Breakout Session

We scheduled several breakout sessions throughout the meeting, each one lasting around 45 minutes. There were 8 groups which stayed together for all the sessions, and each had a stakeholder facilitator and a scribe that was part of the organising committee. The facilitators included a maltster, farmer, baker, distiller, crofter, breeder, academic and agronomist. We tried to ensure that each group had a balance of gender and backgrounds from across MRPs, industry, academic and advisory agencies.
Three questions, which had been sent to facilitators prior to the meeting, were used as the basis for discussions:

1. From your perspective (stakeholders), what are the main challenges for achieving policy goals in barley production and processing? (i.e. net zero carbon farming, climate adaptation, future sustainability). What are the trade-offs/conflicts?

2. How much progress has barley research already made in addressing these goals? What further research is needed to fill knowledge gaps?

3. Where should we focus effort in translating research into practical applications?

All of the information from each of the groups has been collated and there were several themes that were echoed across all groups and these are briefly described. These responses will be the basis of the roadmap document.

Main challenges for barley production in reducing carbon, adapting to variable and unpredictable climates and reduced inputs while maintaining yields.

- All groups agreed that the key to achieving this is by **working together** and that a meeting such as this was a good starting point. We need **communication between government and policy makers, consumers, scientists, breeders, farmers, levy and government agencies, maltsters and distillers.**

Some quotes from groups

- 'The general feeling that there is not much interaction between agriculture and environment'
- 'The main issue is to set up a link between politicians, the public and businesses. We felt that the link is not great – we don't know what the policies are, and on what grounds the politicians are actually making them.'
- 'We need a dialogue with policy makers to understand how they envisage policy is delivered'

A suggestion was that the International Barley Hub (IBH) addresses these challenges and develop proof of concept projects, feasibility studies and become the conduit that links policy makers, government, industry, the supply chain and research communities.

- Most groups discussed specific challenges at all levels of the barley supply chain. In general, groups agreed that change is needed, and that production is progressive and doesn't stand still. There are conflicts between quality of product and price, and similarly with products being locally sourced vs imported from further afield. We need to have a supply chain and infrastructure to support this.

	Challenges	Issues/conflicts/trade-offs	Stakeholders affected
Environmental	Reduce inputs: fertiliser, pesticides, herbicides and fungicides	Unsustainable and irreversible damage to the environment. lack of advice/knowledge on the alternatives and how to adapt practices to make use of the alternatives (and ensure efficiencies).	All, but a major scientific challenge
	Resilient farming systems	Farmers need to make a living and a reward system in place for long-term farming solutions.	All, scientists and farmers in participatory activities
	Better and more meaningful measures of carbon emissions	Re-evaluate how this is achieved, with common platforms. Similarly, with terminology of net zero carbon, clear and measurable definitions and expectations	All, scientists and environment and government agencies
Agronomic	Maintaining diversity	Conserving what we have. There is a perceived conflict between heritage and innovation	Breeders and researchers
	Breeding for different and unpredictable environments	Most breeding is carried out by big companies, as above needs to be complemented by regional approaches	Scientists, breeders and government agencies
	Breeding for resilience	AHDB trialling system outmoded - need more region-specific recommendations	Scientists, breeders and government agencies
	Sowing, growing and harvesting the crop	Balancing act between when to plant, crop maturity and seasonality. Too wet and too late - no harvest	All
	More effective and specific chemicals	Part of reduced inputs, to develop more effective chemicals which do not damage the environment	All, but a major scientific challenge
	New emerging diseases	As the environment changes, new diseases may emerge which will require fast action	All, but a major scientific challenge
Socioeco nomic	Economics and yield	Balancing these, while considering the effects of inputs on the environment	Growers, maltsters, distillers, consumers

	Transport	Less and more local. This would take more time and organisation	Farmers, maltsters & distillers
	More efficient use of water	Malting and distilling both require water - how do we reduce the use to become more efficient and recycle?	Scientists, maltsters and distillers
	New uses of grain	Main use of barley is whisky - major economic value. Can we open new markets for food?	All, consumers, growers, crofters, craft industry
	Different approaches to malt	Often if grain doesn't meet the specifications for malt it's rejected. Can we have a better understanding of the process and other uses?	Growers, maltster, distillers and scientists
	Traceability	Where food comes from, which is linked to local production. More costly for consumer - will they pay more?	All, consumer, government and agencies
All	Working at different scales: local, regional, national and international. Variety choice, agronomy and end product.	With environments changing and unpredictability, a 'one size fits all' is no longer a solution	All, scientist, breeders, environment, advisory and government agencies

Some quotes from groups on trade-offs and conflicts

'Not all proposed solutions work for the varying end users of barley, for example intercropping doesn't work for malting and distilling.'

'The economics doesn't stack up for some of the solutions and neither do the yields. A balance is needed between new cropping systems, economics and yield.'

'The UK breeding system and recommended lists requires revisions in the light of low input systems – are we breeding for lower inputs and marginal land, as well as end use?'

How much progress has barley research already made in addressing these goals?
What further research is needed to fill knowledge gaps?
Where should we focus effort in translating research into practical applications?

All groups agreed, based on the talks from MRPs, that the barley research carried out in Scotland is of the highest quality and is a well-integrated programme that covers agroecology, agronomy, genetics, quality, pathology and IPM as well as modelling and statistical analyses. All groups recognised the strong international links that these groups have established.

The second part of this question and the third question are linked and will be addressed together. **It was noted by several groups that we should always remember that**

research is curiosity-driven, and the challenge is to combine discoveries with impact and translation. This requires a systems approach that joins up research and fine tunes it to fit research to policy.

Future Areas	Research	Translation impact	5-year aspirations	10-year aspirations
Environmental sustainability				
Development of low-carbon barley varieties (climate mitigation)	Developing methods to measure carbon in the system which can be applied in a cropping system (Computational and modelling, agricultural engineering, agronomy & environment)	Meet government policy to reduce carbon, as well as meeting industry requirements. Links directly with other future research areas (innovation crop systems, nutrient use efficiency, breeding for sustainability)	Development of a systems and modelling approach to be able to predict and measure the carbon footprint of barley production. Use of this model to set breeding targets for low carbon barley	Routine use of the metric to determine whether we are achieving low carbon footprint. Develop pre-breeding material for low carbon cultivars and sustainable farming practices, along with appropriate use of agritechnologies, that reduce the carbon footprint. Longer term, these data can inform future policy and practice.
Reduce reliance on chemical inputs in integrated cropping systems	Testing methods to minimise reliance on synthetic inputs (fertiliser, pesticides, herbicides and fungicides), including more efficient and targeted use of inputs, alternative inputs and partial replacement through alternative cropping practices/rotations. (crop physiology/nutrition, agronomy, crop protection/IPM experts, environmental science, social scientists, agricultural economists)	Meet government policy targets for resource efficiency, water/nitrate/emissions, sustainable pesticide use, integrated pest management (IPM) action plans	Determine the features of a low input and economically sustainable cereal production system in Scotland (under a changing climate) based around IPM and integrated farm management (IFM). Includes barley varieties suited to low input conditions, nature-based solutions that optimise ESs and management practices that minimise current and future pest/disease risks (e.g. invasive species). Characterise social/economic	Work with partners (e.g. LEAF, Soil Association, AHDB) to monitor the agronomic, environmental and economic performance of low chemical input farming case studies at commercial scale (on farm, CSC) and to disseminate knowledge gathered on best practice. Identify the main features of a certification scheme for recognising sustainability credentials of the harvested barley product.

			acceptability of alternative practices and identify main knowledge gaps as a focus for further research.	
Reverse land degradation	Management approaches to preserve/enhance the quality of productive land and restore degraded land (soil/environmental scientists, agroecologists, social scientists)	Policy drivers for soil health, land use, sustainable food production	Survey farm networks to identify common issues of land degradation in cereal production systems. Identify and test solutions (e.g. diversified rotations and alternative crop/cover crops that can maintain and restore soil function)	Identify specific land degradation issues amongst farm networks and work with farmers to test and demonstrate best practice solutions at commercial scale.
Biodiversity protection	Biodiversity-sensitive farming practices, understanding the current state of agrobiodiversity and mechanisms that underpin sensitivity/resilience to environmental change, provide evidence for the contribution of biodiversity to ecosystem service provision. (agroecologists, environmental scientists, socioeconomists)	Meet policy targets for mitigating against biodiversity declines and preserving/enhancing biodiversity and non-crop habitats, and reducing reliance on chemical inputs	Gather baseline information on current state of biodiversity in arable farm landscapes in relation to major environmental drivers (climate, pesticide use, land use). Work with farmers and environmental stakeholders to identify local biodiversity targets and determine appropriate biodiversity-sensitive practices. Implement biodiversity-sensitive practices on-farm and monitor outcomes to gather evidence and gain a mechanistic understanding (this approach is being	Devise environmental stewardship schemes to encourage best practice biodiversity-sensitive farming with evidence-based outcomes for biodiversity.

			adopted in the new FRAMEwork project).	
Climate-smart farming (climate adaptation)	Characterise the components needed for resilient and climate-adapted farming systems (crop scientists/physiologists, climate modellers, agritechnologists, agronomists)	Future-proof UK farming systems and agricultural industries	Identify barley cultivars with improved abiotic stress tolerance, soil and crop management practices to mitigate abiotic stress, precision ag solutions (e.g. for optimised spatial sowing patterns, irrigation)	Use modelling predictions to characterise regions and soil types that will support future climate-smart barley production. Establish a climate-smart demo farm for lowland arable systems. Test and showcase the package of climate-smart practices on-farm.
Improved farming practice and agronomy				
Intercropping innovative rotations and other novel cropping practices	Examine the genetics of breeding for intercropping, developing populations hand in hand. On-farm testing of different combinations of crop species- e.g. Scotland used to grow buckwheat (ecology, genetics & agronomy)	New cropping systems for growers that maintain soil nutrients, while providing yield and quality required for the industry	Identify compatible intercropping components and suitable germplasm. Common garden experiments across Scotland using the network of Monitor and Experimental farms available (Figure 1). Parental lines identified and breeding protocols and populations developed and tested.	Crop to crop combinations provided for validation under field conditions, new intercropping varieties available and targeted specially for the different farming practices, environmental conditions and processing uses.
Micronutrient uptake as well as grain content	Growing important research area requiring multidisciplinary approaches from soil nutrient studies including interactions between roots and microbiome to understand nutrient movement in the plant and deposition in the grain.	Improved uptake of nutrients from the soil, reduced inputs for the farmer. Increased nutrient content of the grain for a wide range of uses including food and feed.	Developing new approaches to examine the soil microbial community and their interactions with roots. Examine the impact of agronomy and genetics on the uptake of nutrients from the soil and the	Development of genotype x management interventions which enhance the human and animal nutritional value of barley.

	(Microbiology, soils science, agroecology, plant physiology, cereal chemistry, nutritional science)		network of genes that control transport to the grain. Ionomics studies of systems under a range of environments	
Pest and diseases particularly those associated with a changing environment such as Ramularia	This requires a multidisciplinary approach, including fundamental molecular and genetic analysis of the pathogen, plant and pathogen interactions, field scale trials under different environments and genetic breeding and gene editing to develop new varieties. (cereal pathology, agroecology, modelling, bioinformatics, agencies)	New methods of detection and improved forecasting. New climate friendly chemistry for control. New resistant or tolerant varieties.	Smart pesticide use, resistance management, alternative control methods. Understand why endophytes become pathogens, and how they interact with environmental change. Identify resistance genes using genetics and genomics.	Using the information generated for both the pathogen and plants, new markers will be developed that can be used in breeding. Understanding the relationship between environment and pathogenicity will be further developed and modelled to forecast outbreaks and develop new safe chemistry.
Regional DUS characters, similar to a Scandinavian model, testing systems for resilience, moving away from DUS approaches	This would require a complete rethink of the system for registering varieties and breeding locally. This would have been achieved by non-profit means as this approach would not be economically viable for large companies. Proof of concept project funded through government. MRP institutes have access to experimental farms that represent the range of arable land in Scotland, these could provide the sites for breeding, selection and trialling.	Simplified, more efficient screening and regulatory systems. Better suited local varieties, ultimately improving yield and quality	Instigation of a Scottish Government commissioned recommended and national list not limited to conventional practice but also extended to marginal soils and alternative cropping and cultivation systems This should inform as to the way forward for Scotland as well as the UK.	Recommended lists of barley varieties for a range of production systems across Scotland driving specific breeding programmes for Scottish systems.
On farm advice – model real farm	New on farm sensors, research on farm rather than on research farms. Development of new sensing technology, soil	Provide data for forecasting and models, as well as reducing inputs and more accurate	Develop a research programme that works with monitor farms and LEAF farms to determine	Data provided from these sensors will be used to develop machine learning approaches to

	moisture, damage by pathogens	disease monitoring on farm	‘on farm’ methods for monitoring environmental parameters (e.g. soil moisture, temperature and rainfall) throughout the growing season and explore use of these data for predictive modelling or management decisions about specific issues (e.g. nutrient, pest, disease management).	forecast future cropping systems under a range of climate scenarios
Crop improvement and breeding				
Nutritional use and nutrition value as breeding targets for plant breeding community	Developing methods to screen large numbers of accessions for human nutrition and developing pre-breeding germplasm for breeding (cereal biochemistry and nutrition, physiology & genetics)	On-farm diversification and new products. Links into changing diets and more emphasis on food in addition to feed	Introducing ‘foodomics’ large scale screening of germplasm for nutritionally interesting components and linking nutritional to genes and begin deliberate breeding for nutrition	Develop new lines that can be grown on farm under different environments and determine the effect of genotype and environment on nutritional quality. Open new markets for a range of interesting products from barley
Value of heritage and wild relatives as novel sources of variation	Novel methods to link location to genetics, to identify potentially useful variation. Can we model future climate predictions for UK (see Climate change adaptation in the agriculture sector in Europe) and identify landraces that have the genetic capacity to thrive? (Modelling, genetics & conservation)	Conservation is a key global challenge. As well as providing pre-breeding material for future use	Identify potentially useful germplasm using landscape genomics approaches which combine state of the art genome sequencing and ecogeographical satellite data. Using these data to identify good parental combinations to start a bespoke breeding programme for Scottish agriculture, using the	Using ‘speed breeding’ to accelerate through breeding cycles and release material for field selections across different environments using the network of monitor, LEAF and experimental farms (participatory selection-farmer led) Characterise appropriate seed storage conditions

			past to resource the future approach.	to conserve diverse range of germplasm.
Pre-breeding activities (targeted and bespoke)	Can we breed for resilience different trialling sites across the UK. Expensive- could we devise models to achieve this? Environmental genomic selection. Large scale projects similar to Designing Future Wheat (DFW) **New breeding technologies – genomic prediction particularly for resilience)** (genetics, quantitative genetics, agroecologist, agronomy, engagement with breeders)	This area links to the above using our large germplasm collections.	Develop pre-breeding material for testing across different environments and marginal land. Begin to develop prediction models using genomic selection and other new available breeding technologies.	Release new varieties and also provide pre-breeding material for commercial breeding companies which are part of IBH stakeholders.
Spring and winter varieties or facultative landraces exhibit a flexible flowering system	Understanding the genetics of vernalisation and subsequent flowering and maturation. If we can understand the relationship between temperature and flowering and hence yield (natural variation or mutant populations) we can develop new varieties for different environments	New varieties that are better adapted to differing environments such as warmer winters, early harvest before increased summer rains	See above	See above
Gene expression and gene networks in the context of a changing environment	Understanding gene expression. Most traits are controlled by a number of genes with small effects, and often linked in a cascade or network. Research in this area is in its infancy and identifying genes and understanding patterns of expression under different environment requires fundamental and basic molecular study.	Improved variety development and tailoring to different environments	Use newly developed technologies to study gene expression under differing environments and in the field. Facilitate this by establishing experimental platforms to generate and interpret gene network expression data.	After several years of data generation across our experimental farms, we will work with digital and machine learning organisations to exploit this data and provide predictions for future breeding strategies- Developing a completely new way of predicting the future.

	(molecular biology, bioinformatics, quantitative genetics)			
Innovative phenotyping using artificial environments for cold and heat experiments	Field scale ‘artificial’ environments to monitor future climate scenarios, identifying genes and select new varieties	Provide forecast data for future models. Identify genetic markers for breeding and generate pre-breeding material.	Use state-of-the-art artificial environments that can emulate future climate change, with variable temperature, water and daylength accurately monitored and screen germplasm collections and new breeding populations for adaptation to climate change.	Identification of genes that are associated with changes in climate which can be used in breeding, both bespoke programmes developed by IBH and commercial breeders. Use these data for machine learning approaches to identify combinations of genes that will be required for future and develop these as ‘proof of concept’ varieties for testing under controlled and field conditions.
GM and gene editing in barley	This research area in barley has started but requires a more coordinated approach to lead the way in gene editing. This will require government policy changes to be translated into varieties. (genetics & molecular biology)	Potential to develop new and novel combinations of varieties in a very targeted way, at the gene level. Reduce inputs. Catch-up with non-European countries with less restrictive regulations	Produce evidence from both the scientific and societal perspective for the value of GM and gene editing approaches to solve issues facing the industry associated with environmental change	Routine screening of gene edited lines toto determine the effect of gene. These lines can then be included in breeding programs directly or by selecting lines from our large germplasm collections that contain natural variation in these genes.
Value chain requirements				
Malting and distilling quality improvements and optimisation	We know very little about how to improve malting quality traits in a pre-breeding or breeding context. We should develop a programme of research which focuses on understand the	Identify genetic markers that can be used in breeding to develop new improved malting varieties.	Fundamental and basic research to understand malting and the process from steeping to kilning. This needs to be in conjunction with MAGB	Identify the gene networks that are involved in malting and develop methods to improve and maintain yields that meet quality

	genes expressed at all stages of malting from micro- to macro-malting commercially. (cereal chemistry, molecular biology, genetics, maltsters)	Simple, cheap and easy phenotypic screening to provide data for national and recommended list	and SWRI (sampling both large scale malting and micro-malting used for testing new varieties) and Heriot Watt University MSc research programme. Examine the interaction between environment, grain nitrogen, yield and water used during germination under field conditions.	standards for malting sustainably and consistent across environments. Co-develop simple screening methods for new varieties with MAGB, AHDB, SASA and SWRI.
Research into co-products and by-products husks and straw at different levels field, malt and distilling	Develop novel approaches to use the non-grain barley plant. Fundamental research to identify components of husks and straw could lead to improvements in digestibility (cereal chemistry, molecular biology and physiology)	New untapped potential and crop value. Novel and cash value use for straw, providing farmers with alternative uses.	Combine the genetic and molecular understanding of cell wall components with chemistry to develop a clear picture of the value of straw and husks.	Novel products that are fit for purpose in terms of environment and sustainability. Large scale testing and product development
Social and cultural barriers				
GM acceptability, education and consumer perceptions	A positive campaign is required to identify the benefits of such approaches in context of reduced positive environmental effects (social sciences, government and advisory agencies)	Government and public acceptance of novel technologies	As with brand ambassadors, a ‘peer to peer’ approach will be in place to mobilise opinion and get the message across.	Whether a product is GM or gene edited will not be an issue as the benefits will have been proven to far outweigh the negatives
Brand ambassadors getting the message to a younger audience	This links in with social sciences and citizen science programmes, which is a neglected area	Getting the message across to this demographic about barley will have an impact which is not just about promoting the	Enthuse young people about the issues facing agriculture with emphasis on barley creating brand ambassadors for a ‘peer to peer’ approach	Drive policy on barley sustainability from the ground up.

	(Social science, industry, bakers, crofters and craft industries)	products, but also promoting plant sciences to future generations		
Rural population retention	Research is needed to identify why people move to urban areas. More awareness of the benefits of agriculture through knowledge exchange	A new generation excited about technological advances and professional recognition of working and living in rural areas.	A review of rural communities and in particular the role of agriculture. Fund a joint PhD to examine all aspects of rural life, including a historical review (Scottish Studies department at University of Edinburgh for example). A novel approach would be to have a split PhD working as part of a rural community - this could be a farm, croft or distillery.	Development of new training courses that promote rural economy and influence policy to enhance investment in rural population retention with particular respect to barley production and use.

Some quotes from groups about future research and translation

‘Research is curiosity-driven and fundamental research is still required. Whisky is the economic driver and it is important from a scientific and curiosity perspective. We still know very little about the malting process in terms of which genes are switched on and off, how we can reduce water use but maintain germination? These are fundamental processes that require discovery-based research with impact’.

Future directions and roadmap to maintain barley as a major crop for Scotland

The key to future barley research is to develop a transdisciplinary scientific approach (‘team barley’) bringing together researchers from a wide range of disciplines and organisations to work together with an equally trans-sectional stakeholder engagement (Figure 1).

Key Areas of research

Developing a dynamic barley crop

Genetic dissection of sustainability traits while maintaining or increasing yield. This requires basic research to identify genes involved in adaptation. Adaptation is a complex process that requires trait expression and trait functions to be studied under a range of climate scenarios and reduced inputs. The key components include: soil microbial root interactions (microbiome and rhizosphere), nutrient uptake efficiency (microbiome, rhizosphere, rhizosheath); nutrient transport (cell to cell interactions and physiology); adaptation to developing biotic and abiotic stress (heat, water, salt, pests, disease, competition); seedling vigour and establishment (cell cycling); tillering and flowering (reproductive development), grain filling and composition (nutrient partitioning) and maturity and harvest. We need better understanding all of these components and how they influence the crop to turn certain functions on and off during the adaptation process.

Enhancing nutritional value and quality barley

Altering the plant composition, straw and grain for feed, food, secondary products/biofuels and malt also requires a systems approach. The term ‘foodomics’ has been used when describing the combined approaches of genetics, genomics, transcriptomics, proteomics and metabolomics to enhance grain for nutrients and micronutrients. Knowledge of the cell wall composition in straw development is required to increase digestibility for both animal feed and biofuel production. Understanding the process of malting and characteristics contributing to improved malting quality requires studying the genetic control of germination, the cascade and network of genes that are involved when stored grain comes into contact with water, and the breakdown and mobilisation of grain nutrients. Finally, to enhance barley as a food product requires consumer acceptability of a new product, barley needs to become the ‘new oats’ (porridge) and the ‘new rice’ (risotto) and possibly ‘new wheat’ (bread).

Maintaining soil quality and enhancing marginal soils for barley production

We need to maintain our high-quality arable soils and consider whether marginal soils could be used for cultivation. This requires research into best agronomic practices combined with sensing technologies to increase precision application of inputs, as well as developing germplasm that can more efficiently use the available nutrients, particularly on marginal soils. Studying land management and innovative rotations and alternative cropping practices such as intercropping. Creating more sustainable production systems by identifying and promoting activity of soil microbes to increase nutrient availability, prime crop immunity and stress tolerance, and enhance crop performance.

What is required to address these challenges in a coherent manner?

1. Investment in research infrastructure that can facilitate the convergence of disciplines. The Tay Cities deal has gone some way to address this, in that the International Barley Hub can make this possible (Figure 1). Not just providing the infrastructure for experimentation but also a hub for sharing ideas and knowledge, as well as a convenient location for stakeholder engagement. The hub can facilitate the development of private and public partnerships and importantly engage the public in barley research. By supporting this network, we will be in a strong position to identify the next generation of important traits that will underpin the ability of UK and global agriculture to respond to the pressing strategic opportunities and challenges and changing research opportunities and demands. We must have appropriate access to the necessary tools, resources, and funding channels, and to interact effectively with sector stakeholders to ensure maximised knowledge exchange and impact. It also gives us the opportunity to focus the integration and mentoring of the next generation of stakeholders in the entire barley value chain, such that it is instinct to interact and strengthen the whole system.

2. Field based research is crucial to validate and translate research to achieve impact at all levels. Our science is grounded on basic research, but its application requires field-based testing. Across the MRPs, SASA, SAC consultancy, AHDB Monitor and LEAF farms we have a network of experimental farms representing the diversity of soils, environments (temperature and rainfall) and management that can translate the laboratory based research into the real world, reaching our key stakeholders and forging partnerships with processors, regulatory agencies, breeders, farmers and crofters, retailers and consumers, policy advisers and knowledge transfer organisations (Figure 1).

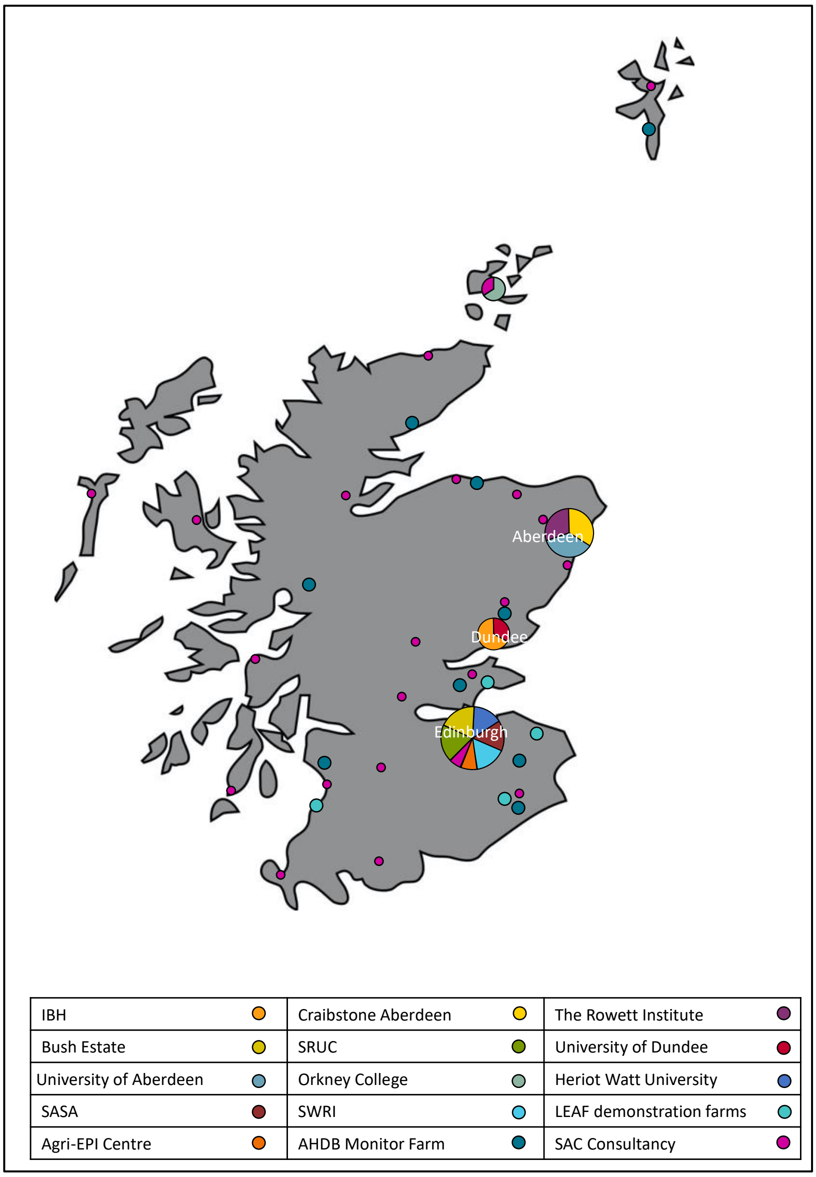

Figure 1. Identification and location of Research Institutes, Universities and Colleges, Agencies, Consultants, Experimental farms, AHDB monitor farms and LEAF farms.