training and research and innovation. Across the University engagement with industrial partners, such as the UoN-Unilever Framework agreement (2013), is facilitated by BEIS, promoting knowledge transfer, partnerships, technology transfer and commercialisation. BEIS was responsible for the roll out of internal Hermes Fellowships, a UoN investment of £2M (Higher Education Innovation Fund) over four years (2012-2016) in a programme supporting outreach, innovation and business engagement activities for economic and/or social benefit to the UK. SBS researchers have employed Hermes investment to develop a new basophil-microarray device for the diagnosis of food allergy and to establish ISO9001 laboratory accreditation in microbiology, to expand research opportunities and impact of research in industry. Both Schools are engaged in technology transfer and development of research networks through the BBSRC AATP and internationally. Researchers have roles as consultants or members of technology advisory boards for a number of companies (Pepsico S Hill, Fisk; Marks and Spencer Wiseman; Mars England, S Hill, Seymour) and SBS is at the forefront of the strategic UoN alliances with Unilever and SAB Miller.

Engagement of researchers with external partners extends into clinical settings, allowing research expertise to influence animal care. In addition to influencing treatment and prevention strategies (e.g. in management of bovine mastitis), SVMS has opened clinical facilities at Dick White Referrals, Newmarket 2013) and contributed to a small animal hospital in Derby (opened 2009).

Esteem and standing*:* External partners and collaborators place a high value upon UoN expertise and capability in AgVFd. This is exemplified by, prestigious awards (e.g. Queens Award), involvement of researchers in review and shaping research strategies (e.g. BBSRC, NERC, EPSRC), international collaboration, interactions with industry and partnership with global companies (e.g. Unilever, SABMiller). This external engagement recognises the capacity for international excellence that UoN has built through investment in outstanding facilities, infrastructure, student training, research and support staff. The diversity of the research of our

Schools, brought together under clear strategic objectives, provides a strong platform for international competitiveness in agriculture, food and veterinary science.