Application of Science to Realise the Potential of the Agricultural Transition

A report on why Agriculture in the United Kingdom (UK) has lagged behind other nations in productivity and innovation and recommendations which would help the sector to develop solutions needed and move forward quickly to meet food security, carbon net-zero and biodiversity challenges.

Published at a breakfast briefing in the House of Lords, hosted by Lord Curry of Kirkharle on Wednesday, 23 November 2022.

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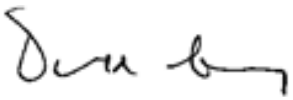
Preface

On the 24th February 2022 an online webinar was organised by Food and Farming Futures supported by Harper Adams University's School of Sustainable Food and Farming to explore how the application of science could be best delivered to ensure a just agricultural transition in the United Kingdom (UK) in response to the Agricultural Act 2020, climate change and the reality of a war in Europe. The webinar included leading authorities from academia, industry and policy with a full list of all attendees given in the Appendix. A key outcome of the webinar was the formation of a working group (see Appendix for full membership), selected to represent the sector, tasked to develop a report to make recommendations to UK policy makers and agricultural leaders on the application of science to realise the potential of the agricultural transition. The group met five times online with the aim to reach consensus on the key recommendations for achieving the desired outcome. Consensus was confirmed across most recommendations, although, members representing the Agri-Tech Centres recommended a closer working of the centres, rather than a single management structure.

Lord Curry of Kirkharle – Food and Farming Futures
(Chair of the working group)



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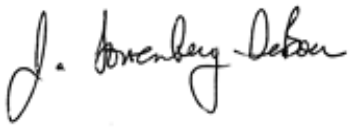

Application of Science to Realise the Potential of the Agricultural Transition

Executive Summary

The objective of the Application of Science to Realise the Potential of the Agricultural Transition working group (see appendix for the full participant list) was to explore why the United Kingdom (UK) has lagged behind other nations in productivity and innovation.

The group concluded that a key factor is fragmentation at all stages in the delivery of scientific knowledge which is impacting the sector's ability to advance agricultural production, achieve carbon net-zero and enhance other sustainability parameters (e.g. biodiversity, animal welfare, 'rural levelling-up'). This document is a synthesis of the group's discussions intended primarily for an audience of UK policy makers and agricultural leaders.

A summary of the recommendations:

1) Food security should be considered by the UK government as a public good and included in the criteria for funding under the "public money for public goods" approach.

2) Additional Government funding should be allocated to agricultural extension and the delivery of scientific knowledge. This is justified because UK carbon net-zero goals are designed for the public good, due to the urgency imposed by climate change, the biodiversity crisis and food security.

3) To achieve food security, carbon net-zero and biodiversity goals, the agricultural sector must attract talent from throughout UK society.

4) Universities with strong local and regional agricultural interests should consider making farm level extension an explicit part of the job description and evaluation of some academic staff.

5) While in-person, facilitated peer-to-peer events at monitor/demonstration farms should continue to be an important part of the extension effort, the tools of interactive electronic communication should also be harnessed to help farmers in developing their knowledge.

6) National co-ordination of demonstration farms throughout the UK should be encouraged. These farms are currently managed within the ecosystems of various agricultural innovation and technology organisations.

7) The Government review of the Agri Tech Centres should consider establishing a single management structure to build on their shared vision, improve cross-sector working, achieve greater efficiencies and influence.

8) Government should establish a "What Works Centre" to streamline the evaluation and dissemination of agri-food research. To reduce fragmentation of the agricultural research and extension system, the centre should use a joined-up approach to coordinate closely with all parts of the UK agricultural research and extension system.

9) Agricultural research funding should include stronger support for collaborative, problem-solving science and extension requirements. These requirements could be fulfilled by the research funding recipient or partner organisations.

Conclusion

The UK agri-food sector is facing unparalleled challenges created by the confluence of climate change, food security concerns, and the farm policy/trade changes linked to Brexit.

To respond to these challenges UK farmers and agribusinesses need access to the latest science and technology, but evidence shows that the UK lags behind comparable high-income countries in effective agricultural technology use.

The recommendations from this working group are intended to speed technology development and adoption by reducing fragmentation and increasing coordination of extension organisations.

Without these changes the UK agri-food sector will continue to lag behind on agricultural productivity and innovation.

Introduction

The United Kingdom (UK) has many opportunities and challenges in the 21st Century, but the challenges and opportunities of maintaining food security while reducing the environmental impact of farming and transitioning agriculture towards a carbon net-zero sector, within wider aspects of sustainability (biodiversity, animal welfare, rural justice), are among the greatest.

Adding to the challenges and to the opportunities is the transition in government agricultural and trade policy post-Brexit, transitioning from subsidising rural stability to the payment for generation of public goods and productivity stimulations. Addressing these challenges and seizing these opportunities will inevitably require science, technology and innovation, as well as changes in consumer mindset.

By Nobel Prizes awarded, scientific papers published and many other measures, the UK has some of the most creative and productive basic scientists on earth, but it has lagged in application of science to realise agricultural production. One indicator of this lag is UK annual growth of agricultural Total Factor Productivity (TFP) of only 0.8% in the 2001-2012 period; less than half the growth rates in Germany, France and the USA during the same period (NFU, 2022).

More recent data from the United States Department of Agriculture (USDA) suggests that this lower UK agricultural TFP growth is persisting (USDA, 2022). Boosting the application of science in agriculture would help achieve the UK government's goals of becoming a nation of innovators, connecting basic science with the domestic economy (UK BIS, 2013, Freeman, 2022).

The objective of the Application of Science to Realise the Potential of the Agricultural Transition working group (see appendix for the full participant list) was to propose changes in government, industry and non-profit organisation strategies and structures to increase the application of science to advance agricultural production, achieve carbon net-zero and enhance wider sustainability parameters (biodiversity, animal welfare, 'rural levelling-up'). This document is a synthesis of the group's discussions intended primarily for an audience of UK policy makers and agricultural leaders.

Background

Around the world, the links in the agricultural science to farm application continuum that move from fundamental science to well-proven applied science at the farm level are grouped under several names. In the USA, and many other countries, the term "extension" is often used. Extension is historically associated with assistance to farm practice and provided by the public sector.

Extension is characterised by a multifaceted flow of information in which the "extension agent" was not only a mechanism for information and related technology to flow to farmers, but also a conduit for farmer concerns and experience to flow back to researchers, entrepreneurs and regulators. Elsewhere those links in the science-innovation process may be called "farm advisory services," "outreach," "adult education" or "knowledge exchange (KE)". In places where those activities have been privatised they may be called "farm consultants". For embodied technologies that involve the farmer buying a machine or an input, company marketing and sales personnel often provide information that affect technology choices, with the obvious risk of bias.

In recognition of the public good aspects of farm innovation and the non-linear nature of the relationship, this document will use the term "extension". In the UK the flow of agricultural science knowledge from research to the farm level is fragmented. No one institution or group of institutions is responsible for extension (Figure 1).

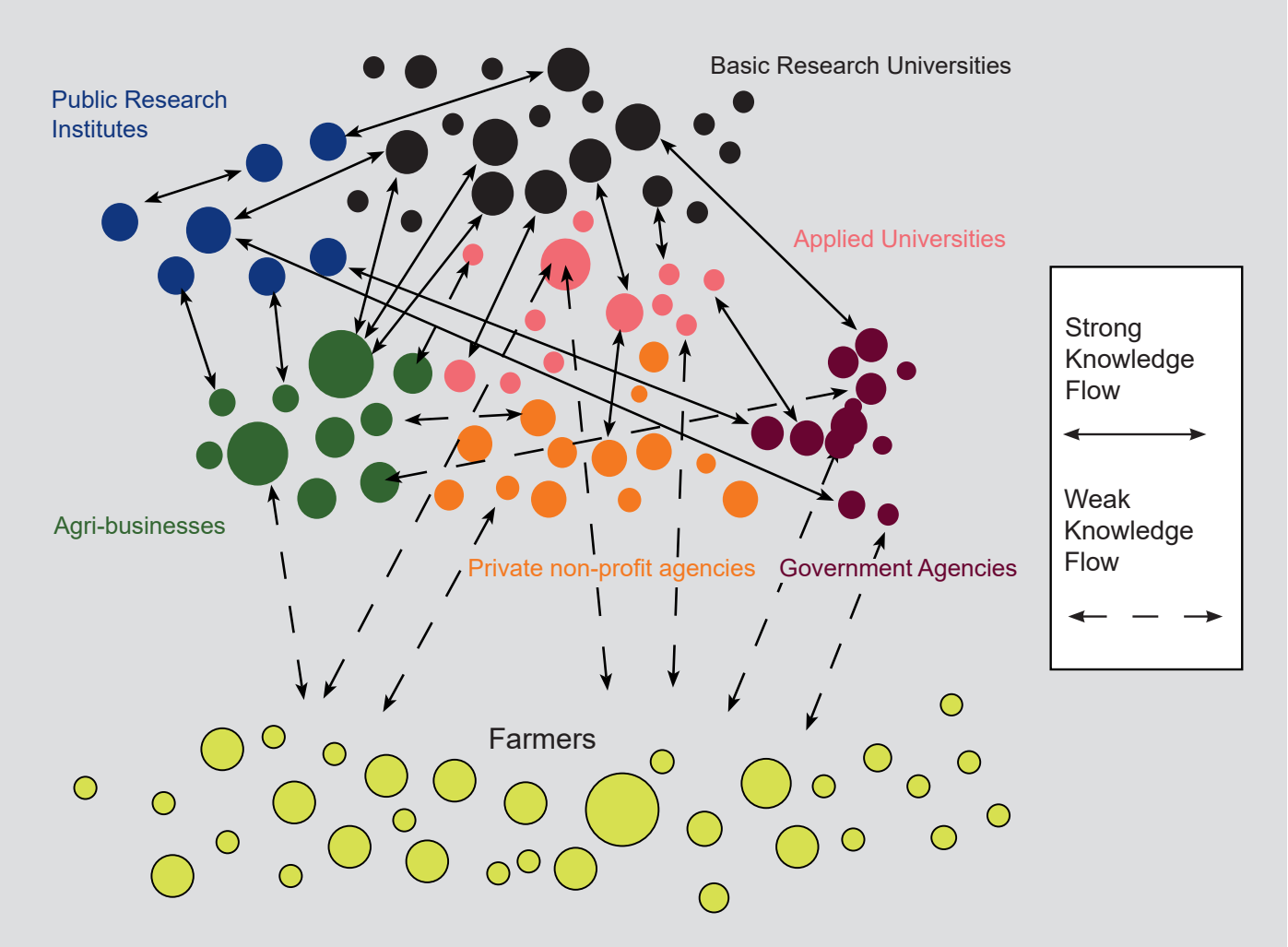

Figure 1. Current UK Flow of Agricultural Science Knowledge

In addressing these challenges and seizing these opportunities it is important to remember the context. The UK is located on some relatively crowded islands in the north Atlantic and is blessed with a mild climate, adequate rainfall and some good soils, albeit with some climate-change-induced challenges (and opportunities) predicted.

The UK is the birth place of industrialisation and has long relied on imports to maintain affordability of food supply to the urban population. In the past some of the most successful British exports were agricultural technology used to improve productivity in some of those food exporting nations.

A historical example of this technology export success was the Massey Ferguson 35 tractor designed in the UK, originally built in Coventry in the 1950s and 1960s, exported worldwide and later licensed for manufacturing in Turkey, India, and Pakistan. Currently the UK exports more than £1.12 billion worth of tractors and £480 million of agricultural machinery each year.

While the interest of the urban population in food and how it is produced is growing in the UK, at the current time most of that urban population is disconnected from farming and from what is practically possible given the British climate, soils and economic system.

Changing lifestyles and dietary tastes means that most of that urban population is comfortable with the dependency on imported food supply that does not reflect seasonality.

Britain is still adapting to being a post-industrial society which brings a different set of opportunities and challenges including an everchanging technological landscape and is fully connected to the global economy complete with all of its economic shocks. In the context of that transition, the chances for substantial increases in public funding for agricultural research and

extension are challenging. The UK has proved to be a difficult environment in which to make substantial structural adjustments that would improve the flow of science and innovation to farming practice.

Given that context, the aspiration of the working group is to help create a UK agriculture system that provides affordable food security to its people. In concert, we also need to reduce the carbon footprint of farming, enhance biodiversity, maintain animal welfare, generate specialised food products for export and develop technology that can be profitably sold elsewhere in the world whilst providing attractive, rewarding and recognised careers in the UK.

The more immediate objective is to identify potential strategies to improve the agricultural science role in realising the potential of the transition to a post-Brexit aspirational carbon net-zero farming agricultural policy within wider sustainability parameters. This report will identify main areas of agreement among working group participants with recommendations that point to a way forward.

Agriculture and the Public Good:

- Food security is a public good. According to the United Nations (UN) Food and Agriculture Organisation (FAO) food security exists when all people, at all times, have physical, social and economic access to sufficient, safe and nutritious food which meets their dietary needs and food preferences for an active and healthy life (FAO, 1996). The recent food price increases linked to the Russian invasion of Ukraine and the empty shelves early in the COVID pandemic are recent reminders of the fragility of our interconnected food system. A brief review of history provides other examples. World War II era food rationing persisted in the UK until the mid-1950s. There were also food shortages in the UK due to the German blockade of shipping in World War I.

  Food security is not the same as food supply. Food itself is a private good, but food security is more about the sense that there will be enough food. That sense of food insecurity changes behaviour.

  A recent example is the role of food shortages and dramatic price increases in the political turmoil and regime change during the Arab Spring of 2010-2011. Food insecure people are often anxious, tense and angry. They may hoard food or prevent access by others. In a food secure society, the sense of food security felt by one person does not diminish the food security of another. A society is food secure together. A well-fed individual in the midst of hungry people will suffer the effects of their food insecurity.

- It is in the public interest to reduce carbon emissions, and associated greenhouse gases (GHG) (e.g. nitrous oxide), released into the atmosphere by all sectors of the economy. The UK has legislated the goal of reducing GHG to net-zero carbon (when converted to carbon dioxide equivalents) by 2050 and set out a general research and innovation plan to achieve that goal (UK BEIS, 2021). Reducing the carbon footprint of UK agriculture will require major changes in farming practices as well as changes to the population's consumption and levels of waste. The "moonshot" of transforming agriculture demands science and technology that has not yet been developed. Accomplishing this transformation while building food supply resilience, maintaining animal welfare and enhancing biodiversity will be even more difficult. This transformation would be a challenge even for a well-functioning agricultural research and extension system. It is not clear that the current UK system is up to the task.

  Too often carbon reduction and sequestration technologies are proposed and developed without an in-depth understanding of farm economics and physical conditions. In the UK, agriculture's

role in GHG reduction is too often seen in the form of removing land from food production (e.g. solar farms, tree planting, peat bog restoration) or by the shrinkage of the livestock sector (especially the ruminant sector), thereby exacerbating food insecurity and food sovereignty issues, which could seriously undermine the UK government's levelling up agenda in rural communities centred around grassland agriculture. After years of EU subsidies, many UK farmers have well-practiced skills in dealing with bureaucracy, but the business skills needed to handle that transition and manage the new technologies need developing to give the farmers the confidence to deliver on this agenda.

- Public interest requires action. In the UK there have been many committees, working groups, programmes, studies, white papers and reports with the aim of optimising agricultural science and extension (e.g. Thirtle et al. 2004, Commercial Farmers Group Statement, 2008; Leaver 2010, Dimbleby, 2021). Global Food Security (GFS) is a UK cross-government program with the mandate to coordinate scientific research on food security (https://www.foodsecurity.ac.uk/about/).
  Simultaneous with this Application of Science working group is the Centre for Effective Innovation in Agriculture (CEIA) research strategy study for the Agricultural Universities Council (AUC) that complements the working group's focus on the organisational responsibilities for increasing application of science on farms. Even in the ideal circumstances, research and innovation are creative processes that can be guided, but not micromanaged.
- The change in agricultural policy and trade brought about by Brexit will require major adjustments in how UK farmers do business above and beyond those required by climate change, shifts in consumer preferences, disruptions due to the Ukraine War and other farm business developments. The major UK policy change is the shift from the European Union (EU) style Basic Payment Scheme (BPS) to paying farmers for the production of public goods. So far, those public goods have been thought of mainly in terms of environmental services and climate change mitigation, but food security and food sovereignty must be included in this list of public goods eligible for support.
  The physical impacts of climate change (e.g. temperatures, rainfall, variability) and the policy response to climate change (e.g. push for net-zero) will require major adjustments in farm businesses even if Brexit had not. These changes will require a change in farm mindset and management approach, as well as a change in farming practices. Farm management for profit from providing food and environmental services is quite different from farming to attract the BPS.
- The UK agricultural sector must be responsive to consumer trends, dietary preferences and the taxpayer's interest. Agricultural science and extension should help the public and agencies/organisations that work with the public to better understand food systems and farming alternatives, and assist the farming sector in responding to the resulting well-informed demands. For example, if UK consumers want more plant-based protein options, agricultural research, innovation and extension should help farmers supply the grain legumes, tree nuts and other plant-based proteins, as well as providing information on the nutritional, environmental and climate impacts of plant-based proteins and the comparative informed value (environmental, social and economic) of other protein sources (terrestrial livestock, aquaculture, myco-protein, lab-based protein etc.). If UK taxpayers want more biodiversity in rural areas, then research and extension can help develop and demonstrate techniques that farmers can use to increase habitat for non-domesticated species of plants and animals, while simultaneously maintaining food security.
- The public good requires a more unified response by the agricultural sector. Many of the previous studies, white papers and reports have pointed out that UK agricultural research and extension is too fragmented. Too many public and private organisations are competing for limited resources.
  The communication among funders, researchers, entrepreneurs and extension is not good. Should thought be given to

manage rationalisation of these entities or at least their remits in an "over-supplied" agricultural science and extension market? This fragmentation is in contrast to a country like the Netherlands, where Wageningen University is the "front door" for agricultural research and extension. Most publicly funded agricultural research in the Netherlands has a link to Wageningen and much of the agribusiness research and development (R&D) does as well.

The regional differences in UK agriculture (e.g. broadacre arable crops in East Anglia, intensive horticulture in Lincolnshire and parts of southern England, extensive grazing in North Wales and Scotland) do not lend themselves to focusing agricultural research and extension on a single institution, but may be amenable to more flexible forms of coordination among regional entities. For example, the wide diversity of US agriculture is accommodated in a system of state "Land Grant" universities, regional Agricultural Research Service (ARS) research stations and a variety of private organisations, loosely coordinated by the US Department of Agriculture (USDA). That coordination is made effective through several mechanisms, including centrally allocated funding (e.g. National Institute for Food and Agriculture (NIFA)), regional research and extension committees that encourage communication and collaboration on specific topics across state line, and periodic reviews of university departments and other units. It is possible to imagine a similar system functioning across the devolved nations and regions of the UK. Both the US and Netherlands' systems for agricultural research have been effective for their agricultural contexts. The UK critically needs to find an effective approach with less fragmentation.

Challenges for rapid agricultural technology adoption:

- Social and cultural resistance to change can slow down agricultural technology adoption. Studies of agricultural technology adoption worldwide indicate that in the long run, farm level benefits are the strongest determinant of widespread adoption. Those benefits are most often monetary, but could also be in terms of more flexible working arrangements, reduced drudgery, lifestyle improvements, better family nutrition, etc. For example, milking robots have been widely adopted in northern Europe even though studies suggest that the average profitability improvement linked to this technology is modest, but farmers often cite the more flexible working schedule as being the key benefit. It allows them to spend more time with their families and in community activities. Studies of agricultural technology adoption indicate that social, structural and cultural factors can play a major role in the speed of adoption over the short to intermediate term (i.e. 1 to 10 years). The key social, structural and cultural factors include: educational level of farmers, age, farm size, access to credit, land tenure and neighbourhood opinions about the technology.
- For technologies that have substantial farm level benefits, extension can play a major role in facilitating quicker adoption. Given the fact that many of the agricultural carbon emissions and wider GHG reduction technologies are still in the research and development phase, achieving the National Farmers Union (NFU) ambition of agriculture net-zero by 2040 and the UK government goal of net-zero in all sectors by 2050 will require rapid adoption once the technology is proven. Farmers will need to identify which technologies are appropriate for their farms and manage the transition. Extension can help them learn new skills and make that transition more quickly and more successfully.
- In the short-term lack of information about technology can slow adoption. This is the implicit hypothesis behind the many knowledge transfer efforts in the UK [e.g. Farmers Weekly Learning Centre, Soil Association Exchange, National Libraries for Agri-Food, Agricultural Development and Advisory Service (ADAS) Farm Performance Enhancement Program (PEP), Farm and Food Education (FarmED), the School of Sustainable Food and Farming (SSFF) and many more]. It is also behind the concept of a "What Works Centre" to review and

organise evidence about new technology. Studies in industrialised countries indicate that lack of information can be an adoption constraint in the short-term, but in the longer-term many farmers are relatively well informed about new technology. They may not know everything about the technology, but they often know enough to understand whether it would be beneficial on their farm. They have many sources of information (e.g. farm media, research field days, farm shows, research and commercial sites on the internet, agronomists, vets, the experience of their family and neighbours).

When a technology has been commercially available for a decade or more, but has not been uniformly adopted, a common hypothesis is that farmers have not found it sufficiently beneficial to justify the investment, time and effort needed to make the change. For example, variable rate fertiliser technology has been commercialised in industrialised countries since the 1990s but, to the chagrin of environmentalists, overall adoption is quite modest. Evidence suggests in most applications the profitability of variable rate fertiliser is not consistent and this explains why adoption has been lacklustre. Niche uses (e.g. variable rate nitrogen on sugar beets, variable rate lime on soils with high pH variability), where profitability is quite reliable, have seen much higher adoption levels. If the basic science in the UK is strong and lack of information is not the problem, the alternative is that the weak link is knowledge application and getting the right knowledge to the relevant people in a timely manner.

Changing roles in agri-tech adoption:

- The National Library for Agri-Food is being developed in the UK to serve agri-food practitioners and students across the UK by providing access to recent, high quality, science-evidenced information and guidance in an online repository with good metadata standards for easy searching and robust perma-links to content. The concept is built on similar libraries and access tools serving other sectors for example health professionals have the Cochrane Library and PubMed, veterinarians have the RCVS Knowledge library, surveyors have the RICS library. In America there is the USDA's National Agricultural Library and the Institute of Electrical and Electronics Engineers' (IEEE) Xplore for their sectors. These repositories are quality assured sources of practical information, advisory notices; open learning resources and syntheses of new knowledge.

  The National Library for Agri-Food seeks to develop and deliver:

  1) An independent place with transparent governance and competent oversight where quality-vetted grey literature, advisory notices and research papers are held in collections appropriate to the agri-food sectors in the devolved nations of the UK;

  2) a large and competent repository of actual documents (mostly PDF files), videos and other electronic media files, rather than links to documents held elsewhere through often ephemeral internet links;

  3) a place where agri-food research and knowledge exchange organisations choose to submit their branded documents for deposit in addition to depositing them on their own web sites;

  4) a place where systematic review for agri-food could lay foundations and that social media can use to draw wider attention and discussion on content.

- Well qualified, highly motivated young people from all segments of society are needed to speed technology adoption in UK agriculture, but careers in the agriculture sector are seldom attractive to UK young people outside of farming communities. The Agri-Food Industry Workforce Skills and Development Strategy (Swadling, 2018) documented that in agriculture production the level of qualifications is low, there is poor uptake of professional development and less than 35% of UK farmers have any formal management training. A 2022 study supported by The Institute for Agriculture

and Horticulture (TIAH) found that outside of farming families and communities there is low awareness of opportunities in agriculture, that the perception of UK agriculture is dated (e.g. long hours of hard physical work for low wages, entry mainly by inheritance, lacks diversity) and that with more complete information, enthusiasm for agriculture careers increases (Family Kids & Youth, 2022).

For agricultural research and extension, the Biotechnology and Biological Sciences Research Council (BBSRC) and Medical Research Council (MRC) review of vulnerable skills and capabilities in 2017 identified looming shortages in agricultural science, particularly in plant based and field studies. Traditionally the agriculture sector has relied on recruiting from among those who grew up on or around farms, but that is a shrinking pool. Most UK young people have no direct knowledge of agriculture. Instead of seeing opportunities to use the latest technology to feed the world, most think of agriculture as low paid drudgery in a social environment dominated by hereditary privilege.
For those who grew up outside the farming sector, there is no clear career path into agriculture and primary food production but better awareness can lead to change. TIAH and education providers such as SSFF are working to provide a professional framework and support to production agriculture and encourage lifelong learning, but much remains to be done. In agricultural science, opportunities in the UK for post-graduate training and early career mentoring are diminishing as senior agricultural professionals retire and are not replaced (BBSRC, 2017). Many of the UK agricultural scientists work outside the UK because of higher salaries and greater funding opportunities.

If food security and the agricultural role in enhancing biodiversity, maintaining animal welfare, and mitigating climate change is a national priority, then it is important to provide training, and create attractive career opportunities for up and coming farmers, agribusiness staff, food processing and marketing personnel, scientists and extension professionals.

- Worldwide higher education institutions (HEIs) play a major role in agricultural knowledge exchange and extension. The UK has historically had an agricultural science system with a modest role for HEIs (see Table1 from Heisey and Fuglie 2018 below). The table shows that countries of all HEI involvement levels have had successful agricultural technology development

	Small < $100 million	Intermediate $100-$499 million	Large $500 million - $999 million	Very large ≥ $1 billion
Government-oriented < 1/3 public research performed by higher education institutions	Israel Slovak Republic Greece Luxembourg	Norway Finland New Zealand Ireland	Spain United Kingdom	Japan France
Mixed 1/3 to 2/3 public research performed by higher education institutions	Iceland	Poland Switzerland Austria Portugal Czech Republic Hungary	Spain United Kingdom	Japan France
University-oriented >2/3 public research performed by higher education institutions	Slovenia Estonia	Belgium Denmark Sweden		United States

Table 1: Public research expenditures and some features of public research organisation, by country. Modified from Heisey and Fuglie, 2018.

and adoption, but extension history suggests that if one were to start the development of an agricultural research and extension system from scratch (e.g. on that proverbial uninhabited island or new planet), the starting point would probably be a system which combines agricultural education, research and extension in the same institution. This is because of the enormous synergies which are created when the teachers, researchers and extension personnel work within the same incentive structure and "rub shoulders" daily. In that case, the material taught in the classroom more easily reflects the technology in the pipeline and the farm level realities of extension (and vice versa), than if each of those functions were in a separate organisation.

In most integrated agricultural HEIs these functions not only exist in the same institution, but are exercised by at least some of the same individuals (e.g. a professor might have teaching, research and extension duties).

However, history suggests that it is difficult to superimpose an integrated education-research-extension structure on pre-existing agricultural science institutions. In particular, these institutions must have hiring, evaluation and promotion systems that reflect their tripartite mission.

The most successful integrated agricultural education-research- extension HEI systems (i.e. USA, India) were new universities built from scratch. The US Agency for International Development (USAID) spent millions of dollars in the 1960s, 70s and 80s trying to build integrated agricultural universities in developing countries and at most was partially successful in a few. In most developing country cases, the pre-existing agricultural science institutions resisted integration into these new HEIs and the hiring/evaluation/promotion practices of the new universities continued to reflect historical scholarly preoccupations. However, it is not obvious that the best strategy with pre-existing universities and agricultural science institutions is to increase the role of HEIs, but it may be possible to reinforce the existing outreach and extension functions that exist at some UK agricultural universities to cover the breadth of UK farming typologies and devolved administrations. Scotland's Rural University College (SRUC) has an integrated education/research/extension approach and other agricultural universities across the devolved nations (e.g. Harper Adams University, Aberystwyth University and Queens University Belfast) have outreach efforts. Additionally, given the aforementioned competition for resources and "over-supply" in the academic sector, what HEI (focus activity) rationalisation strategy could allow additional extension functions to be delivered within limited resource ceilings?

- The UK needs a more coordinated, collaborative response to agricultural research and extension. The Netherlands solution of concentrating the funding and responsibility in one institution (i.e. like Wageningen University) is unlikely to work in the UK for reasons mentioned earlier. UK agriculture is much more diverse than that of the Netherlands. The agro-ecological potential of a farm in Norfolk is quite different from that of a farm in Cornwall and even more different from a farm in the highlands of Scotland. In contrast, the agro-ecological potential of most Dutch farms are more similar to each other.

  Even before the Netherlands' agricultural education and research reforms in the 1990s, much of their national agricultural science capacity was linked to Wageningen. For historical and agroecological reasons, the UK currently has agricultural science expertise spread over a broader range of institutions. While there are differences among the devolved nations, among the current UK agricultural science institutions (e.g. AHDB, various universities -specialist and cosmopolitan - various former BBSRC research institutes, Agri-Tech Centres), none seem to have the capacity to manage a research and extension system of this complexity. The Netherlands seems to have found an agricultural science and extension solution that fits their opportunities and constraints. The UK needs to find a structure for agricultural science and extension that fits its opportunities and constraints.

- The role of the Agri-Tech Centres in bringing new science and technology to UK farms should be revisited. Their initial tranche of public funding is coming to an end and they are being evaluated by the primary sponsors to determine what their role would be in the current and future challenges of agri-tech and agriculture.

  The Agri-Tech Centres have formed major partnerships across the food system with industry and academia to develop new agricultural technology and by doing so played a significant role in achieving the original intent to help "business develop, adopt and exploit new agricultural technologies and processes" (UK Industrial Strategy for Agricultural Technologies 2013; Agri-Tech Centres, 2013). With the £120 million invested by the UK government, as of March 2022, they have created over 55 leading edge assets in all regions of the UK, attracted £43 million in matching funds from commercial and research partners, and implemented over 500 projects with a worth of £99 million to the agri-food sector (https://www.agritechcentres.com/impact). Over 280 new jobs have been created, mostly in project partner organisations, and they have connected more than 430 organisations including farmers. The Agri-Tech Centres working with their academic partners have succeeded in generating commercial benefits for the companies involved and are projected to return over £13 to the Exchequer for every £1 spent on the Centres.

  It is time for the four Agri-Tech Centres to go beyond the "one vision" proclaimed on their website (www.agritechcentres.com/about).

  The current review of the Centres should consider a single management structure to better achieve a future vision for the application of science to realise the potential of the agricultural transition. This should deliver efficiencies; better cross sector working, and establish a body with greater influence.

- The Agricultural Productivity Taskforce, within the Food and Drink Sector Council has been exploring the concept of a 'What Works Centre' for agriculture. This was reinforced by Henry Dimbleby in his Food Strategy Report. The 'What Works Centre' would cover all of agriculture, including horticulture, potatoes, peas, poultry and other farm products that are not currently covered by levy funding.

  The following statement has been provided by AHDB for this report:

  "In its Food Strategy the UK government is committed to working with the agriculture sector to develop a 'What Works Centre' (United Kingdom Secretary of State for Environment, Food and Rural Affairs (2022), but the structure, organisation and funding of that centre has not been determined. AHDB has been tasked by Government to work with the industry to develop a proposal that could avoid further duplication and lead to better alignment and connection between research, extension and farmers, driven by farmers' needs. If UK agricultural research and extension is already too fragmented, a 'What Works Centre' initially co-ordinated by AHDB would avoid creating yet another organisation. A 'What Works Centre' needs to be a cross industry initiative that depends on collaboration and AHDB's role would be as co-ordinator and facilitator. AHDB will be establishing a governance structure including current key participants in this arena to develop and oversee pilots, building on the good works of others. The 'What Works Centre', if successful, will provide greater connection between farmers and researchers and greater alignment amongst the diverse set of organisations that make up UK agricultural research & KE, leading to faster uptake of best practice on farm, increasing the profitability, sustainability, and resilience of farming.

- TIAH's Online Service has been designed to streamline farmers' access to Continuous Professional Development (CPD) opportunities. It will give individuals a personalised experience by learning about them through the content they visit on the site and recommending additional, relevant content that similar farmers have engaged with and rated. It will also allow them to browse CPD categorised by TIAH's Professional Framework of competencies relevant to job roles. Personalisation will allow TIAH to actively push out relevant content related to changes in policy and

legislation. All user interactions with training and CPD are recorded by the system, therefore evidence of training availability, uptake and impact could be fed into a 'What Works Centre'. This would support a 'What Works Centre' in enabling farmers to better understand how they can improve their knowledge and businesses.

- The allocation of public funds in the UK agricultural research system is complex and largely directed by competitive grant processes (Figure 2).

  But are competitive grants the best approach to research funding allocation?

  Competitive grants have at least two draw backs: 1) they tend to be conservative because the reviewers and selection panels are inclined to pick safe research that they are confident will succeed and be socially/politically acceptable; and 2) competitive grants favour organisations that invest in grantsmanship. Large philanthropic organisations (e.g. Gates Foundation) often have a targeted grant process for a major portion of their portfolio or use competition only for an initial screening. The targeted grant process requires more staff time and expertise by the funding body than competitive grants, and thus is difficult for public agencies to implement. In the UK could public funds be allocated through a "mission level" targeting interaction between funder and researcher? There are certain legal and governance issues that would need to be resolved (e.g. open bidding requirements for allocation of public funds) but framework agreements perhaps provide a template from which to start a collaborative mission-based approach.

  Another alternative is to outsource that funding allocation process to educational-research-extension institutions for extension focused activities (innovation itself has a wider pool of initiation around private sector and supply chain/end users). For example, in the US a major portion of the federal funding for the agricultural universities is in the form of formula funds based on the number of farms and other demographic characteristics of the state. Those formula funds were flexible resources that played key roles in developing agricultural technologies specific for the state involved.

- The formation of the cross UK Research and Innovation (UKRI) council Global Food Security Programme, has been broadly welcomed by the scientific community to prioritise agri-food investments through collaborative 'large' grant submissions (e.g. the £47.5M Transforming UK Food Systems call).

  Traditionally in the UK, fundamental agri-food research has been predominately supported by two councils: BBSRC and National Environmental Research Council (NERC), with a risk of innovative research falling between these two council's remits. Within BBSRC, the leading funder, agri-food projects also often fall between research committees' remits. Even within committees, strong competition with more fundamental discovery biological research orientated projects, would frequently out-score discovery agricultural related research projects within the current academic focused composition of committees (e.g. within committee B cellular systems research versus farm systems research). Accommodation of food system representation on committees would go a long way to focusing strategic research priorities.

  There is an obvious need for continued cross council support of agri-food research focused on problem solving science and within BBSRC the potential of an agri-food focused committee. Collaborative research calls with expression of interest stages which, post initial screening, could be combined to form fewer-larger collaborative team bids would be greatly welcomed to reduce wasted academic time on failed research bid writing. Recent examples include the UKRI's Network+ bids which encouraged initial consortium submissions, at the expression of interest stage, to merge to reduce competition and improve the collaborative nature of the eventual successful bid.

  Agri-food research is, by its very definition, industry aligned and therefore a greater emphasis should be on food system-industry-academic collaborative

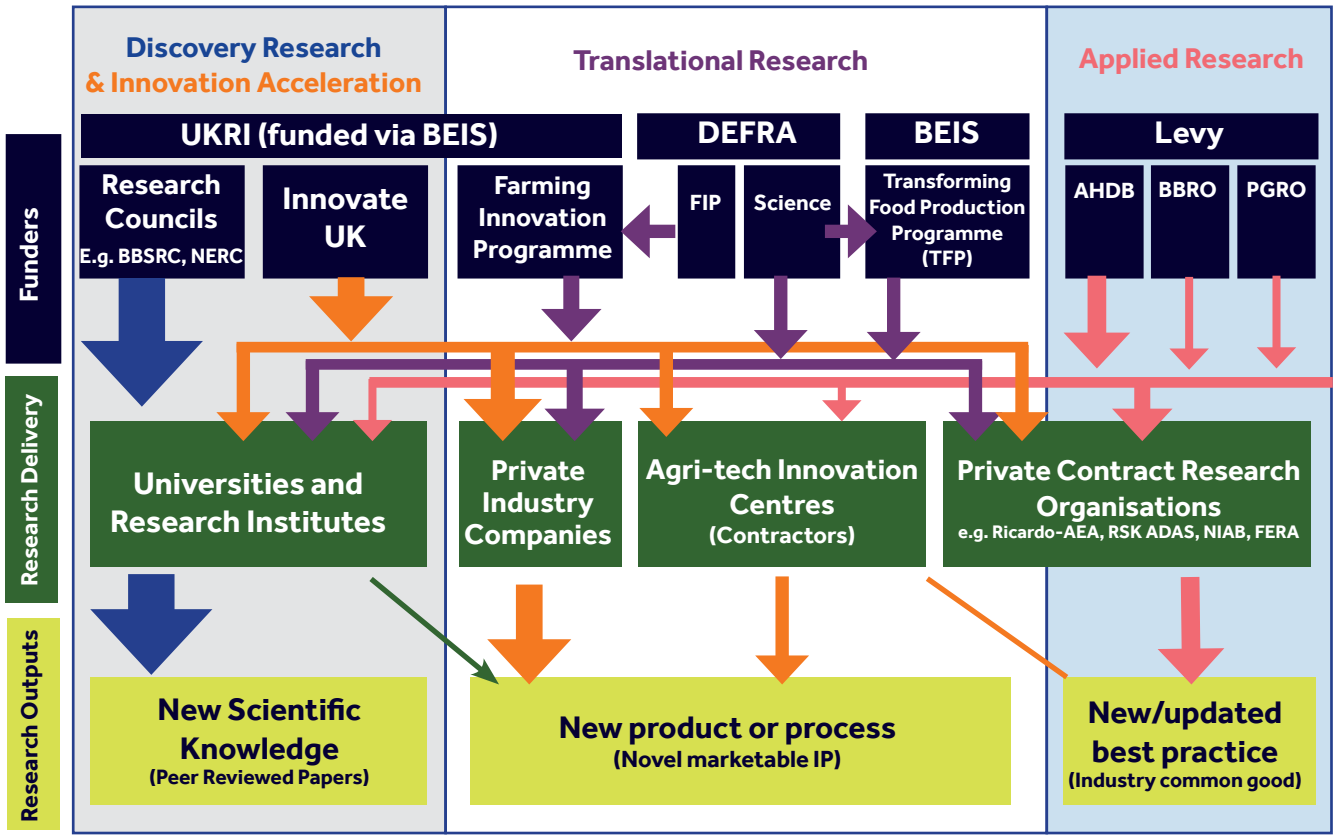

Figure 2 – Current major flows of UK public money through the agricultural research system. The size of the arrow illustrates the magnitude of the financial flow. (Source – AHDB)

competitions such as LINK programmes (see below). Although, positive steps have been taken by Innovate UK and DEFRA, with their Farming Innovation Programme (FIP) farmer led projects at the more applied level of innovation and adoption, much more is needed to ensure a continual pipe-line of problem solving and application science for agri-food.

- Farmers must be involved in the extension process. In the UK, lip service is often given to the "farmer led" model of agricultural innovation, but in practice the linear technology transfer model is most commonly used and widely accepted by farmers, researchers, agribusiness, and consultants.

  In practice it has been quite difficult for UK farmer feedback to get back to researchers and technology developers. There has been some success in this area with the Satellite Farm Network of the Agri-EPI Agri-Tech Centre and with not-for-profit groups engaging specific groups of farmers in technology development, assessment and adoption, for example, the Innovative Farmers group organised by the Soil Association (https://www.soilassociation.org/farmers-growers/innovative-farming/). Among publicly supported efforts, the DEFRA and BBSRC "LINK" programmes which operated from about 1990 to 2009 were seen as largely successful by many stakeholders in commercial agriculture (UK House of Commons, 2010). In LINK programmes research concepts would be developed by an agricultural industry consortium and implemented by teams including university and other public sector researchers. The LINK programmes, with direct farmer and agribusiness involvement in planning and managing research, were ended when funding was moved to the Technology Strategy Board (TSB) which was later renamed INNOVATE UK. The recently launched FIP (UK DEFRA, 2022) attempts to bridge the innovator–farmer gap with funding for farmer initiated/scientist supported research, but it is too early to determine if FIP will be successful. An integrated education-research-extension HEI, already better established in Scotland and Northern Ireland than in England and Wales, could

help develop a system with better feedback mechanisms, but as noted above that option has its own constraints, and exemplifies the need for a connected 'What Works Centre', where findings of research can be translated and disseminated.

- While acknowledging UK budget constraints and other domestic and international challenges the Government should consider an increase in the public budget for agricultural research, development and innovation, as well as extension. An increase in funds is justified based on the renewed importance of food security as a public good, the role of nutrition in health, and the ever increasing environmental and climate threats.

  The Dimbleby report urges an investment of £1 billion to respond to food and nutrition challenges, including substantial increases in agricultural research funding. Increased funding, combined with a unilaterally supported and integrated strategy, to improve dissemination and uptake of KE would help the sector to develop solutions needed and move forward quickly to meet food security, carbon net-zero and biodiversity challenges.

Recommendations:

1) Food security should be considered by the UK government as a public good and included in the "public money for public goods" approach.
2) Because UK carbon net-zero goals are designed for the public good, in light of the urgency of the UK net-zero goals (in response to rapidly progressing climate change) and the biodiversity crisis, and due to the seriousness of food security, additional Government funding should be allocated to extension and the delivery of scientific knowledge.
3) To achieve food security, carbon net-zero and biodiversity goals, the agricultural sector needs talent from throughout UK society. Food systems education should be incorporated into the primary and secondary school curriculum and career advisors should be informed about opportunities in the food and agricultural sector.
4) While integrated education-research-extension universities are unlikely to become the dominant agricultural research and extension approach in the UK any time soon, universities with strong local and regional agricultural and related interests should consider making farm level extension an explicit part of the job description and evaluation of some staff. Continuous professional development (CPD) including agri-tech should be required of extension staff. Government or other funding needs to be identified for specific universities to be able to appropriate staff to undertake extension.
5) While in person facilitated events at monitor/demonstration farms should continue to be an important part of the extension effort, the tools of interactive electronic communication (e.g. podcasts, webinars, on-line discussion forums, social media) should be increasingly harnessed to support farmers in developing their knowledge. The online system being developed by TIAH is a concrete example of this approach as it will be able to personalise content and thereby be relevant and time efficient to farmers and growers. In person farm field days should be reserved for those more transformational technologies and management approaches that must be seen to be understood.
6) National co-ordination of demonstration farms throughout the UK should be encouraged. These are farms that are currently within the ecosystems of various bodies (e.g. AHDB Strategic and Monitor Farms, Farm PEP, Agri-EPI EPIC farms, SSFF, LEAF, etc). Their purpose is to encourage adoption of new knowledge and agri-tech solutions across the wide spectrum of UK farmers and producers. Their knowledge and experience should be shared and easily accessible, perhaps coordinated by the proposed 'What Works Centre'. Collaborative links should be developed with HEI farm-based assets, where earlier stage development activity can be efficiently translated.

7) The Innovate UK/DEFRA review of the Agri-Tech Centres should consider a single management structure to help advance their 'shared vision' and in doing so achieve greater efficiencies. A stronger and re-aligned capacity could deliver cross cutting priorities more effectively and be more influential in negotiations with both Government and Industry. The Agri-Tech Centres should work with the proposed 'What Works Centre' and other bodies to deliver the results of their work to farmers.

8) Government should establish the 'What Works Centre'. To reduce fragmentation of the agricultural research and extension system, the centre should be designed to coordinate closely with the Agri-Tech Centres, the National Libraries for Agri-Food, TIAH, the HEIs and other parts of the UK agricultural research and extension system. Appropriate public funding for both the Agri-Tech Centres and the 'What Works Centre' should be linked to a strong delivery component in collaboration with other agricultural extension partners. AHDB should conduct an annual review of communications among members of the agricultural research and innovation system, especially communication between researchers and farmers.

9) Discovery research funding for Agri-Food should be supported through a combination of cross council collaborative large consortium bids, such as GFS and industry-academia LINK schemes, with BBSRC considering a fifth Agri-Food committee to greater support success in fundamental problem-solving science. Agricultural research funding should include extension requirements which could be fulfilled by the research funding recipient or by partner organisations. The outputs of Agri-Food research, especially applied research, need better dissemination support through extension services and a central Agri-Food 'What Works Centre'.

Conclusion:

The UK agri-food sector is facing unparalleled challenges created by the confluence of climate change, food security concerns, and the farm policy/trade changes linked to Brexit. To respond to these challenges UK farmers and agribusinesses need access to the latest science and technology, but the track record indicates that the UK lags behind comparable high-income countries in effective agricultural technology use. The recommendations from this working group are intended to speed technology development and adoption by reducing fragmentation and increasing coordination of extension organisations facilitating communication and collaboration between researchers, entrepreneurs, agribusinesses and farmers (Figure 3). Without these changes the UK agri-food sector will continue to lag behind on agricultural productivity and innovation.

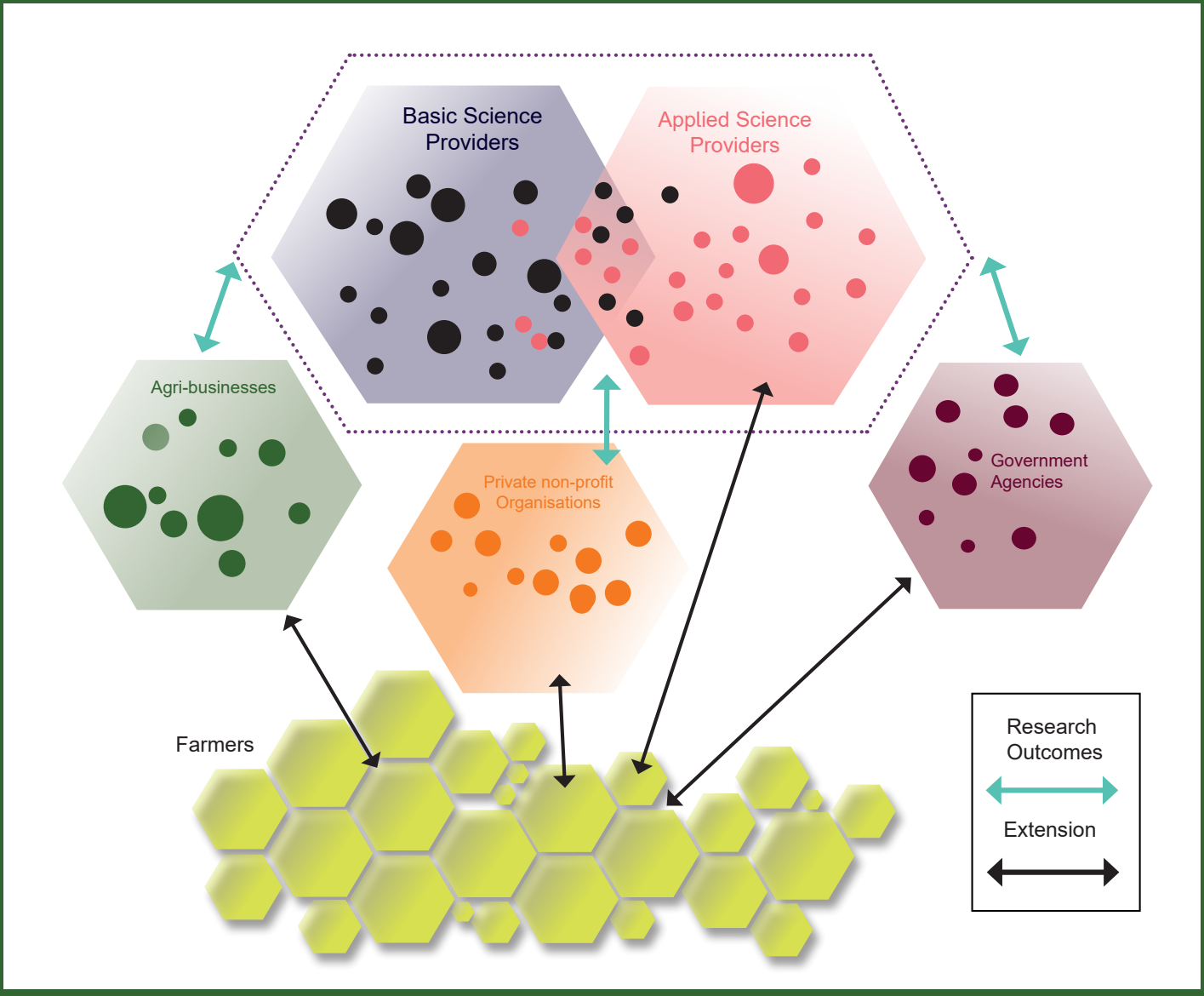

Figure 3. Future UK Flow of Agricultural Science Knowledge

Members of the initial webinar organised jointly by Food and Farming Futures and Harper Adams University's School of Sustainable Food and Farming held on 24th February 2022. (in alphabetical order by surname with affiliation).

Chair:
Lord Curry of Kirkharle - Food & Farming Futures

Speakers:
Tom Bradshaw – National Farmers Union
Rt Hon George Freeman MP. – The Department for Business, Energy and Industrial Strategy
Dr Justa Hopma – The National Libraries for Agri-Food
Dr David Kennedy – Department for Environment, Food and Rural Affairs (DEFRA)
Janet Swadling - The Institute for Agriculture and Horticulture
Professor Melanie Welham – UKRI Biotechnology and Biological Sciences Research Council

Attendees:
Professor Dawn Arnold – Harper Adams University
Dr Ruth Bastow – Centre for Crop Health and Protection (CHAP)
Professor Karl Behrandt – Harper Adams University
Chris Brown – Asda
Lyndsay Chapman – Centre for Innovation Excellence in Livestock (CIEL)
Professor Iain Donnison – Aberystwyth University
Stephane Durand – Queens University Belfast
Sarah Evered – Department for Environment, Food and Rural Affairs (DEFRA)
Chris Fellows – Agri Web Media
Dr Jonathan Foot – Agriculture and Horticulture Development Board (AHDB)
Professor Lynn Frewer – Newcastle University
Julian Gairdner – Map of Ag
John Giles – Genus Plc
Hetty Gittus – McDonalds UK & Ireland
Phillip Gready – Savills plc
Grace Hester – OSI Food Solutions
Nigel Hill – Harper Adams University
Rose Judeh-Elwell – Harper Adams University School of Sustainable Food and Farming
Professor Angela Karp – Rothamsted Research
Martin Kennedy – National Farmers Union Scotland
Dr Daniel Kindred – ADAS
Martin Lines – Nature Friendly Farming Network
Professor James Lowenberg-DeBoer – Harper Adams University
Katie Major – Dawn Meats
Roxanne Martin – Barclays - Agritech Eagle Labs
Oliver Mcintyre – Barclays Bank
Tim Mordan – Department for Environment, Food and Rural Affairs (DEFRA)
Rt Hon Neil Parrish MP – Member of Parliament
Becky Payne – Harper Adams University
Tony Pexton – Food & Farming Futures
James Leavesley – Leavesley Group
Professor Michael Lee – Harper Adams University School of Sustainable Food and Farming
John Mercer – National Farmers Union

Dr Kate Pressland – Royal Agricultural University
Professor Jo Price – Food & Farming Futures
Dave Ross – Agri EPI Centre
Matt Ryan – Oxbury Bank
Professor Nigel Scollan – Queens University Belfast
Professor Jonathan Statham – Raft Solutions
Dawn Teverson – LEAF (Linking Environment And Farming)
Simon Thelwell – Harper Adams University School of Sustainable Food and Farming
Sophie Throup – Wm Morrison Supermarkets Ltd
Jess Tomley – Wm Morrison Supermarkets Ltd
Dr Trisha Toop – Agri EPI Centre
Elizabeth Warham – Department for International Trade (DIT)
Amy Watkins – Agrii
Amanda Watson – Wm Morrison Supermarkets Ltd
Jack Watts – National Farmers Union
Alan Wilkinson – HSBC Bank plc
Karl Williams – FAI Farms
Professor Michael Winter – University of Exeter

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Dr Justa Hopma, Advisor – The National Libraries for Agri-Food
Martin Lines – Nature Friendly Farming Network
Tony Pexton – Food & Farming Futures
Dave Ross – Agri-EPI Centre
Professor Nigel Scollan, Director of The Institute for Global Food Security and Professor of Animal Science - Queen's University, Belfast
Janet Swadling, Chief Executive Officer – The Institute for Agriculture and Horticulture
Jack Watts – National Farmers Union
Professor Michael Winter OBE – University of Exeter

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