REPORT OF THE BBSRC WORKING GROUP ON SUSTAINABLE INTENSIFICATION OF AGRICULTURE

SUMMARY

This report presents the findings of a Working Group established by BBSRC's Food Security Strategy Advisory Panel (FS SAP) to advise on the Council's role in relation to the **sustainable intensification** (SI) of agriculture: **sustainably increasing the production of food** (or other agricultural products), combined **with improved resource use efficiency and better environmental** (and social and economic) **outcomes** (including animal welfare).

Delivering SI requires **balancing production** (and optimising inevitable trade-offs) **with maintenance of** the **natural capital** on which it **and other ecosystem services** depend - as distinct from increasing yield *per se* or just "growing more with less". There is a need for **equal and joint emphasis on "S" and "I"** in approaches to the use of land for agriculture in order to balance production with the other benefits it provides. Inherently holistic and **interdisciplinary**, this will require **systems approaches at appropriate scale**, as well as partnership working between BBSRC and others (Figure 1), and activities across the spectrum of basic, strategic and applied research and translation into practice (Figure 2). The optimisation of agricultural systems is not a matter only of technology, which needs to be considered alongside its environmental, economic and social dimensions.

The **background and context** are set out in a Foreword (1)[1] and introduction (2). The food and nutritional security of a growing population will depend on the management of demand as well as supply, and agriculture should not be considered in isolation from the use (and waste) of food or the effects on health of under- or (increasingly) over-nutrition: sustainable production, sustainable consumption and "sustainable nutrition" need to be viewed together as parts of an overall picture. The Sustainable Intensification Working Group (SIWG) had regard to those related issues, but focused on the sustainability of production to keep the scope of its task within reasonable bounds. Similarly, although aspects of BBSRC research relevant to SI will also have potential for application overseas, the Working Group considered it in a UK context, and did not address the particular requirements of developing countries.

The SIWG identified four **thematic areas** in which BBSRC could contribute to SI:

- **defining and measuring sustainability** - including the needs for "outcome-based" as distinct from "action-based" metrics, multidimensional criteria, trade-offs and issues of (spatial and temporal) scale (3.1);

- **more appropriate soil and land management** to balance production with other ecosystem services and maintenance of natural capital - including the impacts of multiple drivers acting simultaneously and their long-term consequences for sustainability (3.2);

- **greater resilience to biotic and abiotic stresses** (in crops and livestock) - particularly problems of resistance to agents used to control pathogens, pests and weeds, and the need for alternative approaches based on understanding of interactions between host, pathogen/pest and environment (3.3);

[1] Numbers in parentheses refer to subsequent sections of the report.

- **more effective and sustainable use of resources** to fully exploit the metabolic potential of crops and livestock (3.4).

Under each theme, the report summarises the background, identifies research priorities and advises how those priorities might be delivered, either by BBSRC or in partnership with others. 3.3 and 3.4 build mainly on BBSRC's core remit and long-standing support for innovative research in agriculture and related underpinning science. 3.1 and 3.2 are broader and span the interface between BBSRC and other Research Councils, particularly NERC, but also ESRC. They will require integrated, systems approaches that bring together new interdisciplinary combinations of researchers - for which there is potential to build on the legacy of the former Rural Economy and Land Use (RELU) programme.

The SIWG also highlighted a number of **cross-cutting issues** relevant to more than one theme (4). Many of these relate to the **integration of genetics** (in its broadest sense) **with agronomy or ecology** to optimise production and balance it with the maintenance of other ecosystem services and the natural capital on which they depend. To inform SI, knowledge of the biology of farmed animals or crops needs to be better linked with understanding of the environments in which they are kept or cultivated and the effects of the ways in which they are managed. This aligns with both earlier advice from the FS SAP and a broader emerging emphasis across BBSRC on **interactions between genotype, phenotype and environment**. Framing of the topic in that context could help to link the types of research traditionally supported by BBSRC with the wider requirements of SI.

Enabling SI will require a range of approaches, some involving action on particular aspects of production, but most requiring integrated approaches to address questions in a broader interdisciplinary context. BBSRC has traditionally funded research relating to the enhancement of production, with less emphasis on understanding (from environmental, economic and social perspectives) how enhanced production could be sustainable (at relevant scales), or how to define and measure the sustainability of agricultural systems - for which there are now pressing needs if widespread rhetoric about SI is to be turned into reality.

The SIWG formulated a set of **overall recommendations** as follows (5):

1. BBSRC should promote novel approaches to working across disciplines, co-designing both questions and analyses with research users and permitting joint consideration of the trade-offs between production, natural capital and economic and social values.

2. BBSRC should promote systems thinking: SI goes beyond "growing more with less".

3. BBSRC should promote equal and joint emphasis on S and I.

4. BBSRC should include SI as a highlight area in its next call for Strategic Longer and Larger grants.

5. BBSRC should explore with other Research Councils (NERC as a minimum, ideally ESRC too) the potential for a joint interdisciplinary initiative with a common funding pool (similar to the former RELU initiative).

6. BBSRC should provide funding for a network, perhaps based on the GARNet or AGRI-net (http://www.agri-net.net/) models, to bring together the relevant "BBSRC", "NERC" and possibly "ESRC" communities.

7. BBSRC should encourage relevant institutes to address aspects of SI in the next round of Institute Strategic Programme Grant funding (from April 2017), and in revisions of existing ISPGs following mid-term reviews towards the end of 2014.

8. BBSRC should establish a working group to consider in greater depth issues of "resistance" in agriculture - to crop protection agents (against diseases, pests and weeds) and veterinary pharmaceuticals (anthelmintics *etc*).

CONTENTS

1. Foreword

In October 2013, the BBSRC Food Security Strategy Advisory Panel (FS SAP) approved the establishment of a time-limited Working Group to advise BBSRC on the Council's role (potentially with others) in relation to the sustainable intensification of agriculture (SI). The purpose of the Sustainable Intensification Working Group (SIWG) is to consider how BBSRC can best contribute to supporting research or related activities (infrastructure, training and skills, translation of research into practice *etc.*) in the area of SI. The decision to set up the Working Group followed previous discussions by the Panel, during which some key points included:

- recognition that the issue of SI is inherently multidisciplinary and will require BBSRC to work with partners including other research funders
- the importance of knowledge exchange between researchers and industry or other users, and the challenges of translating basic research into practical application
- the need to consider the policy context in the UK (e.g., are certain policies preventing the implementation of more sustainable practices?)
- recognition that research should not be limited to the UK, and that there are many opportunities to deliver knowledge and innovation overseas.

The Working Group met three times, in January, March and May 2014. The Terms of Reference and membership of the SIWG are presented in **Annex 1** and **2**, respectively.

This report advises BBSRC (and potentially other funders) on strategy and priorities for research relevant to SI. It is not aimed at policymakers, but the Working Group hopes that the outputs of its recommended areas of and approaches to research will contribute to the development of national and international policy (particularly the EU's CAP), as well as informing future land management and agricultural practice.

2. Introduction

Food production is one of the most vital uses of land, and indeed there is a very clear consensus that agricultural outputs will have to increase over the foreseeable future. This consensus derives from the observation of a confluence of factors increasing pressures on the global food system. These factors include ongoing increases in world population, greater numbers of affluent consumers demanding high input foodstuffs (notably meat products), and the dislocating effect of climate change with an increasing frequency and amplitude of weather extremes (i.e. changes in both mean and variability). These drivers operate not just within the UK but globally across the major food producing centres of the world. This, combined with the (albeit uncertain) potential for substantial increases in the costs of production (e.g. energy, fertilizers, etc.), means that longer term increases in food prices appear likely (although the impacts of technological change in mitigating this are also challenging to predict).

One of the suggested mechanisms to increase agricultural output whilst minimising adverse outcomes is SI. There are numerous definitions of SI, with many publications using slightly different functional definitions[2]. Smith (2013) proposed a definition which built on the Brundtland definition of sustainable development: "The process of delivering more safe, nutritious food per unit of input resource, whilst allowing the current generation to meet its needs without compromising the ability of future generations to meet their own needs". Another proposed by Pretty (2014) defines SI as "a process or system where agricultural yields are increased without adverse environmental impact and without the cultivation of more land", and a concept that "does not articulate or privilege any particular vision or method of agricultural production", but "emphasises ends rather than means, and does not predetermine technologies, species mix, or particular design components".

Whichever definition is used, the key component of SI is that the intensification should be achieved through mechanisms that also deliver improved environmental, social and economic outcomes. Though controversial to some, the combination of the terms "sustainable" and "intensification" is an attempt to indicate that desirable outcomes around both more food and enhanced natural capital and/or other ecosystem services could be achieved by a variety of means. The scope of SI has been considered by Garnett *et al*. (2013)[2].

One of the contested framings of SI is "doing more with less". This begs the question of "more what?" More "yield" implies the need to simply grow more produce (without clarity if this is more food or more commodities, livestock feed or biofuels), whereas the current food

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[2] Burney, J., Davis, S.J., Lobell, D.B., 2010. Greenhouse gas mitigation by agricultural intensification. *Proc. Natl. Acad. Sci. U.S.A.* 107: 12052–12057; Foley, J.A., Ramankutty, N., Brauman, K.A., Cassidy, E.S., Gerber, J.S., Johnston, M., Mueller, N.D., O‟Connell, C., Ray, D.K., West, P.C., Balzer, C., Bennett, E.M., Carpenter, S.R., Hill, J., Monfreda, C., Polasky, S., Rockström, J., Sheehan, J., Siebert, S., Tilman, D., Zaks, D.P.M., 2011. Solutions for a cultivated planet. *Nature* 478, 337-342; Garnett, T., Appleby, M.C., Balmford, A., Bateman, I.J., Benton, T.G., Bloomer, P., Burlingame, B., Dawkins, M., Dolan, L., Fraser, D., Herrero, M., Smith, P., Thornton, P.K., Toulmin, C., Vermeulen, S.J., Godfray, H.C.J. 2013. Sustainable intensification in agriculture. *Science* 341, 33-34; Mueller N. D., Gerber J. S., Johnston M. *et al.*, 2012. Closing yield gaps through nutrient and water management. *Nature* 490, 254-257; Smith, P. 2013. Delivering food security without increasing pressure on land. *Global Food Security* 2, 18-23. doi: 10.1016/j.gfs.2012.11.008; Tilman, D., Balzer, C., Hill, J., Befort, B.L. 2011. Global food demand and the sustainable intensification of agriculture. *Proc. Natl. Acad. Sci. U.S.A.* 108, 20260-20264. Pretty, J., Bharucha, Z.P., 2014. Sustainable intensification of agricultural systems. *Ann. Bot.* in press.

system arguably both focuses on too few products. There are risks associated of relying on a handful of crops and livestock systems (and few varieties and breeds) and this also leads to concentration on calories as the most important characteristic of food, with potential adverse public health benefits. More “nutrition” implies a broader focus on producing high quality, nutritious foods for people, which implies a broader focus on a diversity of production. A recent discussion further suggests “more” should be defined in terms of “people fed adequately per unit of resource” (e.g. area, water, energy input), which implies shifting production from feed for livestock or biofuel feedstocks to nutritionally adequate food for people. Thus, more nuanced views of “growing yields” include growing different sorts of food, not simply growing more of what we already do. There is also potential for both “multiplicative” improvements to food production (more of the same product, usually through increased yield, but sometimes by changes to crop duration), and “additive” improvements (usually by introducing other elements into production systems, e.g. aquaculture, intensive patches, agro-forestry rotations etc).

“Doing more with less” is a contested definition for SI because it implicitly defines sustainability as synonymous with efficiency; this is clearly not a complete definition. “How to define sustainability” is a significant research question in itself. Farming management can simultaneously impact upon many different aspects of the environment, and also affect ecosystem processes and functions that may work at different scales. This implies that any “holistic” assessment of sustainability requires multiple metrics and attention to multiple scales of measurement (e.g. plant/animal, field and landscape/catchment). The notion of sustainability also includes social, ethical, welfare and economic dimensions. The latter may be more straightforward to assess at the farm scale, but less so in terms of the broader rural environment or the rural-urban interface. Social sustainability at the farm scale revolves around the people within that enterprise, but the farm management may affect social sustainability in the broader rural environment *via* affecting public good ecosystem services in the landscape (including rural and urban links) or may have ethical or welfare implications that also need to be considered. The topic of SI encompasses sustainably increasing the production of food (or other agricultural products), combined with improved resource use efficiency and better environmental outcomes. Delivering SI will require balancing yield (and optimising inevitable trade-offs) with maintenance of the natural capital necessary for the provision of other ecosystem services - as distinct from increasing yield *per se* or just producing “more from less”.

Inevitably, the multiple aspects of sustainability have the potential to negatively relate, i.e. trade-off, against each other. The notion of SI therefore implicitly requires balancing production against its impacts on different aspects of the economic, social and biophysical environments to maintain the natural capital necessary for the provision of other ecosystem services. Working out how to judge this balance, and who judges this balance is a research question. In some places, SI may not be about “growing more”, but growing produce less intensively to mitigate other impacts.

Challenges for sustainable intensification of production are driven by increasing food demand from a growing global population of over 7 billion people in 2014, set to reach 9-10 billion by 2050. Not only is food demand increasing, but dietary patterns are also projected to change as the wealth gap between developed and developing countries becomes smaller, with a projected increase in demand for livestock products in developing countries, should past trends be repeated. These challenges need to be met in the face of climate change and competing demands for land, water, energy, and other resources; whilst at the same time reducing GHG emissions from agricultural production, and protecting biodiversity and other ecosystem services which underpin natural capital.

The achievement of food and nutritional security will depend on the management of demand as well as supply. The sustainable intensification of agricultural production should not be considered in isolation from the use (and waste) of food and the effects on health of under- or (increasingly) over-nutrition: sustainable production, sustainable consumption and “sustainable nutrition” need to be viewed together as part of the overall picture. Changes to farming practices intended to help achieve SI might also have (beneficial or harmful) nutritional implications (e.g. unintended impacts on nutrient content or availability of foods), and there is also a need to consider production in the context of relationships between nutrition, diet and health.

However, in order to keep the scope of its task within reasonable bounds, the SIWG, while having regard to those wider related issues, have focussed on the sustainability of agricultural production (food and non-food – including forestry and aquaculture, but focussing primarily on crops and livestock), but where appropriate have identified opportunities for joint working with other agencies to deliver to this broader agenda. The SIWG have considered both the reliance and impacts of agricultural production on other ecosystem services, and the need to maintain or enhance the natural capital on which it and they depend, as well as related spatial issues, particularly the scales at which many of the associated ecological processes operate. Systems approaches that address issues of scale in relation to the implementation of SI will be required.

It is recognised that there may be trade-offs among differing requirements / objectives. Food production itself is a provisioning ecosystem service, and is dependent on other ecosystem services as well as having impacts on them. SI therefore has to be framed in terms of balancing agricultural production with the provision of other ecosystem services.

Given the scale of the challenge for SI, we will need to consider multiple approaches / solutions, including new technologies, and the better / wider implementation of existing technologies. As with any complex challenge, there will likely be no simple answers. The SIWG recognise that technology will not be sufficient on its own, and the wider economic, social and political context needs to be considered. Addressing SI will require trans-, inter- and multi-disciplinary work and we expect some of greatest progress to be made from work at interfaces between disciplines. We anticipate benefits from integration of different approaches / types of research to address SI.

The scope of this report focuses on the potential contribution of BBSRC to SI, which includes input from BBSRC’s core remit but includes overlaps with other funders as shown in **Figure 1**. Given the nature of the challenge for SI, it will be essential to work effectively in partnerships, with collaboration across environmental, social, economic and engineering sciences playing a key role in potential solutions. The focus of this report is mainly on the UK, with work solely in developing countries deemed out of scope, but some of the research and developments may also be relevant to developing countries. The report aims to identify roles for UK research strengths, to help to deliver SI worldwide.

Basic, strategic and applied research are all important for delivering SI, as is the translation of research into practical application. **Figure 2** shows the roles of different funders across the spectrum from basic to applied science and its application in industry.

Figure 1. Overlapping research remits in agriculture and food

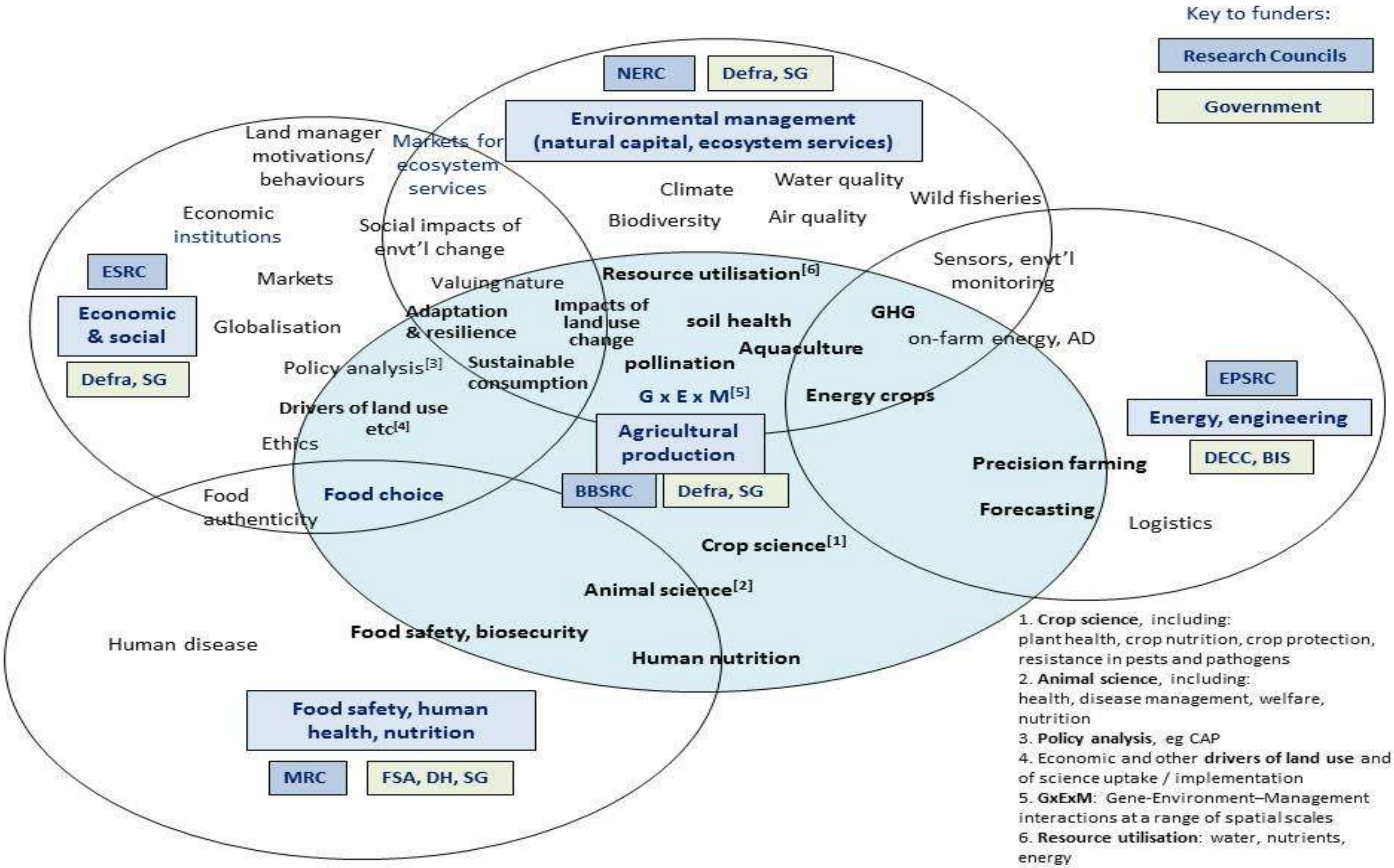
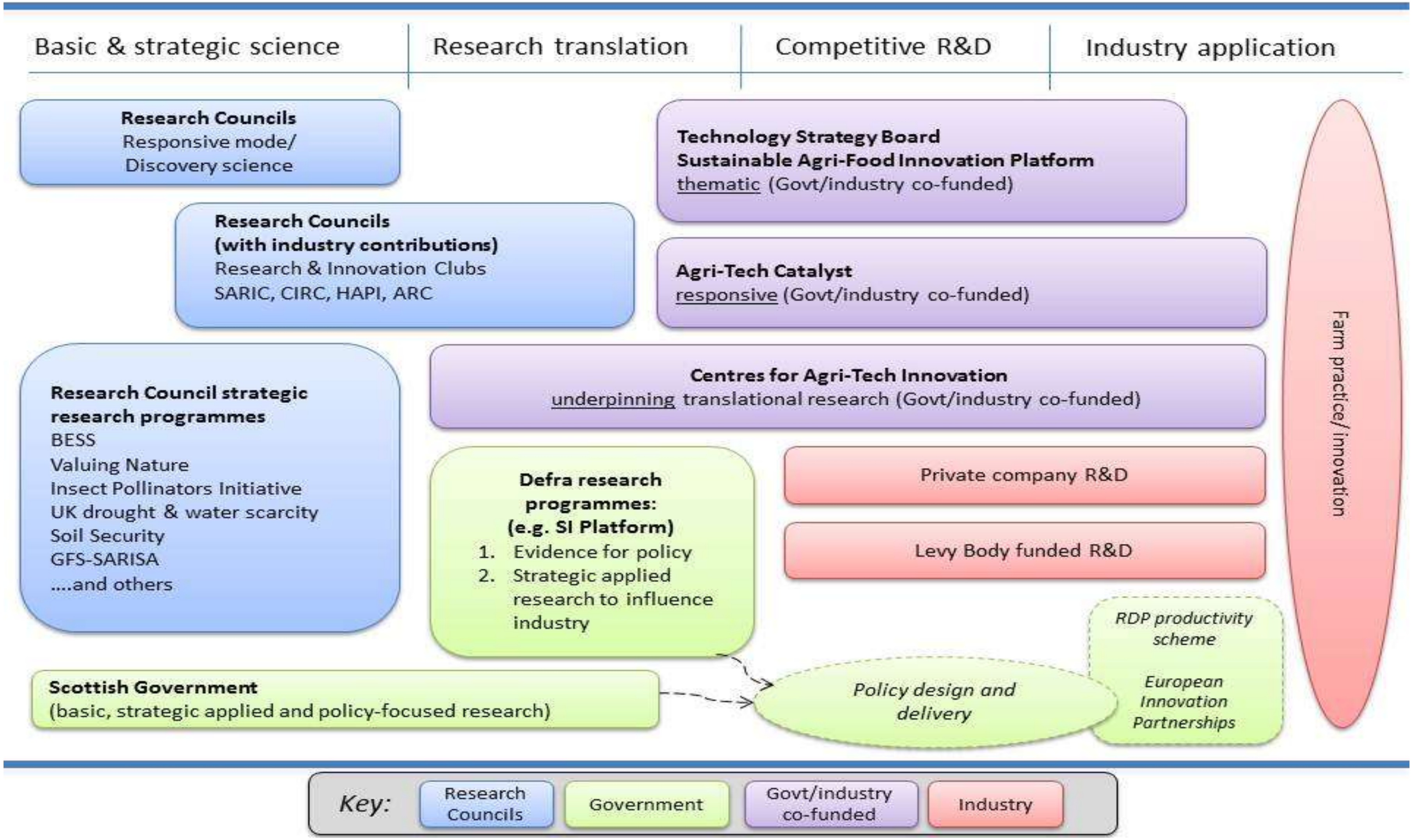


Figure 2. The UK agricultural research landscape



The report is organised around four main themes, identified by the SIWG as those to which BBSRC can contribute significantly in addressing SI:

- Defining and measuring sustainability
- More appropriate soil and land management - to balance production with other ecosystem services and maintenance of natural capital
- Greater resilience to biotic and abiotic stresses (in crops and livestock)
- More effective and sustainable use of resources to fully exploit the metabolic potential of crops and livestock

Under each of these themes we briefly summarise the background/state-of-the-art, priority research areas, and how these outcomes might be delivered (research, infrastructure, collaborative working) either by BBSRC or in partnership with others. In section 4 we briefly explore cross-cutting issues which span more than one theme before presenting our overall conclusions and recommendations in section 5.

3. Themes to which BBSRC can contribute significantly in addressing SI

3.1 Defining and measuring sustainability

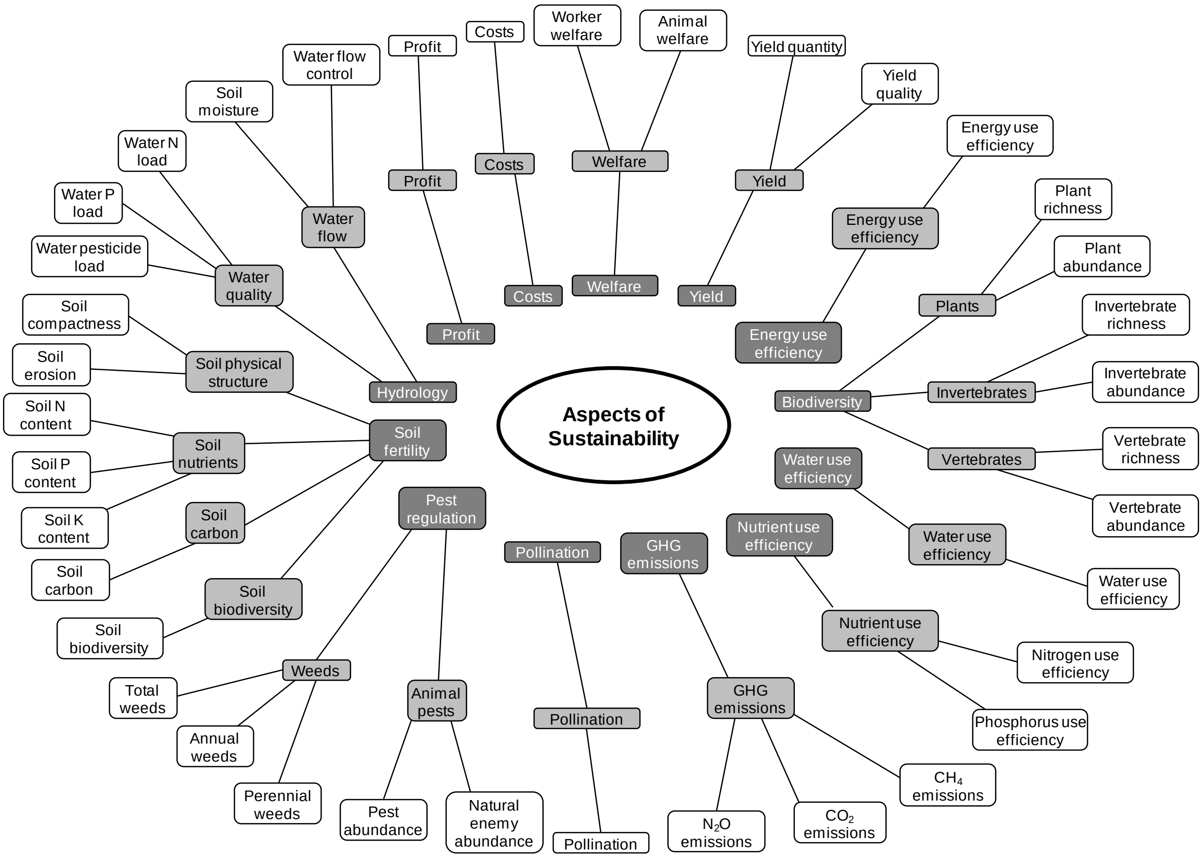
3.1.1 Background

Sustainable intensification requires better appreciation of what constitutes "sustainability". Increasing sustainability of production (of what?) may require:

- Increasing efficiency: in terms of not using more external inputs (fertiliser, pesticides, pharmaceuticals but also energy, water and imported feeds) than needed to optimise production; or in terms of reducing external inputs in favour of strengthening ecosystem functioning in the production system.
- Mitigating environmental impacts and/or enhancing natural capital *via*, for example, enhancing carbon storage, managing soils to preserve carbon, structure, reduce runoff and avoid erosion, increasing diversity in the production system (for example, above and below ground agricultural biodiversity),managing the non-cropped elements (such as hedges, margins, buffer strips, woodlots) to enhance ecosystem services and biodiversity (*via* increasing the quality, amount, connectivity, landscape appropriateness on non-cropped land)
- Building resilience. Resilience, like sustainability, is multidimensional and scale dependent. It may include, for example, diversifying farming systems to generate multiple income streams to spread risk, enhancing ecosystem services to buffer shocks to the system (market and environmental). Non-resilient systems are also likely to have higher environmental impacts, especially when a shock hits.
- While BBSRC may focus on the environmental aspects of sustainability, social (including health) and economic aspects of sustainability also need to be considered, which could be addressed by a wider partnership across RCUK.

One of the emerging notions in the sustainability literature is that every place is unique: the same management practice will vary in its effects according to location. Metrics of sustainability, therefore, need to be outcome-based not action-based, as the same action can have different outcomes depending on the situation. Furthermore, changes in management in one location can impact on management in other places via the market.

Figure 3. This figure comes from a meta-analysis looking at the literature on sustainable



agriculture, selecting studies where more than one aspect of performance has been monitored. The outer ring of white is what has been measured, the inner ring of grey are statistical groupings what was measured into "families" of impact.

The range of aspects of sustainability is illustrated in figure 3; including environmental and non-environmental metrics. Adding other aspects (e.g. nutritional, social and ethical impacts) would expand the diagram further.

3.1.2 Research questions

Theme 1: What metrics are needed to measure farming's impact?

Given the impacts of farming, metrics are needed to cover a wide range of factors:

- **Effectiveness and productivity metrics:** these include assessing e.g. yield per unit of input (where input could be water, energy, nutrient, feed, pesticide, GHG, land), and addressing the question of how to assess yield (in terms of caloric, nutritional or economic value or in terms of unit of ecosystem value obtained) and assessing impact per unit of agricultural product (output).
- **Field-level metrics:** metrics of soil carbon, structure, loss *via* erosion, impact of management on ground water, impact of the production system on in-field agricultural biodiversity (above and below ground), management of the marginal land and its value for promoting biodiversity or ecosystem services.
- **Landscape-level metrics:** for biodiversity (which species, which groups, which scales?); metrics for a range of ecosystem services including those supporting

agriculture (pollination, pest control, soil function), water quality, and the cultural and amenity value.

- **Social, ethical and economic metrics** at farm and landscape level. These may include metrics for assessing overall large-scale systems' performance (e.g. promoting system performance: contributing to a "mixed farming landscape" may help optimise at the landscape level in addition to affecting local farm performance).
- Additional metrics may be required to assess **resilience.**

Key research questions include defining which aspects of sustainability need to be measured and how. For example, how do you assess outcomes, at farm, field or system level, for farm management on agricultural and wider biodiversity, where changes in above-ground and below-ground biodiversity are also governed by landscape-scale processes and weather? To what extent can standardised techniques apply in every situation and every location given measurement biases? Beyond the field or farm scale, what is the most appropriate "large scale" to consider? Over what time period should outcomes be assessed? (e.g. if a 5 year period, there is scope for offsetting bad performance in one year against improved performance in other years). Furthermore, where is the "systems' boundary" for assessing impacts? Reducing production to gain environmental goods in one place can create a shortfall in supply leading to a market opportunity to intensify elsewhere.

Theme 2: Identifying and managing trade-offs

Single aspects of sustainability do not present the full picture. Often single aspects are partly mutually exclusive and hence they fail to reflect trade-offs. For example, 'maximising carbon storage' is very likely to lead to a different strategy for land use to 'minimising water pollution'. Therefore trade-offs have to be recognised. These will vary in intensity with location. The key research question is how to optimise the system to produce the "best" mix of production and minimising impacts. "Best" can be defined in many ways, but clearly it is a strongly social construct. Are some impacts absolutely more important (and if so which)? Are some more important at some times or places (or timescales and spatial scales)? Where trade-offs exist, to what extent can they be softened by appropriate management intervention? Who decides on how to balance trade-offs and how to judge them?

Theme 3: Incentivising sustainable intensification

All changes in management resulting from trying to improve sustainability will involve some degree of opportunity cost: doing one thing rules out doing another. Furthermore, the costs of change will, if left uncompensated by price improvements or subsidy, often fall disproportionately upon the farmer. After all, the present mosaic of land uses in an agricultural area reflects to some degree, the farmers' attempt to maximise long run profits within the constraints of the physical environment, the policy context and price and cost expectations. Existing data suggest that profit is a significant determinant of land use (though there are others, such as to sustain their enterprise in the long-term, including sustaining biological and landscape functions) – so if a hypothetical change in land use in a more sustainable direction will, on average, lower profits, then in practice that land use change might be less likely to occur if all other things are equal. This therefore requires identification of ways to compensate for profits foregone (such as well-planned "payments for ecosystem services" systems).

This of course necessitates the inclusion of economic cost-benefit analyses of sustainability initiatives as a key aspect of the metrics side. This would allow us to change the definition of efficiency to one where we look at the net benefits of changes. This would further allow us to calculate the compensation needed to induce change or the consequences of altering regulations. As well as relevant economic metrics, there is also a need to understand better how relevant "social capital" (relations between farmers and between farmers and researchers) could be configured to improve on-farm experimentation and trialling of new technologies and practices at appropriate scale, in order to encourage and facilitate wider uptake of beneficial changes.

3.1.3 Adding value, research needs, infrastructure and mechanisms

BBSRC is a key player in UK agricultural science. However, to deliver research to address the three key questions inevitably requires inputs from other disciplines, notably environmental and social sciences. Some elements of the first research question can be delivered mono-disciplinarily, but effective delivery of this research agenda implicitly requires inter-disciplinarity.

The discussion above highlights that assessing sustainability is an inherently trans-disciplinary question, and requires working across biological, environmental, social, economic and ethical domains. Inherently, sustainability metrics require measurements of multiple factors, at multiple spatial scales from each farm. It will require greater farmer inclusion in the collection of information and monitoring of change, from field/housing unit to landscape levels. This therefore is a social and informatics challenge with the issues of open access, personal data and privacy, inter-operability and big data. In addition, the development of new technology for sensing (from instrumented farm platforms, like North Wyke, to the availability of remotely sensed data) will provide an unprecedented opportunity to understand fine scale variation in understanding the environmental impacts of agriculture.

In terms of delivery mechanisms, what is needed is significant investment in building a trans- and interdisciplinary research communities and funding. Any such investment builds on the legacy of RELU, and will align with Defra's SI platform and the Agri-Tech Centre for Environmental Informatics and Metrics of Sustainability.

In summary, to make progress in defining and measuring SI, BBSRC should promote inter-disciplinarity, promote systems' thinking, i.e. SI goes beyond "growing more with less", and promote an equal emphasis on both S and I.

3.2 More appropriate soil and land management - to balance production with other ecosystem services and maintenance of natural capital

3.2.1 Background

The long term impacts of intensive agriculture upon underlying stocks of natural capital and the ecosystem services which they provide highlight the need to ensure that any intensification of agriculture is sustainable. This means that any assessment of agricultural production must take into account its wider externalities, most particularly in terms of impacts upon natural capital and ecosystem services. This research challenge seeks to make explicit these various trade-offs.

3.2.2 Research questions

Delivering world class research on Sustainable Intensification will require new standards of inter-disciplinarity. This needs to go beyond what would normally be considered a broad church to deliver new combinations of biology, technology, climate change, economics and behavioural sciences. Research will need to be co-designed between analysts and users in the private and policy communities. An integrated analysis of the potential for balancing production with other ecosystem services and maintenance of natural capital is needed; something which the three research themes below would provide[3]:

Theme 1. Why is agricultural land use the way it is, and what makes it change?"
(understanding the major drivers of agricultural land use and food production)

[3] Exemplar projects under each of these themes are presented in Annex 3

Key drivers include: the physical environment and changes thereof, economic forces, technology and policy. It is important that this analysis considers the effects of these drivers acting individually and simultaneously; it is the latter which is much more likely to be the real world context. Furthermore, while it is accepted that much of the BBSRC emphasis will be upon the UK, certain issues need a more global perspective. An obvious example concerns likely trends in global supply and demand for food and their impact upon the UK and its food security. Analyses need to be spatially and temporally sensitive thereby allowing for natural variation in the environment and variation in management practices.

Theme 2. What are the effects of differing patterns of land use and management? (understanding the physical impacts of change in land use and land management upon production, natural capital and the ecosystem services it generates)

Changes in farm land use and management obviously impact upon agricultural production and in a world of increasing challenges to food security this needs to remain a key concern of any research initiative. However, the objective of Sustainable Intensification is to balance such concerns with the need to ensure long term sustainability. This major research challenge here is to understand the relationship between production and its impacts upon natural capital and the ecosystem services which it provides. Again these impacts need to be assessed both individually and in combination with obvious foci of concern including food production, water, greenhouse gases, the nitrogen economy, biodiversity (including pollinators), animal welfare, plant health, recreation and other issues.

Theme 3. What are the values and trade-offs of changes in land use and management to land users and wider society? (understanding the market and non-market values generated by changes in land use and its management and consequent impacts upon production, natural capital and ecosystem services).

Both the Sustainable Intensification and related ecosystem service literatures recognise that anthropogenic values underpin the allocation of natural, manufactured and human capital. Following the Brundtland paradigm, the challenge for successful delivery of sustainability will be to ensure that the needs of the present generation do not compromise the opportunities of future generations. However, the corollary of this observation is that, for change to be successful, it needs to be designed to ensure its present adoption within the confines of longer term sustainability. This theme addresses the need to consider both the short and long term socio-economic values generated by change. It is important that analyses are both spatially and temporally sensitive. For example, consideration of the trade-offs between production and water quality requires incorporation of both upstream and downstream land use.

3.2.3 Adding value, research needs, infrastructure and mechanisms

'Safe', incremental science is unlikely to provide the best way forward here. BBSRC need to avoid conventional, risk-averse, disciplinary research funding strategies and instead invest in the high quality interdisciplinary work needed to address the complex issues raised by the Sustainable Intensification challenge. For example, it is vital to measure not only the ecological effects of intervention options, but also to understand the economics of each intervention. Does it increase the farmer's profits? If not then, without additional measures, it is unlikely to generate a move towards Sustainable Intensification.

The challenges set out above are inherently interdisciplinary and incentives need to be provided to build new teams of researchers. A substantial element of this research could be usefully and efficiently be conducted in collaboration with ESRC (provided that their 'Nexus' programme is sufficiently quantitative) and NERC. The Pollinator Initiative could be considered as a role model here with a single but significant funding event funding a suite of questions to be directed at a single issue. There are economies of scale in this type of initiative, new collaborations and a critical mass of scientists all working on a common aim. A Sustainable Intensification programme needs the individual programmes to be interdisciplinary though, as well as the overall scheme.

3.3 Greater resilience to biotic and abiotic stresses (in crops and livestock)

3.3.1 Background

The sustainability of crop and livestock production, essential for global food security, is threatened by a wide variety of stressors. These can be broadly divided into stress caused by infectious agents and abiotic factors. These stressors may also impact on numerous interactions among crops, livestock, biodiversity and the environment. Infectious diseases, pests, and weeds are responsible for huge losses of crop and livestock production, in both biological terms and economic terms, measured in a variety of sustainability metrics.

In livestock, epidemic diseases may result in very high prevalence and morbidity and mortality, especially in non-exposed and non-immune populations. Endemic infectious diseases of livestock species, however, have a significant impact on efficiency as they account for a loss of approximately 17% in productivity in developed countries and between 30-50% loss in developing countries.

Crop growers are experiencing significant problems of poor efficacy and lack of control from current agrochemical options; key weeds, pests and disease are developing resistance at an alarming rate. The lack of new active ingredients coming from the manufacturers in the foreseeable future is shifting the emphasis on plant-based defence solutions.

The principal effects of abiotic stresses on crops are on reduction in yield, with variable effects on quality. The detrimental effect of ozone may be partially responsible for the yield plateau in wheat production. This provides research opportunities to improve yield and quality of food for humans and feed for livestock. Abiotic stresses affecting livestock include excessive heat, drought, flooding, salinity, nutrient deficiencies and mineral toxicities. Increasing global warming increases the risk of severe impacts of abiotic stress of animals kept in tropical regions of the world, and also results in abiotic stresses being increasingly recognised in temperate regions.

If agro-ecologists, land managers and policy makers are to manage farmland biodiversity in the long term, then they need to understand the ways in which species interact. This is because these interactions can have a profound impact on a number of key ecological processes, for example the response of agro-ecosystems to pests and diseases, the resilience of ecosystem services to climate change and the impact of species loss, along with our ability to restore biodiversity via agri-environmental schemes.

3.3.2 Research questions

Theme 1. How can sustainability of UK farming sectors (livestock and crops) be improved optimally through understanding resistance to drugs (e.g. antimicrobials, anthelmintics and pesticides) used to control pests, pathogens or weeds?

Some of the key areas are:

Resistance to a number of active ingredients used in the control of pests and diseases in livestock and crops (and weeds) in crops is a significant and increasing problem for sustainable agricultural production.

For example, in crop production, *Septoria tritici* resistance to the triazole, and QoI group of fungicides, grain aphid resistance to pyrethroids, the lack of neonicotinoid insecticides, and *Myzus persicae* resistance to carbamates, pyrethroids and neonicotinoids. Black grass resistance is a major threat to crop production, it is now a significant weed in 16,000 farms in 34 counties. Yield penalties can be greater than 50%. Better integrated weed management strategies, for example by a shift towards spring cropping and rotational changes, might be the most the most effective way to bring this weed under control. These changes in themselves present an ecological change.

In livestock science, anti-microbial resistance in livestock production and the interactions between anti-microbial usage in the animal and human populations. Trematode resistance to flukicides, nematode resistance to all established drug classes and emergence of resistance to newly marketed drugs, ectoparasite resistance to pesticides.

This research will involve development of new management techniques, national monitoring programmes, identification of marker genes, development of drug combinations, and post-emergence semiochemical usage to divert insect species away from host crops. New approaches will be required in order to demonstrate reduced drug requirement, improved efficiency/efficacy, reduced labour, better farm incomes, reduced residue issues, improved environmental outcomes, and improved animal welfare.

Theme 2. How can sustainability of UK farming sectors (livestock and crops) be improved optimally through development of alternative strategies for disease control (e.g. vaccines, diagnostics, breeding strategies)?

Some of the key areas are:

Identification of novel solutions to both epidemic and endemic disease prevention and control, including novel and DIVA vaccines, rapid, pen-side diagnostics of high effectiveness, and practical methods of selecting genes for future breeding objectives that will include resilience, high quality and increased production of food from animals.

Novel livestock vaccines are required: active at the site of infection, often multiple mucosal surfaces, that stimulate protective immunity of sufficient duration to cover the life span of the species involved. Vaccines will increasingly be multivalent, recombinant and with the ability for differentiation between infected and vaccinated animals. Research will exploit existing, cutting-edge molecular genomic techniques, including the development of synthetic biological processes where applicable. This will allow development of vaccines that pose no risk to countries and populations of animals that are currently free of specific diseases. For sustainable intensification objectives, vaccines will replace anti-microbials for the diseases which are most severe, prevalent, and where the greatest prophylactic or metaphylactic use is currently present (e.g. reproductive failure, intramammary infections, respiratory syndromes, infectious lameness).

Disease often presents as syndromes and, as such can involve multiple pathogens affecting multiple organs, systems. Metagenomics of complex systems/organs of livestock, crops and grasses will increase understanding of the impact of the presence and interactions of micro-organisms/macro-organisms and host tissues and immune systems. Poly-omics and deep sequencing will increase understanding of commensal and pathogenic organisms and their impact on production systems and transmissibility within populations. Mathematical and statistical modelling will be an essential element of understanding systems. The focus will be on co-infections rather than single infections/diseases especially in those systems that are likely to be adopted for sustainable intensification including for livestock: housed environments, increased pasture stocking densities, improved genetics for growth rates and feed conversion efficiencies, improved animal welfare and for crops: A baseline national monitoring scheme needs to be introduced to identify the true extent of various resistance issues and more importantly to track the shift in severity. A simple “rapid test” should be developed that a grower can ascertain his resistance status at the outset of the spring summer period to enable alternative strategies to be employed based on protectant chemistry.

Development of a set of markers for black grass would allow growers to identify which herbicides are going to be ineffective on the weed when it is still at the one leaf stage at the beginning of the season. This will prevent unnecessary expenditure on ineffective herbicides and minimize environmental impact.

Using natural defence mechanisms of other crop types, e.g. avenocins from the roots of oats to minimize black grass seed germination should be examined together with other companion crop options.

The technologies of automated phenotyping together with high throughput sequencing need, marker discovery and marker assisted breeding need to be focused on providing more robust solutions to growers.

Breeding strategies for crops and livestock will exploit genomic/polyomic technologies in concert with improved phenotyping for optimal traits associated with sustainability targets in different farming systems, including those anticipated as optimal for the UK and for other countries and continents. Breeding targets will encompass resource efficiency, reduction in waste, resilience to biotic and abiotic stresses, wellbeing in livestock, and will span food and fibre production in differing geo-physical locations.

3.3.3. Adding value, research needs, infrastructure and mechanisms

BBSRC, with other funders where appropriate, should fund multi-disciplinary, larger farm or population scale projects that are required to answer complex questions about interactions among the host, the environment (nutrition, housing, management) and exposure to infectious agents. Many diseases and pests persist in the environment or have complex life cycles that may be affected by management approaches and environmental factors (e.g. abiotic stresses). It is particularly important that research funds allow for investigation of the interactions among host, pathogen and pest/weed, as many current funding bodies focus only on a single aspect, thus the interactions are often not addressed. Individual unit (cell, organ, animal/plant) and experimental plot level approaches are also required to address some of the complex issues identified. It is essential that research uses interdisciplinary approaches by biologists/environmental scientists, farmers and growers, engineers, and social scientists. Past history has clearly demonstrated a gulf exists between scientists and crop producers who have the problems. It is essential that there is a two way dialogue to make any new investment in research as cost effective as possible.

Research in this area should address the sustainability of UK farming sectors (livestock and crops) through:

- Understanding mechanisms of resistance of pathogens, pests and weeds to drugs and other chemicals, extending the period over which they are effective, and developing alternative strategies for control.
- Initiate national monitoring programmes for disease, pest and weed resistance that is not linked to manufacturers.
- Development of rapid, accurate diagnostics for pathogens, pests and weeds to allow management decisions to be made effectively in differing farming systems.
- Development of novel vaccines / plant protection products to protect crops and livestock against those pathogens and pests that most affect production efficiency

and animal welfare and reduce yield thus reducing the output per unit of environmental impact.

- Development of breeding strategies through exploitation of genomics and genetics to allow selection of traits that ensure resistance of hosts (animals and crops) to diseases.
- Development of improved farm practices that encompass primary food production, support of biodiversity and environmental protection, through understanding the effects of ozone on crops, weather prediction and breeding strategies that support resilience to abiotic stress.

Mechanisms for delivery include: research projects – responsive mode and special initiatives. Some may include longer/larger grants due to the complexity of researchable questions. Linked grants with NERC, EPSRC and MRC (anti-microbial resistance) are to be encouraged. The area is ideal for industrial partnership awards (and for funds through Agri-Tech, TSB, Defra and others). Other mechanisms could include: 1) an industry: science forum where growers can articulate their problems to scientists to make their work effective and relevant, 2) enable industry to be part of BBSRC funded research away from the conventional routes such as TSB, 3) closer engagement with other European Centres to share experience and ideas through networking mechanisms such as FACCE-JPI.

3.4 More effective and sustainable use of resources to fully exploit the metabolic potential of crops and livestock

3.4.1 Background

Food production is almost totally dependent on carbon fixation in photosynthetic organisms, and to a lesser extent on the fixation of atmospheric nitrogen. The overall efficiency in utilisation of light energy by these processes is relatively low as evolution has selected more powerfully for other factors such as resistance to biotic stress and weather variation. Crops rely on water and nutrients to achieve optimal growth, but their injudicious input can contribute to environmental damage such as climate change, air and water pollution - so inputs such as water, energy, nitrogen and phosphorus need to be carefully managed.

Livestock for food production convert plant materials into meat or milk, foods valued for their taste with a more complete amino acid profile than most vegetable proteins. Rapid increases in the global population highlight the need for more efficient, resilient and sustainable crop and livestock production systems. Global demand for animal derived foods is increasing by more than two per cent per annum, against a background of greater competition for natural resources, risks of biodiversity loss and climate change. Research outside of the BBSRC remit to moderate demand for animal products is also likely to be of major importance in meeting these challenges.

Adverse nutritional consequences of such dietary changes, including reductions in intakes of essential nutrients such as iron, zinc, vitamin D and calcium, will require further research into the metabolic capabilities of plants and livestock which can compensate these dietary deficits. Although beyond the remit of the SIWG, BBSRC should consider the opportunity arising from these challenges, some of which are outlined below.

Crop and animal agriculture in developed and rapidly developing countries plays an important role in society, supporting food security, land management and biodiversity, but contribute to food-related greenhouse gas (GHG) emissions. Livestock production should strive to decrease the dependence on foods that directly compete with humans, i.e. cereals and soybean while at the same time lower GHG emissions. Pigs and poultry systems have made large gains in feed conversion efficiency, but much less progress has been made in ruminants. Crop based systems should focus on optimising production whilst reducing environmental damage caused by over-use of inputs.

3.4.2 Research questions

To date, re-engineering of the fundamental pathways of carbon and nitrogen fixation has been largely unsuccessful, at best providing some improvement under specific controlled conditions, but little or none under field conditions. In an era of climate change, the responses of plants to environmental stress, is becoming an even more important component of resilient crop production.

Many of the basic metabolic processes have been strongly conserved over the long evolutionary times through which plants and algae have developed, but there are a few major differences, for example C_4 anatomy and biochemistry, and the ability to host nitrogen-fixing bacteria within the plant. Transferring such complex and major alterations in plant crops metabolism has not yet been achieved.

Historically, much more progress in crop production has been made in changing plant habit, maturity and harvest index. Selection of *Brassicas* for oil production, or for storage roots, has led to crops that superficially appear to be different species. Even though the extent of progress differs among crops, there remains significant opportunity for beneficial change in the future. However, the associated costs have limited the segmentation of crops for food or non-food (biofuels, industrial feedstock) production.

Soil structure and chemical composition have a major influence on crop productivity. Soil microflora and other components of soil biodiversity also play an important role. Soil not only determines water and nutrient availability in the plant, but also leaching to groundwater and loss to the atmosphere. Our understanding of soil chemistry and biology is limited, but recent metagenomic studies have started to provide an insight. Most products or processes which manipulate soil to increase plant yield have been discovered empirically, and with the natural variation in soils it has proved hard to draw generalised conclusions to allow widespread use. Indeed, the only safe label recommendation for phosphorus is to over-apply, to avoid tight retention which occurs in some soils.

In developing countries, biofortification programmes have yielded examples of micronutrient enriched staple crops (orange sweet potato, golden rice, and zinc enriched rice) that have been shown to significantly improve the nutritional status of deficient populations. These advances may become more relevant to the UK diet as consumption of animal products is reduced, with potential adverse consequences for micronutrient adequacy. A good example would be vitamin D intake which is already marginal in the UK diet and for which animal products are an important dietary source.

Currently the major dietary challenges in developed countries (heart diseases, diabetes, cancers) arise from diets high in energy, saturated fats, sugar and processed meats and which are also low in fibre and micronutrient- and flavonoid-rich fruits and vegetables. Large population-based studies of the effects of changes in plant or animal metabolism on disease outcomes in developed countries are not feasible in free living subjects due to their high cost. However there are well documented examples of controlled studies which have demonstrated the benefits of modified plant or animal products on disease biomarkers. These include effects on circulating cholesterol of feeding volunteer subjects dairy products from cattle fed modified diets, improvements in cancer biomarkers of sulfurofane-rich Brassica and of flavonoid rich diets on cardiovascular and cognitive function. Emerging evidence for beneficial effects of non-digestible carbohydrates (including dietary fibre) on human metabolic function, arising via their fermentation in the gut, provides potential opportunity to modulate risk factors for diabetes and obesity *via* changes in the carbohydrate composition of cereal products.

Another example is the potential benefit of producing long-chain ω-3 fatty acids in higher plants e.g. in seed oils. These fatty acids are vital for brain development, and have been shown to reduce risk of heart disease; they are not normally made by higher plants, but only in certain algae. Consumption of algae by fish results in ω-3 entering the human food chain, but there are concerns over the supply of these oils available for fish feeds and depletion of wild fish stocks that have become major limitations to the sustainable productivity of fish farming.

Animal manure is an important source of fixed nitrogen, and to a lesser extent carbon and phosphorus. Optimising the balance between manure and biologically- and chemically-fixed nitrogen, to minimise energy usage and optimise soil fertility is complicated and typically less than ideal. Selection of crops for animal feeds and animals or fixing more nitrogen and carbon is the production of meat and milk has to be balanced against the need to recycle these materials to maintain soil fertility.

The impact of prion diseases has also impacted on the use of human food "waste" as a source of animal feed, and of some types of animal waste, such as bone meal as a source of phosphate. Some of these practices seem to have the potential to reduce overall energy use and improve sustainability provided there is no risk from transmissible diseases.

Progress towards sustainable intensification will require increased knowledge to predict performance, product quality, health and environmental impact responses to changes in inputs including feed resources, management and animal genetics. Focusing on the diversification of inputs based on novel crops (new grasses and legume crops), anaerobic fermentation (including algal protein), industrial by-products (from human food, biofuel and plastics industries), etc may lower food security risks and decrease competition of resources for human consumption, bioenergy and animal feeds, though land competition could still be an issue if production is displaced elsewhere. Increased integration between genetics and nutrition inputs will be required to understand how the environment interacts with animal or plant genetics to predict the effects of management and production systems on crop yields, feed conversion efficiency, GHG emissions and product quality. This would also require the development of advanced feed evaluation systems to understand how an animal responds to different diets and how such changes impact on livestock production, efficiency, product quality, environmental impact and health and welfare. There has also been limited selection of plants for efficient animal conversion.

It may be possible to use new post harvesting technologies (i.e. processing, fermentation, enzymatic) for optimising the nutritive value of conventional feeds (i.e. forages, cereals) and allow a wider range of plant materials to be utilised as feeds.

Increased understanding of and development of improved risk-based measures to prevent and control hazards is required. Hazards associated with feed are biological, chemical and physical agents such pathogenic microorganisms, mycotoxins, heavy metals, dioxins, dibenzofurans and polychlorinated biphenyls and residues of veterinary drugs and pesticides, and radionuclides. New and unconventional feed ingredients are entering the production chain (e.g. agro-industrial by-products i.e. from the biofuel industry; insects; food processing by-products; and food wastes), which may contribute to new safety risks.

3.4.3 Adding value, research needs, infrastructure and mechanisms

Whilst work on basic metabolism remains of value, especially in trying to make major changes to the efficiencies of the carbon and nitrogen pathways, a number of cross-boundary areas could deliver significant impacts:

- Response of plants to external stresses, with the aim of increasing resilience and minimising the loss of potential.

- Understanding the soil microflora and other components of soil biodiversity, its inter-dependence on soil chemistry and structure, in order to maximise crop output and minimise losses to water and air.
- Adapting crops to wider range of product outputs, including improved conversion to meat, use as renewable industrial feedstocks and increasing human and animal health, as well as improving the production of the most valuable food products with minimum unavoidable waste.
- Optimising the input and efficiency of N, P, K, water and energy use efficiency but also broader aspects of performance and persistence under abiotic stresses including drought, water-logging, heat and cold stress in the context of different input regimes. This includes understanding the genetics and the associated potential of the response to selection for these traits.
- In ryegrasses and clovers, developing experimental systems and models to improve prediction of sward performance from data collected on single plants or tractable, experimental swards is required. This will require increased phenomic capacity.
- Increased understanding of the relationship between root architecture and phenology and nutrient/water use efficiency/abiotic stress tolerance
- Understanding the trade-offs between the response to inputs of crop and grasslands, persistency (grasslands) and environmental services? What are the selection criteria that can deliver the best options?
- Selection of animals for efficient conversion of plant feed, including plant material unsuitable as human food (e.g. grass) or making better use of by-products from the human food supply chain.
- Understanding the gut microbiome and its effect on human health and animal, environmental impact, health and welfare, and product quality.

4. Cross-cutting issues

A number of cross cutting issues arise from consideration of the priorities for each of the areas discussed under section 3, some of which are noted below:

- Understanding genetic diversity (agricultural biodiversity) and desirable traits in wild relatives.
- Methods of genetic selection and modification through improved breeding
- Optimisation of metabolism to achieve improvements in field and landscape metrics
- Metagenomics and function of gut and soil microflora and soil biodiversity
- Matching food and feed quality with the gut microbiome to improve human and animal health
- Genetic diversity and agricultural biodiversity
- Precision farming
- Smart delivery of nutrients including sensors
- Modelling of inputs/outputs (linked to sustainability metrics)
- Changes to energy intensity across the entire farm
- Consequences of changes for greenhouse gas emissions and storage
- Economics of production: (i) farm profitability (ii) full cost-benefit analysis of changes

Resistance in agriculture, such as to crop protection agents (against diseases, pests and weeds) or veterinary pharmaceuticals (anthelmintics etc.), is a cross cutting theme that emerged across crop and livestock sectors, and is such a pervasive threat we propose the establishment of a working group to consider issues of “resistance” in agriculture in greater depth.

More broadly, many of the above themes relate to the integration of genetics (in its broadest sense) with agronomy or ecology to optimise production and balance it with the maintenance of other ecosystem services and the natural capital on which they depend. To inform SI, knowledge of the biology of farmed animals or crops needs to be better linked with understanding of the environments in which they are kept or cultivated and the effects of the ways in which they are managed. This aligns with both earlier advice from the FS SAP and a broader emerging emphasis across BBSRC on interactions between genotype, phenotype and environment. Framing of the topic in that context could help to link the types of research traditionally supported by BBSRC with the wider requirements of SI.

5. Overall conclusions and recommendations

Almost all of the research questions identified by the SIWG require an integrated analysis of the potential for balancing production with other ecosystem services and maintenance of natural capital. It is clear that making progress in the field of SI requires a range of approaches, with a few requiring action on particular issues on the production side, but most requiring multi- and inter-disciplinary research, to an extent that have thus far not been achieved. BBSRC has traditionally funded research that increases understanding that will ultimately enhance production, but less resource has been dedicated to understanding how this enhanced production could be sustainable (from environmental, social and economic perspectives) across different scales, or how to measure the sustainability of systems. This work is now urgently required, and BBSRC, working in partnership with other funders where appropriate, would be in an excellent position to lead on this. Resulting research will need to embrace systems thinking and have a clear emphasis on the “S” part of SI.

A range of mechanisms is available for BBSRC to do this, including a) use of a dedicated research programme or focus area on SI, b) use of cross-council and cross-funder mechanisms to promote multi- and inter-disciplinary projects under a cross funder initiative on SI (similar to RELU), c) use of existing funding structures to promote such projects (e.g. Strategic Longer and Larger grants; sLoLas), d) use of existing farm platforms (such as North Wyke and others supported by other funders) as focal areas for research on SI, and e) funding of a network (or networks) to bring together the relevant “BBSRC”, “NERC” and “ESRC” communities who could contribute to work on SI. It would also be useful for BBSRC to encourage relevant institutes to address aspects of SI in the next round of Institute Strategic Programme Grant (ISPG) funding (from April 2017), and in revisions of existing ISPGs following mid-term reviews during 2014.

Overall recommendations

1. BBSRC should promote novel approaches to working across disciplines, co-designing both questions and analyses with research users and permitting joint consideration of the trade-offs between production, natural capital and economic and social values.
2. BBSRC should promote systems’ thinking: SI goes beyond “growing more with less”
3. BBSRC should promote an equal emphasis on both S and I
4. BBSRC should include SI as a highlight area in the next (2015) call for Strategic Longer and Larger grants (sLoLas);
5. BBSRC should explore with other Research Councils (NERC as a minimum, ideally ESRC too) the potential for a joint interdisciplinary initiative with a common funding pool (similar to the RELU initiative);
6. BBSRC should provide funding for a network, perhaps based on the GARNet or AGRI-net (http://www.agri-net.net/) model, to bring together the relevant “BBSRC”, “NERC” and possibly *ESRC” communities;

7. BBSRC should encourage relevant institutes to address aspects of SI in the next round of Institute Strategic Programme Grant funding (from April 2017), and in revisions of existing ISPGs following mid-term reviews later this year;
8. BBSRC should establish a working group to consider in greater depth issues of "resistance" in agriculture - to crop protection agents (against diseases, pests and weeds) and veterinary pharmaceuticals (anthelmintics etc.).

ANNEX 1

BBSRC WORKING GROUP: SUSTAINABLE INTENSIFICATION OF AGRICULTURE

TERMS OF REFERENCE

1. To advise BBSRC, via the Food Security Strategy Advisory Panel, on the Council's role (potentially with others) and future priorities in relation to the sustainable intensification of agriculture, to include crop, livestock and mixed farming systems, and for production of both food and non-food products.

2. To consider in particular the questions:

    i. What are the research needs and (generic) scientific questions in relation to sustainable intensification?

    ii. How should research to enable sustainable intensification (of UK agriculture) be most effectively promoted and developed by BBSRC?

3. In addressing the above questions, to take into consideration:

    i. the inherent multidisciplinary nature of the topic and the need to engage with other relevant research communities;

    ii. the need for development of metrics and data standards to enable sustainable intensification to be measured and progress to be assessed;

    iii. currently available research facilities, the potential need for additional facilities including the requirements for large-scale data collection, analysis, curation and sharing;

    iv. the need to ensure the translation of basic research into practical application;

    v. BBSRC's interactions with other research funding bodies, industry, government and non-governmental stakeholders, and the scope for working with them in productive partnerships.

4. To report accordingly to the Food Security Strategy Advisory Panel.

ANNEX 2

BBSRC WORKING GROUP: SUSTAINABLE INTENSIFICATION OF AGRICULTURE

MEMBERSHIP

Name	**Institution**
Professor Pete Smith (chair)	University of Aberdeen
Professor Ian Bateman	University of East Anglia
Professor Tim Benton	University of Leeds
Professor Julie Fitzpatrick	Moredun Research Institute
Dr Tara Garnett	University of Oxford
Dr David Lawrence	formerly Syngenta
Professor Jane Memmott	University of Bristol
Patrick Mulvany	The UK Food Group (from 3rd meeting)
Keith Norman	Velcourt
Professor Nigel Scollan	IBERS, Aberystwyth University

ANNEX 3

Exemplar projects under the three themes outlined in section 3.2

1) Why is agricultural land use the way it is and what makes it change?

- The influence of physical environmental variation. This includes cross sectional variation across highly heterogeneous areas. Topics include: soils, soil characteristics, changes in soil health, the role of organic matter, mycorrhizal fungi, other soil bacteria and their interactions between themselves and the host crop, including a better understanding of these soil interactions and the shifts caused by different cropping, cultivations and rotations; erosion and land-slips; relationships with geology, slope and topographical exposure; precipitation and water availability including flooding, conventional droughtiness, irrigation and water quality; variation in nutrient uptake and utilisation with respect to change in environmental conditions.
- Dynamic environmental change and its impact upon production (including both climate trend and weather variance changes and their impact upon the resilience of natural capital; e.g. changes in the frequency and intensity of short term weather extremes and associated drought and floods; taking into account likely changes in demand from other sectors including domestic and power sector water demand.
- Market forces and production (including actual and expectations based changes in domestic and world input costs (see also technology below), output production (again see technology based enhancements), output prices; addressing the very considerable uncertainties associated with long term trends in these variables in the light of global population increase, demographic and socio-economic change, climate change, technology change, etc.);
- Technology: impacts of 'conventional' and GM innovations. Effects on cost base and production; likely uptake of crop and livestock science and other agricultural technology.
- The influence of policy (including national policy such as rural development payments, conservation policies, biodiversity offsetting; EU policy including revisions of the Common Agricultural Policy; international policy including trade regulations);
- Expected profits in light of the above; uncertainties and risks; other sources of utility.
- Competing pressures for land use (urban and industrial use, infrastructure (and its impact upon land use decisions), dedicated recreational land, water storage, etc., and trends thereof).

2) What are the effects of differing patterns of land use and management?

- Impacts on agricultural production (raw food outputs for all sectors: arable, livestock, mixed, other outputs) through multiple intensities of production (outdoor, indoor, high/low intensity, etc.);
- Impacts on water availability and quality. Water quality issues include the challenges of nutrients, pesticides, sediments, upon other uses and ecological status. Water quantity issues include downstream effects upon flooding (including siltation), irrigation requirements, etc. Particular attention needs to be paid to the nitrogen cycle and associated challenges and opportunities for change.
- Air quality (including ammonia emissions)
- Pollination services
- Plant and animal disease incidence and resistance
- Herbicide and pesticide resistance
- Impacts upon future soil health and its ability to deliver fertility
- Animal welfare

- Effects on above and below ground greenhouse gases. Including emission and storage of CO_2 (including soil carbon, machinery, fertilizer production and usage, biofuels, etc.), CH_4 (animal emissions) and N_2O (and related GHG emissions from fertiliser use, interactions with plant physiology, etc.). Research should embrace recent development in say anaerobic digestion, displaced emissions, technological change (e.g. adding leguminous characteristics to cereal crops), etc., and also consider climate feedback effects.
- Biodiversity and species richness: microbial, insects (including pollinators), terrestrial, aquatic, birdlife, etc., including a clear understanding of the relationship between habitat extent, spatial location and composition and consequent threshold effects upon populations. Impacts of changes such as intensification upon both hedgerows and field margins, etc., but also via infield changes (important as a small change here can translate into changes across large areas). Examining what might be the appropriate scale for conserving and restoring biodiversity and the ecosystem services which it provides in agro-ecosystems (most studies are at the scale of the field but farm scale and landscape scale interventions may be more appropriate). Analysis of the effects of biofuels on agricultural biodiversity.
- Effects upon pollinators. Examining which pollinators are the important ones to conserve in UK agroecosystems and do the current Stewardship options provide them with what they need? Unless we know this, then it is impossible to know whether we can intensify agricultural production without adversely affecting pollination.
- Direct (exercise) and indirect (food and diet) health implications of land use
- Impacts upon the availability of recreational resources including the effect of land use change upon the quality of those resources (e.g. water pollution effects upon amenity areas)
- Visual aesthetics
- The global impact of change in UK agriculture and effects upon imports and exports of ecosystem services.
- Inter-relationships between all of the above factors (e.g. between crop technology, pollinators, production, water quality and greenhouse gas emissions).
- Understanding how different forms of technology can alter almost all of the above relationships
- Counterfactuals: the change in all of the above effects under alternative land use or intensity of production

3) What are the values and trade-offs of changes in land use and management to land users and wider society?

- Financial (market priced) and economic assessments of production, employment, etc. Sectoral multiplier effects into the wider food industry.
- Understanding the influence of technological change upon profitability and hence uptake.
- Understanding the role of technology upon the value of natural capital and ecosystem services. Assessing the impact of crop science and genetic manipulation upon many of the externalities and ecosystem services associated with agriculture, e.g. examining whether conventional ways of managing pests more or less damaging to the environment than the use of GM crops?
- Implications for food security taking into account trade;
- Undertaking full economic assessment (in line with H.M. Treasury Guidelines) of policy change.
- Ensuring all values vary according to the locations they are generated in (e.g. water quality matters more in abstracted than non-abstracted catchments);

- Ensuring that, where appropriate, values are responsive to overall levels and spatial distribution of provision (e.g. that the ‘marginal value’ of increasing the supply of recreational areas is responsive to existing availability of substitute and complementary areas and access to populations).
- Ensuring that, where appropriate, values are responsive to stock levels, depletion paths and their (ir)reversibility (including hysteresis), and non-linearities arising from thresholds; associated dynamics.
- Examining the potential for using market mechanisms (charges, permits, taxes and auctions) to ensure the efficient implementation and uptake of change.
- Examining whether farmers can manage their land for multiple ecosystem services simultaneously. Are there win: win opportunities whereby several services benefit from single intervention? If so, then intensification could be sustainable as less space is needed for maintaining biodiversity.
- Counterfactuals: the changes and hence trade-offs in all of the above values under alternative land use or intensity of production.