Institution: Royal Agricultural University

Unit of Assessment: Panel 6 Agriculture, Food and Veterinary Sciences

1. Unit Context and Structure, Research and Impact Strategy

The Royal Agricultural University has always positioned itself at the forefront of 'applied research' in agriculture, from its foundation 175 years ago, when the industrial revolution was realigning food supply systems, until today when the societal concern is *how to feed humanity and conserve the land in a period of challenge and change.* At present all the research at the RAU falls into the broad remit of UOA Panel 6, with some outlying research in enterprise, ecology and cultural heritage.

Our research strategy is framed around three goals:

Feeding the world in a changing climate
Food insecurity is a central concern of government. With the UK hosting COP26 in November 2021, there is even greater focus on the need to develop resilient, sustainable systems to optimise food production, promote animal welfare, and implement smart agri-technology solutions that will make food production more efficient, and achieve net-zero in agriculture by 2040. Areas where the RAU's research addresses these issues include: studies in animal feed amendments to reduce methane emissions; gaining greater understanding of appropriate cultivation methods; delivering precision-level inputs into crop and livestock production; maintaining soil health; and mapping carbon sequestration in the landscape.

Sustaining and restoring the global environment
In the face of climate change, globalisation, human population growth, loss of biodiversity and wild habitats and rapid urbanisation, the global environment is both directly and indirectly impacted. Our research strategy combines a holistic and technological focus to promote sustainability, landscape-level resilience and biodiversity, through agro-ecology, regenerative agriculture and regenerating communities, and keeping humans, plants and animals healthy. Central to this is our cross-research cluster expertise in food systems and their interface with ecological systems, and activities to develop societal engagement with the need to address landscape-level resilience and restorative strategies.

Enabling and revitalising Global Britain in a Brexit and Covid world
The socio-economic impact of COVID-19 on the UK and global economy is significant and will influence communities for generations to come. Strategies to revitalise, regenerate and enable recovery at local, national and international levels will be framed by shifts in social trends in an increasingly digital world. The need to "Build Back Better", level up communities and create equal opportunity in the UK and across the world, to regenerate economically and drive export opportunities to new post-Brexit markets, will create opportunity but also require transition, transformation and change. Our critical expertise in disruptive products, technologies and leadership (including food safety, animal welfare, health and wellbeing, food and rural policy, enterprise and entrepreneurship, and agri-technology) will inform food and farming policy, alternative food production and food supply models, and rural enterprise and innovation. Providing innovative solutions to delivering outcomes-based policy forms an essential focus of our research strategy. Research to improve the perceptions of the UK as a "go to destination"

will promote increased commercialisation of cultural heritage and agri-tourism. Our research in rural enterprise, food provenance, heritage and rural recreation will inform such economic growth. Rural pursuits enhance mental well-being and our work in equine health and welfare has nurtured a greener approach to this type of recreation, integrating it into farming systems and encouraging diversification and entrepreneurship within the rural economy.

We see these three **themes** interlocking throughout our five **research clusters**. We undertake focused scientific research, spanning both the UK and Western and Eastern Europe, but we also have a significant global perspective, especially in our doctoral research community and through our active connections with China, Brazil and sub-Saharan Africa. The University's approach to research has been formulated around collaborations between scientists, farmers and innovators. As we are located within a largely rural area, we have been able to leverage collaborations, and develop innovative research projects. This approach embraces farmer-science (a branch of citizen science)[1] and farmer-led innovation networks,[2] in which existing knowledge, skills and practice is widely acknowledged and developed. We have developed methodologies to measure stakeholder engagement and feedback. [3]

Sustainable and regenerative agriculture

A key area of research has been in sustainable, regenerative agriculture, where we have built up a significant research expertise through new appointments, including Professors MacMillan and Horton, and at lecturer level, Crotty, Webber and O'Connor. A key part of this research has been to develop improved methods of cultivation, with nutrient recovery, low carbon agriculture, soil conservation and planting regimes, to enable long-term sustainability, achieving net zero-carbon, and healthier food. Underpinning this has been a long-term systematic experiment (LTE) at Harnhill Farm (we believe the only one in the world) ongoing for 11 years, in which three regimes (plough, minimum till, and direct drill) and three crops have been monitored across 18 plots.[4] This platform is used by our research cluster, to measure outputs (Cannon) from annual harvest, soil biology and worm density (Crotty) and micro-nutrients in soil and plant uptake (Webber), enabling us to connect outputs, nutrients, soil health and cultivation methods. Crotty has secured a STFC grant to develop worm density measures using AI on these plots. Webber's research employs novel pXRF technology to link soil nutrients with plant uptake. Multispectral UAV imaging has also been employed to monitor crop growth over time. We have now converted the LTE to grass, as the farm converts to organic production, and will be monitoring the performance of the plots over the next five years.

A second approach to increased sustainability in agriculture has been a range of projects, mostly undertaken as doctoral research, that examined how to improve outputs through regenerative methods – including crop establishment techniques, low input N efficiency management,

[1] https://doi.org/10.1111/sum.12503, https://doi.org/10.1111/sum.12488,
[2] https://doi.org/10.3390/ani9010024
[3] https://doi.org/10.1016/j.eiar.2020.106415
[4] http://dx.doi.org/10.1002/jsfa.7767, http://dx.doi.org/10.1080/01448765.2013.829754, http://dx.doi.org/10.1080/01448765.2014.951961, http://dx.doi.org/10.1080/01448765.2015.1057865, http://dx.doi.org/10.1017/S0021859616000058, http://dx.doi.org/10.1111/aab.12294,

mulching crop residues, red clover N accumulation,[5] bi-cropping wheat and beans.[6] One innovative project funded by industry, has examined robotic mechanical weeding, linked to UAV/AI tech focussing on blackgrass in wheat and so potentially reducing chemical inputs. We have employed farmer-science approaches to test the impact of soil temperature on spring fertilizer application.[7]

Soil health remains at the centre of our research in sustainable agriculture, and by using this term we are acknowledging that we regard soil as a living ecosystem and not just an inert base for agriculture – and measuring the reliance of the soil to changes within agricultural management, food security and climate change is a key research goal.[8] We have taken a global approach, examining the contribution of soil protists to biological functioning in Canada (funded by Agriculture and Agri-Food Canada), as part of a large project examining the global distribution of earthworm diversity[9] and the study of soil fungivorous microarthropods, using stable isotope ratio mass spectrometry. [10]

Agricultural and industrial activity is often detrimental to soil health owing to the distribution of harmful heavy metal(loid)s into the soil environment. In light of the rapid progress in the emerging field of stable isotope ratio mass spectrometry, the RAU was part of an international collaboration (with Tsinghua University, Imperial College, Princeton University, Karlsruhe Institute of Technology, Tianjin University and the Chinese Academy of Sciences) which performed a state-of-the-art investigation into how stable isotopes can be used in soil metal source identification, with a focus on distinct isotope signals of different sources as the key prerequisites for source apportionment.[11] We have developed a novel method to map soil contamination using machine learning algorithms that can accurately interpret soil sample data combined with high-resolution aerial imaging.[12] This novel approach overcomes the difficulty that highly heterogeneous soil environments create for traditional interpolation methods, such as Kriging. Furthermore, we carried out a study with Tsinghua University at a Cd contaminated agricultural site in the Yangzi River delta in the southeast of China. A human health-based risk assessment revealed that minimal risk mitigation measures could be applied; however, our comprehensive sustainability research showed that more rigorous remediation approaches had lower life-cycle environmental impacts and better performance in the social, economic, and agricultural aspects.

Understanding the contribution of crop-based agriculture to climate change and biodiversity is one of the RAU's key research areas and we are developing methods to measure soil carbon sequestration, [13] greenhouse gas emissions linked to organic food production,[14] developing a

[5] https://doi.org/10.1016/j.fcr.2018.02.006, https://doi.org/10.1007/s10705-018-9947-1, https://doi.org/10.1080/14735903.2018.1498442,
[6] https://doi.org/10.1080/01448765.2020.1788991, https://doi.org/10.1080/01448765.2019.1636717,
[7] https://doi.org/10.1111/sum.12503
[8] https://doi.org/10.1007/s11027-020-09916-3
[9] https://doi.org/10.1126/science.aax4851
[10] https://doi.org/10.3389/fmicb.2019.01274
[11] https://doi.org/10.1016/j.jhazmat.2020.124812
[12] https://doi.org/10.1016/j.envpol.2020.116281
[13] http://dx.doi.org/10.1002/jsfa.7767
[14] https://doi.org/10.1038/s41467-019-12622-7

better understanding of soil micro-nutrients at a granular level, so to reduce chemical inputs[15] and examining climate change impact in sub-Saharan Africa. [16] Connected to our approach to regenerative agriculture has been research into the agri-ecosystem. Working with the ecological charity Plantlife (part of Natural England's Back from the Brink and the Millennium Seed Bank) K. Hemmings and Grange have been able to reintroduce the critically-endangered arable plant, Red Hemp Nettle (*Galeopsis angustifolia*) and are currently working on Spreading Hedge Parsley (*Torilis arvensis*), with results expected in Spring 2021. Our research on the agri-ecology of woodland, field margins and hedgerows focuses on their potential for biodiversity enhancement and carbon sequestration. Grange's estimates for carbon storage in hedge biomass was one of the first studies to do so. Grange and colleagues are also now working on the ecosystem services linked to trees in the farmed landscape. Studies based around long term experiments for up to 10 years and published in *Conservation Evidence* include the impact of bracken control in conservation management,[17] conservation grazing experiments (some using molasses to encourage selective grazing)[18] studies of wood decomposition to encourage bird nesting, and of ancient woodland indicators. [19]

One novel approach in agricultural production, developed at the RAU, relates to the use of natural products for improving health in humans[20] and reducing pest damage in agricultural crops.[21] A project to optimize the galanthamine content of daffodil biomass identified several alkaloids which are important for human health, including galanthamine which is now being used to treat Alzheimer's disease, and lycorine which is being assessed for its potential to limit the spread and distribution of the Covid-19 virus. We have also undertaken studies in the biosynthesis of alkaloids from plants[22] and explored cultivation of lycoris in China. The RAU is currently part of a project on sustainable daffodil-derived galanthamine production in the uplands[23] and during the REF cycle we have completed 7 galanthamine-related funded projects associated with research degrees.

In understanding food systems in sub-Saharan Africa, our research has taken an ethnographic and archaeological approach, being sensitive to the local heritage and tradition. The RAU has led a major AHRC/GCRF-funded project on East Pemba (Zanzibar, Tanzania) that has examined the sustainable maritime cultural heritage of one of the poorest areas of the East African coast. The project is part of the Network+ Rising from the Depths, and has focused on fisheries, shellfish and seaweed production, and associated material culture and traditional fishing boat construction, looking in particular at the role of women in food production. This project developed out of previous work on shell fishing on Mafia island[24] and archaeological researches on Zanzibar. Horton's active fieldwork with the Max Planck Institute for the Science

[15] https://doi.org/10.1002/fes3.169
[16] https://doi.org/10.13140/RG.2.2.33083.92963
[17] https://www.conservationevidence.com/individual-study/4023
[18] https://www.conservationevidence.com/individual-study/5911
[19] https://doi.org/10.1111/avsc.12501, https://doi.org/10.1556/168.2017.18.1.4
[20] https://doi.org/10.3233/JAD-160791
[21] https://doi.org/10.1016/j.cropro.2020.105316
[22] https://doi.org/10.1016/j.indcrop.2019.112058, https://doi.org/10.1016/j.gene.2021.145424
[23] https://doi.org/10.1038/s41598-021-81042-9
[24] https://doi.org/10.2993/0278-0771-39.2.182

of Human History has placed the globalisation of food systems (both plants and animals) within a tight historical, archaeological and genetic framework. [25]

Livestock health and welfare

The focus of our research into livestock is to provide scientific support for welfare and animal health improvement. This has two directions: to provide robust welfare outcome methodologies that can be used in a commercial context; and to develop farmer-led innovation networks (FLIN).[26]

We have built up a significant research expertise through new appointments, including Professor Main and at a lecturer level Stokes, Giebel, Zaleska and Smith. A key focus of the work (by Main, Stokes, van Dijk, Bull) has been the development of welfare-outcome research methods that are relevant in a commercial context including the adoption of outcomes measures in farm assurance schemes.[27] Recently the work has been extended to consider the economic and policy value of positive welfare/good life opportunities in livestock species.[28] We have also developed calf welfare assessment measures.[29] The appointment of Giebel has increased our expertise in epidemiology which will enable us to extend quantitative approaches to animal health and welfare.[30] Two PhD projects include improving dairy beef production systems through industry participation and the study of welfare in Farm Animals in the UK. Other doctoral work (Manning, Stokes, Muhammad) is focusing on sheep welfare and the development of a positive welfare framework to support knowledge exchange activities with farmers and industry stakeholders.

FLIN was founded by the RAU (van Dijk) in October 2018 to share knowledge and experiences and provide a collective advocacy voice for farmers directly involved in these initiatives. The main aim of FLIN is to understand, learn from and 'power up' farmer-led research and innovation initiatives in the UK and increase the impact of these kind of initiatives across the industry. Currently, over 20 organisations involved in farmer-led innovation and research initiatives are part of this network, including governmental and non-governmental organisations, research institutes, the levy boards, farmer organisations and advisory services. The network brings together an estimate of at least 1,500 farmers directly involved in farmer-led research and innovation across the UK (and over 3,000 farmers in initiatives engaging farmers in like-minded types of processes but with a less specific focus on innovation). In the first year of the network, two network meetings took place, one face-to face and one virtual, and several workshops were organised to share experiences, including an Innovation Facilitation workshop. Initial work was commissioned to make an inventory of the monitoring and evaluation approaches and tools used by the network members and how to develop better, more structured and potentially monetized evaluation of the success and effectiveness of these types of initiatives.

A critical theme of the RAU's work, which is also relevant for other agriculture disciplines, is the utilisation of existing knowledge and the motivation to adopt technical innovations. This has

[25] https://doi.org/10.1038/s41559-020-1120-y
[26] https://doi.org/10.3390/ani9010024, https://doi.org/10.5713/ajas.17.0851,
[27] https://doi.org/10.1017/S1751731119000946, https://doi.org/10.7120/09627286.27.1.001
[28] https://doi.org/10.3390/ani10040610
[29] https://doi.org/10.1016/j.envpol.2020.116281
[30] https://doi.org/10.3389/fvets.2020.581342

included adoption of motivational interviewing communication strategies[31] from medical disciplines, participatory famer action groups[32] and farmer-led innovation networks.[33] Furthermore, the RAU (Main, Stokes, van Dijk, Bull) is collaborating in the EU Horizon 2020 EURAKNOS[34] project and its sister project EUREKA[35]. These two projects bring together 21 multi-actors from 16 member states and 48 supporting organizations, to co-create a stronger and reinforced EU wide agricultural knowledge base by developing an open-source e-platform (knowledge reservoir). The future of innovation in European agriculture and forestry is based on the improved (digital) exchange of best practices between farmers, researchers and advisors from different sectors and member states. The EURAKNOS and EUREKA projects aim to ensure the longer-term and wider use by farmers, foresters and other rural businesses of the practical knowledge and innovative solutions that are generated by Horizon 2020 multi-actor projects. The RAU is leading the work on understand knowledge demand through profiling the needs and preferences of end-users; this will help to inform the actual design of the platform as well as verifying the preferred communication and dissemination channels used by end-users.

Food policy, quality and security

The scope of this research cluster is to consider food supply as a subset of wider food systems; therefore, the research described here is both multi-disciplinary and multifaceted. What lies at the heart of the collective research activity is considering food supply as a socio-economic and a socio-technical system. Socio-technical systems inform food safety, food supply and the moral framing and behaviours in supply chains. Extensive collaborative research by Manning[36] has been undertaken in this area, especially in the area of risk assessment,[37] product, process[38] and personal integrity[39] and food supply chain governance.[40] Food waste has been a topic of research interest with publications by Manning[41] and Michel-Villarreal. Main and Stokes have supported this area of research with work on the ethical and economic impacts of promoting good lives for livestock.[42] There has been work across the cluster on aspects of sustainable value creation including social value (Ravenscroft)[43] via farmers' markets (Michel-Villarreal)[44] and alternative food networks (Michel-Villarreal),[45] and sustainable value (Manning).[46]

Doctoral research is focusing on rural-urban food linkage in the UK, Nigeria and Tanzania and the development of alternative food models. Further doctoral research is considering food safety standards in developing countries and how to develop mechanisms to reduce foodborne disease outbreaks, and traceability mechanisms to inform food safety management.

31 https://doi.org/10.3168/jds.2019-16364
32 https://doi.org/10.3168/jds.2020-18874
33 https://doi.org/10.3390/ani9010024, https://doi.org/10.3389/fvets.2020.581342
34 https://euraknos.eu/
35 https://www.h2020eureka.eu/
36 https://doi.org/10.1016/j.tifs.2020.10.007
37 https://doi.org/10.1016/j.tifs.2019.07.007
38 https://doi.org/10.1111/1541-4337.12548
39 https://doi.org/10.1016/j.tifs.2019.09.022
40 https://doi.org/10.1080/10408398.2020.1747978, https://doi.org/10.1016/j.foodcont.2018.08.027
41 https://doi.org/10.1016/j.jclepro.2020.125484, https://doi.org/10.1108/BFJ-07-2018-0481
42 https://doi.org/10.3390/ani10040610
43 https://doi.org/10.1007/s11625-018-0652-4
44 https://doi.org/10.1108/BFJ-09-2019-0731
45 https://doi.org/10.3390/su11030859
46 https://doi.org/10.1016/j.jclepro.2019.06.217

One area of research activity is the functioning of the international sugar market, and how this is influencing sugar production in India, which is seeing a shift away from sugar as a food supply, and towards it being a source of ethanol. [47] Doctoral research within this cluster has a strongly international focus, with two projects in Nigeria, examining the impact of climate change on agricultural productivity, and the economic implications and causes of agricultural food shortage in Nigeria. Research on the efficiency of the international sugar market builds on the studies by Bozward. Manning has also been collaborating with the Universidade Federal de Mato Grosso do Sul in Brazil with research exploring resilience in the sugar and ethanol sector.[48]

Equine science

The cluster's research focuses on the relationship between equine behavioural neuroscience, gastric health and dietary manipulation of stabled performance horses, and makes a significant contribution of horse welfare. The holistic approach involves behavioural and physical health profiling to elucidate the triggers of gut dysbiosis and aberrant behaviours. The team has developed several innovative testing methods that are effective, non-invasive and low cost, but with high animal welfare impact. Much focus has been directed towards improving gut and respiratory health by developing novel feeds, pre-feeding treatments that remove airborne particles from fodder to reduce respiratory diseases, and increasing the understanding of stereotypy behaviour (crib biting) and its underlying causes.[49]

Hemmings has developed post-mortem brain receptor studies that focus on dopamine and opioid systems[50] and uses non-invasive behavioural and cognitive indicators of brain activity, for use in the living horse. The long-term aim is to develop brain-focused indicators of equine welfare status, cognitive profile, temperament and predictors of competition performance in equine athletes.[51] He uses cognitive markers to predict trainability in situations that require impulse control temperament and performance using the *3-Choice Serial Reaction Time Task.*[52] Another approach has been the *Spontaneous Eye Blink Rate*[53] as a welfare and temperament measurement tool and as an indicator of brain dysfunction.

Moore-Colyer has developed nutrition systems to improve gut and respiratory health[54], identified disease-inducing respiratory allergens[55] and mapped the microbial profiles in fodder. The work focuses on the effect that pre-feeding treatments have on the nutrient and hygienic quality of feed and the impact these have on the gastro-intestinal metabolome.[56] A strong element of this research has been industrial partnerships (Haygain Ltd, Eclipse Feeds, Natural Animal Feeds, ADM and Waltham Centre for Pet Nutrition), enabling the research insights to be translated into practical products. Two examples are: (i) the investigation into the efficacy of the total mixed

[47] https://doi.org/10.1177/0972150920988646
[48] https://doi.org/10.1016/j.tifs.2020.05.011
[49] https://doi.org/10.1016/j.jveb.2017.05.003
[50] https://doi.org/10.1016/j.bbr.2018.06.031
[51] https://doi.org/10.1016/j.applanim.2017.02.014
[52] https://doi.org/10.1016/j.jneumeth.2017.01.018
[53] https://doi.org/10.1016/j.physbeh.2016.08.029
[54] https://doi.org/10.1016/j.jevs.2015.09.006
[55] https://doi.org/10.1038/s41598-019-51820-7, https://doi.org/10.1111/jvim.15564
[56] https://doi.org/10.1371/journal.pone.0227151

fibre ration (TMFR)[57] – developed at the RAU in 2015 in collaboration with Eclipse Feeds Ltd, Ireland, in improving digestive health and reducing the expression of Developmental Orthopaedic diseases in thoroughbred weanlings and yearlings; and (ii) the development of the hay steaming technology (in partnership with Haygain Ltd) with the objectives of reducing the airborne respirable dust in forage, improving the stable environment [58] and so reducing the incidence of the performance debilitating and welfare compromising respiratory condition, severe equine asthma (sEA) (this forms an impact case study).

Daniel's research focuses on intestinal health and prevention of intestinal dysbiosis in horses which is the most significant cause of colic and death in the UK horse population.[59] This work includes parasitology focused on anthelmintic efficacy via nematode egg reappearance times, the ovicidal efficacy of fenbendazole in populations of resistant cyathostomins, and efficacy testing in working equids.[60] The fundamental parasitology has extended to investigating the effect of anthelmintic on the hindgut microbiomes structure and mechanistic function[61], to understand risks of parasite treatment and intestinal disease seen in horses. Gut health research includes understanding the microbiota of feeds.[62] *In vivo* digestibility trials are ongoing to support the development of the *in vitro* gut model microbiome and gut brain axis work.

Sustaining the rural economy and landscape.
Researchers at the RAU understand that the land and landscape is a dynamic entity, the product of millennia of human curation, and a delicate relationship between productive activity – that includes farming and rural enterprise – and the conservation of the environment (both historic and green). We have a unique blend of specialists that undertake research on rural enterprise and regeneration, including economists, geographers, planners and heritage and agri-business specialists. We are part of the *National Innovation Centre for Rural Enterprise* (NICRE) along with the Universities of Newcastle, Warwick, and Gloucestershire, supported by Research England and industry partners. Established in 2020, this initiative aims to shift the policy about rural enterprise through research into the rural economy. One interest lies in artisan entrepreneurs, often small rural businesses with highly specialised skills such as food producers or creative artists. Inge Hill's research examines micro-entrepreneurship suggesting methods considering socio-materiality for studying the development of business exchange relations. Central to this research has been the development of a theoretical framework and fine-grained ethnographic methods, which have not been used hitherto in this field. Hill's research examines methods of data capture and the study of micro-entrepreneurship and socio-materiality within artisan entrepreneurs.[63]

Gloucestershire has been greatly affected by bovine TB, and the RAU played an important role in understanding farmer behaviour and compliance. This work was undertaken by Naylor, in collaboration with the University of Gloucestershire and UWE, and adopted a social science approach. The initial multi-disciplinary longitudinal project, completed in 2015, was in support of

[57] https://doi.org/10.1016/j.jevs.2020.103191
[58] https://doi.org/10.1016/j.jevs.2016.12.007
[59] https://doi.org/10.1186/s42523-020-00056-2
[60] https://doi.org/10.1111/evj.13325
[61] https://doi.org/10.1111/eve.04_12792
[62] https://doi.org/10.1371/journal.pone.0242373
[63] https://doi.org/10.1108/IJEBR-11-2019-0642, https://doi/abs/10.1080/08985626.2018.1449015

the DEFRA Badger Vaccination Deployment Project. It explored farmers' levels of confidence in vaccinating badgers against bovine Tuberculosis (bTB) and helped to inform the Government's bTB strategy.[64] A second project 2014-16, supported by a DEFRA social science research fellowship, focused on farmer compliance with mandatory and voluntary bTB disease control measures and an evaluation of new risk communication methods developed by DEFRA and informed the development of new intervention measures. The third project, in 2015, explored livestock-keepers' experiences and their responses to different disease payment mechanisms and directly informed DEFRA's exotic disease compensation policy.[65]

One example of European collaboration has been the study of sustainability of goat and sheep farms in Europe, which analysed 206 farms in Greece, Italy, Spain, Finland and the UK as part of a Horizon 2020 project.[66] Another examined the productivity and economic evaluation of agroforestry systems in comparison to sustainable food production in Denmark and the UK.[67]

Impact and knowledge exchange strategy

Our knowledge exchange and impact strategy is central to our institutional mission to support the land-based sector, rural enterprises and agri-technology innovation. This strategy seeks to increase prosperity and build a bridge between rural and urban civic society through a dynamic integration of science, policy and practice. Our knowledge exchange activity is driven by societal needs and is focused on collaborating expertly with government, industry, civic society and other academic institutions, as well as the involvement of students in real-world learning. We use evidence-based, practice-led approaches to support policy makers through thought leadership, and we provide professional development programmes and business support, and create space for innovation and entrepreneurial business acceleration.

The RAU's vision for impact and KE for the next 10 years is to become the leading research intensive, specialist HEI focused on the land, economy and food-supply sectors, collaborating expertly with government, industry, civic society and other academic institutions, in the UK and around the world. This strategy seeks a dynamic integration of science, social science, policy and practice and must be enabled by rigorous underlying scientific research. We are developing this approach in line with the KE Concordant which we have joined.

Our underpinning knowledge exchange mission is: *"To impact industry, government, employers and rural and urban communities by providing focused thought leadership, relevant research outputs and shaping policy through the development of dedicated interfaces with our stakeholders."* This mission is supported and framed by innovative research and by disseminating best practice.

[64] https://doi.org/10.1111/soru.12269, https://doi.org/10.1016/j.vaccine.2019.11.037, https://doi.org/10.1016/j.landusepol.2017.04.026, https://doi.org/10.1111/soru.12105, https://doi.org/10.1016/j.prevetmed.2016.05.007, https://doi.org/10.1136/vr.103187, https://doi.org/10.1016/j.jrurstud.2014.07.001, https://doi.org/10.1068/a130298p, https://doi.org/10.1111/area.12113

[65] https://doi.org/10.1111/soru.12269, https://doi.org/10.1136/vr.103571

[66] https://doi.org/10.3390/su12083099

[67] https://doi.org/10.3390/su12135429

Future research projects

In April 2021, we are launching the Centre for Effective Innovation in Agriculture (CEIA) at the RAU, funded by the Elizabeth Creek Foundation. This is a collaboration between five agricultural universities to put farmer priorities at the heart of innovation research. This centre aims to increase the adoption of innovation by farmers, by helping scientists and research funders better align their effort and investments with user needs.

We have been awarded a major research grant as part of a European consortium, from Horizon 2020, to research the pathways for transitions to sustainability in livestock husbandry and food systems. The overall goal of the PATHWAYS project is to inform policy, research and business strategies in support of a transition to more sustainable animal protein production and consumption. This will be achieved through improved characterisation and assessment of current livestock systems, identifying the potential trade-offs and synergies of innovations, and through developing and evaluating sustainable development scenarios to derive credible, relevant and effective transition pathways for the livestock sector. To reach its overall goal, the project will combine novel and scientifically supported holistic sustainability assessment methodologies with a wide range of national practice hubs (involving the main livestock species) and collaborations with international stakeholder networks. Together, these groups comprise innovative agents for livestock-system transitions (IALTs) and supply chain actors, who can identify, assess and support innovations and identify transition pathways.

Our recently funded FOODLEVERS project (funded by DEFRA through SUSFOOD2 and CORE ORGANIC Co-fund, worth £100,000) investigates sustainability transitions and aims to identify key leverage points to develop and scale up existing innovative organic and sustainable food systems in order to promote higher resource-efficiency, highlight inefficiencies and specify the reasons for decision-making that led to the configuration of the food systems. Rethinking the organisation of sustainable and organic food systems value chains in this way is necessary to increase the sustainability and efficiency of food systems and to reduce trade-offs between production/distribution stages. The project will analyze several European case studies of innovative organic food systems and innovative sustainable systems and identify best practice processes from multiple perspectives of resource efficiency: environment, economy, social and governance.

A further area of future research will explore an environmentally benign combination of biopesticides. Xianmin Chang is part of a £1.2m Sino/UK Newton Fund project, Transforming Pest Control in Chinese and UK Agriculture (RAU/Greenwich University/AgroPy (UK) Ltd). This project will improve ecosystem welfare through the development of an environmentally benign pesticide that combines effective but non-persistent botanical pesticides with entomopathogenic fungi (EPF) to create a pest control solution for sustainable pest management in China and the UK.

The livestock health and welfare research group has been awarded two projects this year likely to have both major policy and commercial impacts. A DEFRA-funded project is exploring the potential opportunities for public money for ‘public goods’ payments in a welfare-enhancement framework across all major livestock species, and to shape policy for higher farm animal welfare payments post Brexit. This project seeks to embed the ‘good life’ framework which we have been developing with farmers and farm assurance schemes over the last few years for chickens,

cows and sheep. The group has also developed a research contract with a major chicken restaurant company to explore the system changes necessary to deliver animal welfare and sustainability objectives.

Working with the animal feed nutritional company Nutri-San, Main and Horton are developing two projects around seaweed additives to feed, to improve animal health and reduce methane emissions. One has developed from the East Pemba project, to investigate cultivation of different species that hitherto are only found in the wild, and the second to look at the health impact of seaweed additives on cattle and chicken.

The equine science research group is developing an *in vitro* gut model (with Wageningen University, University of Utrecht, Netherlands and University of Glasgow) that addresses the 3Rs (refine, reduce and replace) recommendations when using animals in research, so we can replace horses with accurate in-lab assessment to study new feeds, dietary interactions, impact of medications on the gut microbiome, and the study of gastrointestinal diseases.

We aim to develop research on the economic contribution of rural creative industries, as engines of economic redevelopment in rural areas, aligned with the UN Sustainable Development Goals and have two grant applications outstanding for these research projects. We are also increasing our focus on soil health, biodiversity, and agri-tech, with grant applications for sensor development to understand earthworm ecology and movement within the field.

2. People

(Our university-wide policies are set out in REF5A in more detail). The RAU is a small specialist institution with an academic staff establishment of 58 (54 FTE). During the REF cycle, our policy has been, where possible, to recruit research-active academic staff, and to have an open process for the identification of existing staff as having SRR through our Code of Practice. The University's Recruitment and Selection Policy outlines our commitment to recruit high quality staff within a fair process, free from bias and discrimination and focused on merit and ability. It details a well-planned process that is timely, supports the strategic direction of the University and withstands external scrutiny and audit. New appointments who are research active have research included in their contracts. The REF cycle has also seen the appointment of six new professors, of which five have been external appointments and one an internal promotion. Through restructuring of our academic establishment, the proportion of research-active academics has doubled from 17% to 33%. With open-door encouragement for our academics to transfer to SRR status and new appointments, we hope to achieve 50% SRRs during the next five years.

Our research-active staff (including non-SRRs) are part of a research academy, which provides administrative support, advice on grant writing and planning, as well as financial advice. The academy has a budget to arrange research activities, including seminars and events as well as to operate the laboratories. The Director of Research attends the annual staff appraisals of research-active academic staff and mentors all new appointments. In the staff work-load model, 30% of research-active staff time is allocated to research. All staff are required to place their publications onto the University Repository.

The RAU has a franchise agreement with the University of Gloucestershire (UoG) for the award of research degrees. Research students, studying for both doctorates and MRes degrees are registered at the RAU and are allocated two supervisors and have a minimum of once-monthly meetings. Students are able to develop their research methodology skills via two taught modules run by UoG and on successful completion they are awarded PG Cert in Research Methods. Additional courses in data analyses run by Bristol University are also offered. Project design and writing skills are developed through production of a formal project proposal and feedback is given by an independent reviewer. Each year students develop their presentation skills through weekly Research Workshops and specific PG seminar days. A wide range of PG-relevant on-line material is available on our VLE PG support page, and discussion sessions on a variety of skills are regularly held. Opportunities to develop teaching skills are offered via demonstrating in UG classes. Students are encouraged and supported financially, through a designated fund, to present papers at academic conferences.

The RAU is fully committed to a diverse staff and student community. 50% of our research students come from sub-Sahara Africa, and 6% of University staff are BAME. Eight out of 18 staff submitted in this Unit of Assessment are female (44%), as are 2 out of 6 professors (33%).

3. Income, Infrastructure and Facilities

Research income, as recorded in the HESA returns for the period 2013-2020 was £1,421,000, and largely comprised grants from charities and local and central government. However, recent grant success from UKRI, including GCRF/AHRC, STFC and Horizon Europe from 2019 signal a development in our funded research strategy, and as a consequence an uplift in our research income, which has increased by 88% over the last three years.[68] Research income recorded from 2020 continues this upward trend and we anticipate an annual research income of £500k from 2022.

As a land-based institution, the RAU's principal research infrastructure is located in our farms and associated property. We lease Coates Manor Farm (194 ha.) and the Fossehill Equestrian Centre, while at Harnhill Farm we have the John Oldacre Rural Innovation Centre with wet laboratory facilities and workshops for primary fieldwork. We operate an access agreement with the Bathurst Estate, which provides access to 3,150 ha. of arable land for research purposes as well as extensive forestry, grassland and parkland.

An important new initiative has been the designation of a *living land lab,* an area of 8.5 ha. within the campus area. Established in 2020, this is now being used for a variety of research projects, including plots for monitoring plant yield, soil health and cultural heritage research, and the re-introduction of rare arable plants. We are planning further research projects in this area with industrial partners and members of Farm491, as well as being part of the Wild Campus Project.

Our 650m^2 laboratory space has facilities for chemistry, microbiology, dissection and a clean room. Fully equipped for agricultural science, they include furnaces, freezers, fume cupboards, particle grinders, and homogenizers, with analytical equipment that includes HPLC, PCR, total

[68] There is a discrepancy in the HESA reported figures of £121k with some of our research income for 2019-2020 (validated through TRAC) returned under 'Other'. The total research income figure for 2019-2020 is £239k.

carbon and nitrogen analyzer, atomic adsorption analyzer, Tullgrem funnel, and invertebrate extractors. The genetics facilities in the clean room includes an end-point and real-time (qPCR) machines along with standard gel electrophoresis equipment. There is also an Agilent 2100 Bioanalyzer for rapid lab-on-a-chip analysis of DNA, RNA or proteins. In 2021, we are planning to establish a research campus, adjacent to the *living land lab* with newly equipped laboratories, 200m^2 research laboratory space for post-graduate and staff research, a big-data centre and dedicated post-graduate study space.

At the Fossehill Equestrian centre we have dedicated stabling for up to 80 horses, 30m x 60m enclosed floodlit outdoor arena, a 1,000m all-weather gallop track, a horse walker and a 'stick and ball' outdoor exercise area. We use dedicated stalls for the research ponies which are part of a collaborative agreement with Glasgow University and are used for a variety of PGR and commercial *in vivo* digestive physiology and behaviour trials. We also have the use of the livery polo ponies (approximately 30) for observational behaviour and exercise physiology monitoring.

As part of the impact and KE infrastructure the University completed the £4.2m Alliston Centre, a state-of-the-art incubation hub for agri-tech. Funded by GFirst LEP and the RAU, this Growth Hub provides 1,342m^2 of space to enable academic research to interact and create impact with innovators, who are part of Farm491, an RAU initiative to support and accelerate agri-business.

In 2020, through a partnership with Swindon Borough Council, the University acquired a £1.8m facility in the former railway village, for research and teaching in cultural heritage, located adjacent to the HQ of the UK's national heritage bodies that will enable our land-based research to influence national policy.

4. Collaboration and Contribution to the Research Base, Economy and Society

Our evidence-based, practice-led approach to research means that RAU academics support policy makers through thought leadership in industry, government and civil society organisations, as well as engaging in product development. Through our short, long and on-line professional development programmes in rural, agricultural and agri-food supply chain management and leadership, we provide individuals with the skills and strategic insight required to effectively lead and manage businesses. We aim to enable innovation and local growth through the provision of innovation support services, access to knowledge hubs/platforms and space for innovation. Our academics use innovative approaches to facilitate collaboration and co-learning with students, farmers, charities and businesses through learning labs and farm, land-based and supply chain practice-led innovation.

Our cross-institution programmes support rural entrepreneurship acceleration, enabling wider and deeper stakeholder partnerships to deliver national (Industrial Strategy) and place based (GFirst LEP) priorities. Central to this approach is the creation of pathways for business and social enterprise development within our student, alumni and local communities through the Cirencester Growth Hub, and agri-technology start-ups and growth-stage companies through the Farm491 programme. Furthermore, the Farm491 Knowledge Hub and our work on a European level agricultural e-knowledge reservoir provide opportunities for knowledge sharing and exchange.

Below are listed ten examples of the impact of our research on industry, society and government policy (see also our two impact case studies):

- Professor Tom MacMillan has been undertaking in a central role in developing the **National Food Strategy** as policy advisor to Henry Dimbleby, and in compiling and writing the report of the Food Farming and Countryside Commission. [69] The NFS focuses on the urgent challenges relating to COVID-19 and Brexit and has had a direct impact on policy in the areas where it made recommendations. MacMillan provided strategic advice and research support, designing and commissioning research which included stakeholder engagement, polling on the future of work in the farming sector, polling on public attitudes to COVID-19, and an analytical review of 1,000 relevant previous policy recommendations. He was involved in establishing the Food, Farming & Countryside Commission, and has advised it as a consultant (first as Research Director, then Expert Advisor) since its inception, contributing to its strategic development, co-developing novel methods of inquiry (e.g. a UK-wide rural bike tour involving dozens of researchers over seven months) outputs and impact. He co-authored the final report of the Commission's inquiry, which was welcomed by the Secretary of State and received international media coverage. Ongoing work to implement the Commission's recommendations includes: work with the Environment Minister in Wales to develop a national nature service; work with the Geospatial Commission on strategic frameworks for land use; and analysis of agro-ecological land use scenarios in the UK. A poll MacMillan led for the Commission in April 2020 that found that that only 9% of people wanted a total return to normal after lockdown, was widely reported and continued to be cited in media stories throughout the year.
- Professor David Main and other leading animal welfare academics at the university have been active in the global animal welfare agenda. This has included a high-level workshop on a "UK Vision for World Leading Animal Welfare: Role of Public Goods Payments" with senior policymakers in government, industry and civil society, and drafting of a collaborative policy position by Farm Animal Welfare Forum in August 2019. The work on reducing antibiotics in the dairy beef sector has continued and there has been multi-level stakeholder engagement to support this critical public health and animal welfare agenda.
- The work of FLIN members and specifically Professor MacMillan have contributed to an increased commitment of DEFRA to invest in farmer-centred R&D and an overall increase in focus on the need to engage farmers and growers to ensure uptake and use of innovative technologies and practices. The launch of the Farming Innovation Pathways research funding call is an example of this commitment.
- Dr Jessica Stokes has been leading a co-design process with DEFRA which is investigating options for public payments for animal welfare, including adopting positive welfare practices. In addition, RAU research (Stokes, Main) on positive welfare and promoting good life was included in the February 2020 DEFRA policy statement, *The Future for Food, Farming and the Environment*.
- Dr Nicola Cannon has been collaborating with Cotswold Seeds for over 12 years to investigate how grass and grass legume species mixtures impact subsequent crop growth.[70] The results demonstrated the benefits of including red clover in grass mixtures

[69] https://www.thersa.org/reports/future-land
[70] http://dx.doi.org/10.1080/01448765.2015.1057865

to reduce synthetic fertiliser requirement in the subsequent crop.[71] The next stage determined if different red clover traits impact the nitrogen fixation and therefore subsequent benefit to the following crop [72] so reducing nitrogen fertilisers manufactured using the Haber Bosch process which has a high energy requirement and acts as a major barrier to net-zero cropping systems. Cotswold Seeds used this information for advising farmers on suitable species mixtures and the most suitable red clover varieties to optimise nitrogen fixation and they developed these research themes further with the development of FarmEd and crop rotations trial. Results from this work have been jointly presented at conferences and these farming systems are being considered as sustainable farming systems within the ELMS payment scheme which is currently under development.

- Dr Xianmin Chang developed a template for a completely new industry around daffodil production and processing of alkaloid production which is scalable, sustainable and environmentally friendly, and it will significantly reduce the price of drug production. In addition to galathamine production which is now used for Alzheimer's treatment, we, together with a commercial partner, are working with 12 other universities in research into other alkaloids, e.g. Lycorine, Home-Lycorine, Haemanthamine, Tazettine, and Narciclasine, that may offer potential treatments for virus infections, heart failure, cancer (glioma), inflammatory, impact Protozoa in ruminant digestion which eliminates methane production.
- Professor Horton's research on the East Pemba project is leading to significant international investment in the local seaweed industry for the introduction of new species, which are of much higher market value and which can significantly contribute to long term GHG reduction. The project has also installed new museum displays (replacing the closed and recently collapsed National Museum) that highlight the importance of the maritime and coastal sector.
- Professor Louise Manning was asked to provide written evidence to the EFRA Committee considering COVID-19 and food supply, and also contributed to Parliamentary Office of Science and Technology (POST) publications on supply chain resilience. Manning was also a member of the Institute of Food Science and Technology COVID-19 Advisory Group which created a COVID-19 Knowledge Hub for food operators and the group worked with external Government agencies and departments in developing resilient food supply policy during the pandemic.[73]
- Through the research on disease-inducing respiratory allergens, Professor Moore-Colyer and Dr Hemmings developed pre-feeding treatments of horse feed with industrial partners so significantly improving horse welfare across the world (one of our impact case studies). Moore-Colyer and Daniels collaborated with Eclipse Feeds (Ireland) to design a total fibre mixed ration to be fed to thoroughbred foals to encourage steady healthy growth and development without detrimental effect on joints or gastrointestinal health, both of which can be side effects of traditional high cereal[74] diets, and the product has just been launched as Foal to Yearling TMR.[75]

[71] http://dx.doi.org/10.1080/01448765.2014.1001792
[72] https://doi.org/10.1007/s10705-018-9947-1, https://doi.org/10.1080/14735903.2018.1498442

[73] https://www.ifst.org/membership/networks-and-communities/covid-19-advisory-group
[74] https://doi.org/10.1016/j.jevs.2020.103191
[75] http://www.eclipsefeeds.com/YearlingTMR

- Dr Naylor's research in understanding farmer behaviour and compliance during the bovine Tuberculosis (bTB) epidemic, helped frame government policy on disease control measures. The first project explored farmers' levels of confidence in vaccinating badgers against bovine Tuberculosis (bTB) and helped to inform the Government's bTB strategy. A second project focused on farmer compliance with control measures and informed the development of new intervention measures. A third project in 2015 explored livestock-keepers' experiences with different disease payment mechanisms and informed DEFRA exotic disease compensation policy.

Wider activities and collaborations

- Professor David Main chairs the Home Office *Animals in Science Committee* (2019-) a ministerial appointment providing advice on the regulation of scientific procedures of animals. He is also a member of the Farm Animal Welfare Forum (comprising animal welfare charities farmers and retailers, collaborating on farm animal welfare policy (2006-), McDonald's Chicken Global Sustainability Council (2018-) and Foundation Diplomat of the European College of Animal Welfare and Behaviour Medicine (2011-).
- Professor Joanna Price (Vice-Chancellor) chairs GFirst LEPs Agri-Food and Rural Business Group which led a project to establish the value of the Rural Economy in Gloucestershire, resulting in incorporation of advanced agri-tech into the Local Industrial Strategy and the Gloucestershire Food Strategy. She is a director of Food and Farming Futures, which promotes thought leadership and independent knowledge exchange in the sector and a Trustee of the Royal Agricultural Society of England, which through its "Practice with Science" work, seeks to facilitate informed debate about the future of farming, the environment and the rural economy.
- Professor Louise Manning is a member of the COVID-19 Advisory group of the Institute of Food Science + Technology providing advice to the government on food supply and safety. She collaborates with Aberystwyth, Cambridge, Derby, Gloucestershire, Harper Adams, Lincoln, Newcastle, Nottingham, Royal Holloway, Southampton, Lancaster, QUB, UCLAN, Universidade Federal de Mato Grosso do Sul (Brazil).
- Dr Felicity Crotty is a trustee of the British Grassland Society (2020-), the Soil Biology Special Interest Group convenor (2020-), and a trustee and "Early Career Science Champion" for Association of Applied Biologists (2018-2020). She collaborates with Aberystwyth, Leeds, Liverpool, Reading and Warwick Universities and Hartree Centre (STFC) in the UK, and the Netherlands Institute of Ecology, University of Hohenheim and the German Centre for Integrative Biodiversity Research (iDiv) Halle-Jena-Leipzig within Europe.
- Dr Inge Hill is chair of the British Academy of Management Strategy Special Interest Group and collaborates with Swansea, Newcastle and Gloucestershire universities.
- Professor Horton is a research fellow of the Max Planck Institute for the Science of Human History and collaborates with Leicester, Queen's University Belfast, Bristol, Brisbane, Harvard Medical School, National University of Mongolia, and UC Santa Crux.
- Dr Nicola Cannon is Vice-Chair, Soil Association Farmers and Growers Boards (2018-), Vice-Chair Western Region Tropical Agricultural Association (2017-) and a board member of Agricology (2016-).
- Professor Meriel Moore-Colyer is Chair of Scientific Committee of European Workshop on Equine Nutrition. She collaborates with Haygain, Eclipse feeds, Marigot Ltd, Waltham centre for Pet Nutrition, Caltech, University of Nottingham, Wageningen University, University of Utrecht, Netherlands and University of Glasgow.

- Professor Tom MacMillan is Policy Advisor, National Food Strategy; Expert Advisor (previously Research Director), Food, Farming & Countryside Commission.
- Professor Neil Ravenscroft is a research fellow at Fudan University, China, Advisor to the Chinese Community Supported Agriculture Association, Trustee of the African Fellowship Trust, Director of Tablehurst Farm Ltd, and collaborates with: the Centre for Natural Resource Economics, Fudan University, China; Chinese Community Supported Agriculture Association, Beijing; Department of Law, University of Sussex; School of Environment, University of Brighton; and the Department of Economics, Pontifical Catholic University of Rio Grande do Sul, Brazil.
- Dr Simon Daniels collaborates with ADM, ABVista, Dengie Crops Ltd, Zagazig University Egypt, and the University of Surrey.

Public engagement and media

The RAU has adopted a pro-active policy towards media and public engagement, as part of its role to provide expertise and thought leadership in society. Examples of this are regular appearances on Countryfile, Farming Today and On Your Farm, regional TV news, and national television as well as print media. Professor Louise Manning has had a significant media presence seeking to gain wider public engagement with issues from food poverty through to the impact of Brexit on farmers, and Professor MacMillan has been prominent in the debate about the future of farming. Professor Horton is an expert presenter and contributor to several documentaries including BBC's *Coast*, and Discovery Science's *What on Earth?*