



Government
Office for Science

Knowledge
Transfer
Network

Biosciences

New Innovative Approaches to Crop Protection

*Report from Food Research Partnership
Stakeholder Workshop*

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Executive Summary

Recent EU legislation adopting an increasingly hazard, rather than risk-based approach to the use of crop protection products in Europe, could mean chemicals that play a key role in crop protection are withdrawn from use. This, along with the shortage in discovery of new active compounds and the steady build up of pesticide, fungicide, insecticide and herbicide resistance in crops, is increasing pressure on the effective use of crop protection products. As crop pests and diseases are significant contributing factors to the gap between theoretical and actual crop yields, the public and private sectors of the agricultural community need to work together to determine how UK crops might best be protected within the EU regulatory framework.

In this context, the Government Office for Science - Food Research Partnership commissioned a Sub-Group to consider an approach to realise new innovative approaches to crop protection in UK agriculture, and for international development, including the exploitation of novel cultural practices, natural plant defence mechanisms and biocontrol agents, in the context of integrated pest management. The Innovation in Crop Protection Workshop reported here forms part of this work.

Based on current and projected issues affecting UK crop protection it is clear that a national crop protection strategy needs to be developed and implemented, founded on the principles of integrated management (i.e. using all the available tools and developing more) to provide durable control of those pests, diseases and weeds causing the largest losses in major UK arable and horticultural crops. This strategy needs to be sufficiently robust and far-sighted to enable adaptation to climate change. The strategy, owned and delivered by a single organisation, should prioritize needs at both national and international levels, and be supported by a route for two-way dialogue between the developers and users of agricultural technology. This will enable effective influence of policies controlling agrochemical use and breeding which currently inhibit innovation in crop protection. Suggestions for key initiatives are explored in this document.

Introduction

One of the contributing factors to the gap between theoretical and actual crop yields lies in the effective use of crop protection products. In addition to a shortage in the discovery of new active ingredients and the steady build up of pesticide, fungicide, insecticide and herbicide resistance, increased pressure is now being brought to bear on crop protection products through recent EU legislation adopting an increasingly hazard, rather than risk-based approach to their use in Europe. There is widespread concern among the UK agricultural community that the results of this legislation will be to withdraw from use chemicals that play key roles in crop protection. As these chemicals are subject to the new requirements during this decade, there needs to be joined-up thinking across the public and private sectors of the agricultural community to determine how UK crops might best be protected within the EU regulatory framework.

In this context, the Government Office for Science (GO-Science) Food Research Partnership has commissioned a Sub-Group to consider an approach to realise new innovative approaches to crop protection in UK agriculture, and for international development, including the exploitation of novel cultural practices, natural plant defence mechanisms and biocontrols, in the context of integrated pest management.

The Sub-Group met on the 3rd December 2012 in London and identified four priority themes:

- Theme 1 - Application of 'omics'¹ Technologies
- Theme 2 - Novel Control Agents
- Theme 3 - Agronomics Approaches
- Theme 4 - Knowledge Transfer

¹ 'Omics' informally refers to a field of study in biology ending in *-omics*, such as genomics, proteomics or metabolomics.

Innovation in Crop Protection Workshop

The Food Research Partnership (FRP) Sub Group on New Innovative Approaches to Crop Protection, together with the Biosciences Knowledge Transfer Network (BKTN), organised a workshop on Thursday 10th January 2013 at the BIS Conference Centre in London, to consider the four themes identified above. This workshop was attended by 40 experts from the research-base, industry, organisations, end-users, levy-boards, and governmental agencies.

The aim of the workshop was to explore proposals for concrete, realistic actions that might be considered by the Food Research Partnership, as recommendations that can be taken forward through the BIS/Defra 'Agri-Tech' Strategy, to be launched in Summer 2013.

The first keynote presentation, delivered by Brendan Bayley (HM treasury), gave delegates some insights from agricultural economics in general, and the recent price spikes in particular, stressing that increasing yields and improving resilience in the face of the challenges articulated by the UK Foresight report on Global Food and Farming Futures, is really important, although the impact on household food security will vary depending on the context.

In the second keynote presentation, Mike Bushell (Syngenta) outlined the process for delivery and development of a new crop protection active ingredient and also highlighted the importance of formulation science and application technology in the safe and responsible use of crop protection products. Mike emphasized that continued innovation in this area is important, yet there are real pressures and threats from regulation, resistance and the sheer cost of developing new products. Mike also mentioned the need for sustainable intensification of agriculture (e.g. increasing productivity, making more efficient use of all inputs and reducing the negative impacts of agriculture). As recognized by the UK Foresight project, this requires a much more holistic system-based approach to farming, which includes integrated approaches to pest management. Chemicals will remain a cornerstone of crop protection for the foreseeable future, but there are also opportunities for application of other innovations in crop protection.

Delegates also heard presentations covering the four themes identified in the Sub-Group meeting, on 3rd December 2012 in London. Sophien Kamoun (The Sainsbury Laboratory) talked about the 'Applications of next-generation sequencing technologies to crop improvement and plant pathology'; Marcus Meadows-Smith (Bayer Biologics) presented on the 'Novel Control Agents and Integrated Solutions for Sustainable Agriculture'; Keith Norman (Velcourt) offered an 'Agronomic perspective'; while Bill Clark (National Institute of Agricultural Botany – The Arable Group Ltd NIAB-TAG) discussed aspects of knowledge transfer.

Thereafter, delegates discussed each theme in four groups of mixed expertise (see Annex 2), with the aim of making recommendations for areas of potential innovation in each theme and presenting a view of what success would look like.

Recommendations

The outcomes of these discussions have been captured, and the recommendations for each theme have been summarised below. The overview written by each theme leader is also reported before the recommendations to provide some background.

Theme I: Application for 'Omics' Technologies in Crop Protection

Theme Leader: Robert Edwards, The Food and Environment Research Agency

Overview

The development of non-targeted analytical methods for everything from metabolites to genomes has revolutionized biological research and been a major driver for the adoption of systems-based approaches to biological research. The potential for 'omic'-based technologies to drive innovation in crop protection is powerful when applied to understanding plant-pathogen interactions and genetic variation among crop genotypes and populations of target organisms (weeds, invertebrates and pathogens). Faced with a decline in the discovery of new actives using conventional methods, 'omic' technologies linked to systems approaches are now being increasingly used across the life science area to identify new potential 'drugable' targets.

Some ideas on using 'omics' more extensively in 'conventional' crop protection strategies include:

- Using molecular approaches to optimize the integrated use of agrochemicals with crop varieties of differing genetic background (e.g. matching fungicide mode of action with host resistance);
- Identification of new crop protection targets for intervention in pathogens, pests and weeds which may provide the basis for screening chemical and biological agents;
- Understanding how beneficial endophytes and resistance elicitors enhance crop protection and thereby improve their efficacy;
- Understanding and exploiting 'natural' plant protection strategies including pest and disease resistance, as well as embracing less studied interactions such as allelopathy;
- Understanding the many resistance mechanisms reducing ability to deploy existing toxophore and how they may be counteracted;
- Developing synergistic mixes and formulations of pesticides; and
- Directly identifying novel bioactive natural products through bioprospecting.

Recommendations

1. Virtual National 'Omics' Centre

Issue: The sequencing and making available data on the genomes of invertebrate pests, pathogens and weeds that are specifically detrimental to crop yields in the UK may not be a commercial priority for multinational companies.

Recommendations:

- 1) Development of a virtual national centre to bring together 'omics' activities of relevance to UK crop protection targets with other areas of expertise required for data interpretation and exploitation. This will enhance the dialogue between experts, enable refinement of existing technologies and make them more reliable and accessible (not all 'omics' yet cheaply available), as well as accelerate the development of new technologies;
- 2) Prioritise publicly funded programmes to sequence genomes of invertebrate pests, pathogens and weeds, specifically detrimental to UK crop yield and quality;
- 3) Publicly funded 'omics' research programmes to:
 - a. Better understand plant-pathogen/pest interactions (e.g. matching genetic information and population biology);

- b. Better understand the influence/impact of beneficial microbial interactions with plants, e.g. rhizosphere, phyllosphere and endophyte organisms, on plant health/sickness to enable commercial applications;
- c. Develop more sensitive diagnostic methods (both DNA and metabolite) for use in the field and 'plant clinics';
- d. Better match agrochemistry and crop genetics (cf: personalized medicine);
- e. Better understand and help counteract resistance mechanisms;
- f. Develop reliable resistance elicitor-based crop protectants matched to crop genetics, better exploiting the plant's innate resistance mechanisms; and
- g. Demonstrate safe mode of actions and benefits that might help new crop protection products (e.g. semiochemicals) through the subsequent regulatory process.

4) Prioritise investment to develop/use appropriate bioinformatic skills to organise and analyse the huge amount of data generated with 'omics' technologies and permit the extraction of useful information to develop solutions; making the data publically available; and supported by training for specialists and user engagement initiatives to increase capability in using informatics.

Success: Development of new safe and effective crop protection products and practices, which will have an easier passage through the regulatory process, on the basis of greater knowledge about their mechanisms of action.

Theme 2: Novel Control Agents

Theme Leader: Julian Little, Bayer CropScience Ltd

Overview

Controlling pests and diseases is not a trivial issue, and never has been. Whether dealing with blight in the 17th, 18th and 19th centuries, dealing with diseases in vines for the last 3000 years, dealing with insect attack in all sorts of crops, or controlling blackgrass in wheat over the last 30 years, the issues remain the same. How do you get consistent long term control of pests and diseases? Is it possible to integrate solutions to avoid the spread and build-up of resistance to any treatments that innovations might bring to the market?

Other than innovative farming practices there are three types of intervention:

1. 'Traditionally', farmers have been used to a succession of new chemicals to deal with their crop protection problems. More recently, a combination of new legislation, and increased costs associated with dealing with that legislation have eliminated many pesticides, and slowed down the introduction of new ones to a trickle.
2. There has been much interest in the use of advanced breeding techniques, including agricultural biotechnology, to introduce insect and disease resistance into major crop plants. This has been very successful in many parts of the world, but commercial activity in Europe is limited essentially to the use of insect resistant maize in the Iberian Peninsula.
3. The use of novel control agents and biopesticides has seen many dawns, some of them false. More recently there has been a flurry of interest in this area, highlighted by high visibility acquisitions of biopesticide companies.

Recommendations

1. Employ biological control agents (biologics)

Issue: Biological control agents (BCAs) present immediate opportunities for economically beneficial investments, as there is a need to replace withdrawn crop protection products with

more sustainable alternatives for the UK, where these are unlikely to be high priorities for normal commercial activity and where new pests and diseases need to be controlled.

Recommendations:

- 1) Prioritise research to:
 - a. Understand how interactions with BCAs work, their modes of action and active metabolites;
 - b. Understand how BCAs increase the efficacy of conventional crop protection, and/or help delay/prevent the development of resistance, when used as part of an Integrated Pest Management (IPM) programme (increasing yields in some cases);
 - c. Develop new niche applications for active molecules that might have been discarded from companies' R&D programmes (when looking for more global applications); and
 - d. Apply 'omics' technologies (theme 1) to forecast if resistance can/will develop to these novel control agents.
- 2) Establish Public-Private Partnerships to contribute to the growth agenda.

Success: A future proofing of crop protection with more tools available to deal with problems as they arise, including a wider and more systematic use of novel control agents in UK agriculture, capitalising on past investments in plant and microbial research. More competitive farmers and a more resilient food supply chain that is less reliant on food imports and has less environmental impact.

Theme 3: Agronomic Approaches

Theme Leader: Keith Norman, Velcourt Ltd

Overview

Some of the biggest threats to sustainable crop production are policies and resistance issues. Better informed policy, based on scientific evidence and risk rather than hazard, would improve the maintenance and development of safe and effective crop protection products. The number of situations where resistance to pesticides are occurring is increasing. Against a background of stagnating cereal yields, this is a great cause for concern.

The yet unknown definition of 'Endocrine Disruption' (ED) is key to the future size and content of the armoury that crop producers will have at their disposal. This definition will not be available until the end of 2013. In the interim, there are two opposing views within Europe. A group led by the Danes favour the approach that if there is a trace or risk of endocrine disruption, the pesticide should be banned. A group led by the UK favour a more evidence-based approach that proof is needed of the risk to human health.

Chemicals Regulation Directorate (CRD) is about to publish its own report on the impact of the ED threshold for the UK.

In addition, resistance across a wider number of targets is occurring at a faster pace than ever seen before. There are herbicide resistant weeds (blackgrass, wild oats, ryegrass, chickweed and poppies), diseases resistant to key active ingredients (septoria, mildew) and resistant pests. Any restriction of the number of agrochemical options available to growers could easily exacerbate the situation.

At present, there are few alternative solutions to minimise the impact of resistance apart from crop rotation, the use of fallow and to some extent varietal choice/delayed drilling. Looking to the future, there are a lot of exciting technologies that need much more investment to bring

about applied developments. These include synthetic biology, use of semiochemicals, allelopathy, and biocontrol agents.

As the new EU Pesticide legislation reduces the choice of active ingredients, there will be a considerable challenge in maintaining even the current levels of crop yields.

Recommendations

1. Monitoring for resistance – weeds, pests and diseases.

Issue: Loss of current and new active ingredients in registered pesticides for existing and new pests and pathogens is increasing the risk of crop resistance. The lack of information on the occurrence and spread of resistance among weed, pests, and disease organisms, hinders forward planning in ensuring effective contingencies for epidemics.

Recommendation: Development of a centrally collated, independent monitoring system for resistance to crop protection agents in key weeds, pests and diseases of economic importance, with centralised centres for sample testing and application of diagnostic technologies using consistent sets of molecular markers, and delivering open source information (following model of EU potato blight initiative).

Success: More region specific information on resistance directly available to farmers to allow better decisions in planning and timely application of appropriate control measures, depending on profile of disease and resistance of varieties sown. Knowledge of pest and disease profile/incidence supports development of pest and disease resistant varieties, aided by using genomics.

2. Modelling of crop pest epidemics and disease outbreaks

Issue: More dependable modelling of crop pest epidemics.

Recommendation: Development of pest and disease models using ‘what if?’ scenarios to control disease and yield outcome, capitalising on lessons from models known to work well (e.g. French *septoria* model), and working with counterparts in Europe.

Success: Better understanding of disease development and insect spread; ability to forecast likely pest and disease incidence with weather forecasts; and providing guidance to farmers on prevention and control measures.

3. Weather forecasts

Issue: Lack of reliability in short and medium-term weather forecasts makes it difficult for farmers to plan crop management practices.

Recommendations: Exploration with Met Office of opportunities to improve reliability of medium-range weather forecasting, and access to information for farmers.

Success: More accuracy in weather forecasts supports farmers in decision making on crop management.

4. Precision farming and diagnostics to improve decision support systems

Issue: Developments in precision farming and diagnostics will be influential on crop protection and based on UK scale agriculture applicable to several global markets. Technologies include: mechanized precision agriculture, advanced molecular diagnostics linked to smartphones, and the ability of bringing genomics information to field applications.

Recommendations: Development of technologies and best practice in precision agriculture, including machinery (appropriate for the UK and to export for use in other farming systems overseas), and real time diagnostics/ use of mobile phone apps to support farmers in improving crop protection systems.

Success: Gap between potential and actual yields is reduced.

5. Improved management of crop rotations

Issue: General focus of farmers in maximising production yields through traditional applications of fertilisers and pesticides, with limited incentives and knowledge on use and value of crop rotations.

Recommendations: Increase research on crop rotations to consider the inclusion of new major crops, including industrial crops, companion crops and crops which are likely to be displaced from other regions due to climate change. This would entail increasing plant yield in 'under-improved' crops, applying technologies that researchers employ overseas and taking account of improving crop plants not previously economically viable.

Success: Improved use of crop rotations, utilising integrated pest management principles, and development of novel agronomic solutions to reduce risk of attack by pests, weeds and diseases.

6. Plant listing criteria

Issue: Consider changing national and recommended listing criteria for new plant development to include reducing inputs as well as measuring yield. This would require a larger input for 'public good' in the plant breeding process, but could realize major benefits in driving environmental benefits such as reduced nitrogen inputs.

Recommendations: Extend plant breeding testing to include reduced inputs as well/in place of increased output (yield) alone.

Success: A pipeline leading to new crop varieties better suited to a changing environment, and reduced availability of inputs.

Theme 4: Knowledge Transfer

Theme Leader: Bill Clark, NIAB-TAG

Overview

Following the Foresight Report in 2011, the concept of 'sustainable intensification' became more widely discussed. This term involves:

- Simultaneously raising yields, increasing the efficiency with which inputs are used and reducing the negative environmental effects of food production;
- Economic and social changes to recognise the multiple outputs required of land managers, farmers and food producers; and
- Redirection of research to address a more complex set of goals than just increasing yield.

The industry roadmap 'Feeding the Future'² acknowledges the importance of promoting the development, uptake and use of sustainable, resilient and profitable agricultural practices and highlights the need to:

² <http://feedingthefuture.info/>

Develop a series of "good practice" case studies for effective knowledge transfer and evaluate common features, so that future research can be commissioned with specifications that maximise the likelihood of effective delivery.

The complexity of achieving effective knowledge transfer that has real impact within the industry is frequently underestimated. Farmers are sophisticated and innovative people. They run multi-million pound businesses and adopt technology readily – and yet find it difficult to access research findings from Universities and Research Institutes. The UK farming industry is huge, with over 200,000 arable farm businesses. The larger businesses (over 100 ha) still number c. 40,000 with 11,000 salaried farm managers. These are large numbers to target and yet only represent a small proportion of the total number of people who need to be influenced. Others include agrochemical manufacturers, distribution organisations, plant breeders, machinery manufacturers, the seed trade and independent advisers, all of whom have a significant role to play in changing agricultural practices.

To achieve real impact in agriculture there needs to be a national structure or platform for knowledge transfer and implementation supported by public intervention. This is not a one-way process from researcher to farmer. It is a highly complex multi-directional and multi-disciplinary interaction with industry, involving plant pathology, entomology, and weed science expertise. Specialist knowledge transfer staff are needed to help researchers engage with industry at all levels. Applied researchers need recognition and reward.

Recommendations

1. Incentives for scientists in translation research

Issue: Focus of scientists primarily on peer-reviewed publications for their career development, absence of recognition by Research Councils of scientists involved with good high quality applied research, and lack of incentives for engagement in translating research into use.

Recommendations: Encourage a change of culture to incentivise scientists to engage in research to solve practical problems relevant to industry, e.g. by acknowledging the contribution made to applied industrial R&D and associated dissemination to business; encourage inclusion of end-users on project steering groups; change the rule for industry engagement in BBSRC Industrial Partnership Awards to allow in-kind as well as cash contributions; and encourage more input from venture capitalists.

Success: Two way flow of information between science and industry, with better uptake of knowledge.

2. National Knowledge Transfer Strategy

Issue: Need for better translation and subsequent transfer of crop production/protection science onto farm to meet practical needs of farmers and their consultants, leading by example, and spread of best practice through influence of innovative farmers on others.

Recommendation: Development of a national strategy for knowledge transfer and translational research to fix the broken pipeline, and improve co-ordination across disparate and fragmented activities by different organisations (leadership from AHDB and input from Landex Colleges), with engagement of “non-agricultural” Universities where an enormous potential skill base resides.

Success: Stakeholders signed up to a national strategy and implementation, and working to the same objectives. National Translation Centre established with national and regional roundtable events with researchers and users, and a network of regional experts (using

universities, institutes and existing knowledge transfer organisations). Researchers are actively engaging directly with local farmers and crop associations.

3. Communication / Engagement with Users

Issue: Lack of co-ordination and communication between stakeholders engaged in crop protection science and translation into use.

Recommendations: Establishment of networks, whilst embracing current mechanisms, to promote better coordination and communication between stakeholders through existing demonstration farms, agronomy / farmers clubs, engagement with users during development and implementation of research to tailor outputs to user needs, and establishment of register of expertise and projects.

Success: Better links and more effective knowledge exchange between researchers and farmers/ other users of research.

General recommendations

1. Delivery of a National Crop Protection Strategy

Issue: Lack of joined-up delivery of crop protection tools

Recommendation: Development and implementation of a national crop protection strategy founded in the principles of integrated management (i.e. using all the tools and developing more) to provide durable control of those pests, diseases and weeds causing the largest losses in UK major arable and horticultural crops; and sufficiently robust and far-sighted to enable adaptation to climate change.

Success: Continuing reduction in yield gap and improved crop quality.

2. Better Regulation

Issue: Slow speed of product approvals and re-registration. Cost, time taken and uncertainty to meet regulatory requirements. Uncertainty for the industry regarding future EU pesticide legislation, and lack of new pesticide actives offering solutions.

Recommendation: Joined up action between government and its regulators with adequate resource, to ensure new active ingredients are approved in timely manner, biological controls are fast tracked, and more effective approaches to regulation of new technologies are developed; with continued engagement in EU to try to ensure EU regulation is proportionate.

Success: Encouragement of continued investment in new control measures.

3. Skills Capacity and Expertise

Issue: Insufficient skills in some areas, particularly bioinformatics, chemistry of plants, weed science, entomology, plant pathology, knowledge transfer and translational research.

Recommendations: Investment in training provision among researchers and users to improve use of new technologies and innovation.

Success: Vibrant well skilled sector.

4. Public Debate

Issue: Improve public awareness and understanding of new technologies to avoid the public perceptions that have impeded the application of GM in agriculture.

Recommendation: Development of a communication strategy with carefully thought-out narrative and nomenclature for new technologies (e.g. 'omics').

Success: New technologies are available for uptake by users.

Conclusion

There are ways to stimulate greater innovation in basic and applied research to support farmers with innovative crop protection practices, so that they start to bridge the yield gap. This will be best supported by a national crop protection strategy, founded on the principles of integrated management (i.e. using all the available tools and developing more) to provide durable control of those pests, diseases and weeds causing the largest losses in UK major arable and horticultural crops. The approach needs to be sufficiently robust and far-sighted to enable adaptation to climate change.

The strategy, owned and delivered by a single organisation, should prioritise needs at both national and international levels, and be supported by a route for two-way dialogue between the developers and users of agricultural technology. This will enable effective influence of policies controlling agrochemical use and breeding which currently inhibit innovation in crop protection.

Key initiatives supported through the strategy will:

- Create a Virtual National 'Omics' Centre – to draw on recent developments in 'omics' technologies to characterise major pests, weeds and diseases and the potential for new control strategies and diagnostics;
- Establish public-private partnerships to develop new niche applications for biological control agents;
- Establish National Translation Centre with national and regional roundtable events with researchers and users, and networks to promote coordination and communication between stakeholders through existing demonstration farmers, farmer clubs etc.;
- Develop a centrally collated, independent monitoring system, with centralised centres for sample testing and application of diagnostic technologies, to comprehensively monitor and address pesticide and herbicide resistance at a national level;
- Increase research on integrated approaches in crop protection, from the molecular to agri-system level, including improved management of crop rotations, precision agriculture, and diagnostics to improve decision support systems;
- Make more effective use of existing agricultural data systems and develop more dependable predictive modelling;
- Encourage change of culture to incentivise scientists to engage in research to solve practical problems relevant to industry;
- Facilitate joined up action between government and its regulators with adequate resource, to ensure new active ingredients are approved in timely manner, biological controls are fast tracked, and more effective approaches to regulation of new technologies are developed; and
- Develop a communication strategy with carefully thought-out narrative and nomenclature for new technologies (e.g. 'omics').

Success for these changes overall - A measurable closing of the yield gap.

Annex I: Membership of the Food Research Partnership sub-group on New Innovative Approaches to Crop Protection

David Leaver, Commercial Farmers Group (Chairman)

David Bench, Health and Safety Executive

Rosie Bryson, BASF

Mike Bushell, Syngenta UK Ltd

Bill Clark, The National Institute of Agricultural Botany (Theme leader)

Ian Crute, Agriculture and Horticulture Development Board

Robert Edwards, The Food and Environment Research Agency (Organising committee and Theme leader)

Lin Field, Rothamsted Research

Chris Gaskell, The Royal Agricultural College

Julian Little, Bayer CropScience Ltd (Theme leader)

James Moldon, Frontier Agriculture Ltd

Keith Norman, Velcourt Ltd (Theme leader)

Don Pendergast, National Farmer Union

Dale Sanders, The John Innes Centre (Organising committee)

Observers from UK Government

Department for Business, Innovation and Skills: Alex Chaix, BBSRC secondee

Department for Environment, Food and Rural Affairs: David Cooper

Secretariat

Aurélie Bovi, Biosciences Knowledge Transfer Network (Organising committee)

Elizabeth Warham, Government Office for Science (Organising committee)

Annex 2: List of workshop delegates

	Title	Forename	Surname	Organisation	Job Title
Group 1					
Chair	Prof	Robert	Edwards	FERA	Chief Scientist
scribe	Dr	Aur�lie	Bovi	Biosciences Knowledge Transfer Network	Knowledge Transfer Manager
1	Mr	Andrew	Barr	National Farmers Union	National Crop Board Member, NRoSO chairman
2	Dr	Tina	Barsby	National Institute of Agricultural Botany (NIAB)	CEO and director
3	Mr	Peter	Bassett	ADAS UK Ltd	Principal Consultant
4	Mr	Brendan	Bayley	HM Treasury	Head, (EU) Structural Reform Branch
5	Dr	Anthony	Biddle	Processors & Growers Research Organisation (PGRO)	Research Liaison Manager
6	Dr	Simon	Bright	Crop Improvement Research Club	Coordinator
7	Dr	Brian H.	Brown	Germaines Seed Technology	Senior Scientist
8	Dr	Mike	Bushell	Syngenta	Principal Scientific Advisor
Group 2					
Chair	Dr	Julian	Little	Bayer CropScience Ltd	Communications & Government Affairs Manager
scribe	Dr	Tom	Jenkins	Biosciences Knowledge Transfer Network	Plants & Crops Sector Lead and Assistant Director
1	Mr	Richard	Butler	Voluntary Initiative for Pesticides	Farmer (Wiltshire) and Company Director
2	Dr	Rosemary	Collier	University of Warwick	Director of Warwick Crop Centre
3	Dr	David	Cooper	DEFRA (Observer)	R&D Programme Manager
4	Prof	Ian	Crute	Agriculture and Horticulture Development Board (AHDB)	Chief Scientist
5	Prof	Lin	Field	Rothamsted Research	Head Department Biological Chemistry and Crop Protection
6	Prof	Rob	Field	John Innes Centre	Project Leader
7	Prof	Chris	Gaskell	Royal Agricultural College	Principal
8	Prof	Murray	Grant	University of Exeter	Chair in Plant Molecular Biology

Group 3					
Chair	Mr	Keith	Norman	Velcourt Ltd	Technical Director
scribe	Dr	Elizabeth	Warham	GO Science	Head, Food Security and Environment
1	Dr	Paul	Gosling	AHDB-HGCA	Research & Knowledge Transfer Manager
2	Mr	Julian	Hasler	National Farmer Union (NFU)	NFU representative on Pesticide Forum
3	Prof	Sophien	Kamoun	The Sainsbury Laboratory	Head
4	Prof	David	Leaver	Food Reseach Partnership	Chair of the sub-group in "Innovation in Crop Protection"
5	Mr	Rob	Mason	Chemicals Regulation Directorate. Health and Safety Executive (HSE)	Director of Regulatory Policy
6	Mr	Tim	Mayhew	Velcourt Ltd	Agronomy Services Manager
7	Mr	Marcus	Meadows-Smith	Bayer CropScience Ltd	Head of Bayer Biologics
8	Mr	James	Moldon	Frontier Agriculture Ltd	Crop Inputs Commercial Manager
Group 4					
Chair	Mr	Bill	Clark	National Institute of Agricultural Botany (NIAB)	Commercial Technical Director
scribe	Dr	Huw	Tyson	BIS (observer)	BBSRC secondee (Agri-Tech strategy)
1	Mr	Calum	Murray	Technology Strategy Board (TSB)	Lead Technologist AgriFood
2	Prof	Adrian	Newton	James Hutton Institute	IPM Research Leader
3	Mr	Andrew	Richard	Agrii	Agronomist/ member of Agrii Technical strategy board
4	Prof	Dale	Sanders	John Innes Centre	Director
5	Dr	Paul	Sopp	Fargro Ltd	Technical & Energy Director
6	Dr	Richard	Summers	British Society of Plant Breeders / RAGT Seeds Ltd	Vice chairman / Cereal Breeding and Research Director
7	Dr	Helen	Thompson	FERA	Team Leader, Environmental Risk
8	Mr	John	Young	Crop Protection Association / BASF	Stewardship Manager - Crop Protection

Annex 3: List of recommendations for new innovative approaches in crop protection

Theme 1 - Application of 'omics' technologies	
Issue	The sequencing and making available data on the genomes of invertebrate pests, pathogens and weeds that are specifically detrimental to crop yields in the UK may not be a commercial priority for multinational companies.
Recommendations	1. Virtual National 'Omics' Centre
	1) Development of a virtual national centre to bring together 'omics' activities of relevance to UK crop protection targets with other expertises required for data interpretation and exploitation. This will enhance the dialogue between experts, enable refinement of existing technologies and make them more reliable and accessible (not all 'omics' yet cheaply available), as well as accelerate the development of new technologies.
	2) Prioritise publicly funded programmes to sequence genomes of invertebrate pests, pathogens and weeds, specifically detrimental to UK crop yield and quality.
	3) Publicly funded 'omics' research programmes to:
	a. Better understand plant-pathogen/pest interactions (e.g. matching genetic information and population biology);
	b. Better understand the influence/impact of beneficial microbial interactions with plants, e.g. rhizosphere, phyllosphere and endophyte organisms, on plant health/sickness to enable commercial applications;
	c. Develop more sensitive diagnostic methods (both DNA and metabolite) for use in the field and 'plant clinics';
	d. Better match agrochemistry and crop genetics (cf: personalized medicine);
	e. Better understand and help counteract resistance mechanisms;
	f. Develop reliable resistance elicitor-based crop protectants matched to crop genetics, better exploiting the plant's innate resistance mechanisms;
g. Demonstrate safe mode of actions and benefits that might help new crop protection products (e.g. semiochemicals) through the subsequent regulatory process.	
	4) Prioritise investment to develop/use appropriate bioinformatic skills to organise and analyse the huge amount of data generated with 'omics' technologies and permit the extraction of useful information to develop solutions; making the data publically available; supported by training for specialists and user engagement initiatives to increase capability in using informatics.
Success	Development of new safe and effective crop protection products and practices, which will have an easier passage through the regulatory process, on the basis of greater knowledge about mechanisms of action.

Theme 2 - Novel Control Agents	
Issue	Biological control agents (BCAs) present immediate opportunities for economically beneficial investments, as there is a need to replace withdrawn crop protection products with more sustainable alternatives for the UK, where these are unlikely to be high priorities for normal commercial activity and where new pests and diseases need to be controlled.
Recommendations	1. Employ biological control agents (biologics)
	1) Prioritise research to:
	a. Understand how interactions with BCAs work, their modes of action and active metabolites;
	b. Understand how BCAs increase the efficacy of conventional crop protection, and/or help delay/prevent the development of resistance, when used as part of an Integrated Pest Management (IPM) programme (increasing yields in some cases);
	c. Develop new niche applications for active molecules that might have been discarded from companies' R&D programmes (when looking for more global applications); and
	d. Apply 'omic' technologies (theme 1) to forecast if resistance can/will develop to these novel control agents.
	2) Establish Public-Private Partnerships to contribute to the growth agenda.
Success	A future proofing of crop protection with more tools available to deal with problems as they arise, including a wider and more systematic use of novel control agents in UK agriculture, capitalising on past investments in plant and microbial research. More competitive farmers and a more resilient food supply chain that is less reliant on food imports and has less environmental impact.

Theme 3 - Agronomic Approaches	
Issue 1	Loss of current and new active ingredients in registered pesticides for existing and new pests and pathogens is increasing the risk of crop resistance. The lack of information on the occurrence and spread of resistance among weed, pests, and disease organisms, hinders forward planning in ensuring effective contingencies for epidemics.
Recommendation	1. Monitoring for resistance – weeds, pests and diseases.
	Development of a centrally collated, independent monitoring system for resistance to crop protection agents in key weeds, pests and diseases of economic importance, with centralised centres for sample testing and application of diagnostic technologies using consistent sets of molecular markers and delivering open source information (following model of EU potato blight initiative).
Success	More region specific information on resistance directly available to farmers to allow better decisions in planning and timely application of appropriate control measures, depending on profile of disease and resistance of varieties sown. Knowledge of pest and disease profile/ incidence supports development of pest and disease resistant varieties, aided by using genomics.
Issue 2	More dependable modelling of crop pest epidemics
Recommendation	2. Modelling of crop pest epidemics and disease outbreaks
	Development of pest and disease models using ‘what if?’ scenarios to control disease and yield outcome, capitalising on lessons from models known to work well (e.g. French septoria model), and working with counterparts in Europe.
Success	Better understanding of disease development and insect spread; ability to forecast likely pest and disease incidence with weather forecasts; and providing guidance to farmers on prevention and control measures.
Issue 3	Lack of reliability in short and medium-term weather forecasts makes it difficult for farmers to plan crop management practices.
Recommendation	3. Weather forecasts
	Exploration with Met Office of opportunities to improve reliability of medium-range weather forecasting, and access to information for farmers.
Success	More accuracy in weather forecasts supports farmers in decision making on crop management.
Issue 4	Developments in precision farming and diagnostics will be influential on crop protection and based on UK scale agriculture applicable to several global markets. Technologies include: mechanized precision agriculture, advanced molecular diagnostics linked to smartphones and the ability of bringing genomics information to field applications.
Recommendation	4. Precision farming and diagnostics to improve decision support systems
	Development of technologies and best practice in precision agriculture, including machinery (appropriate for the UK and to export for use in other farming systems overseas, real time diagnostics/ use of mobile phone apps to support farmers in improving crop protection systems.
Success	Gap between potential and actual yields is reduced.

Issue 5	General focus of farmers in maximising production yields through traditional applications of fertilisers and pesticides, with limited incentives and knowledge on use and value of crop rotations.
Recommendation	5. Improved management of crop rotations
	Increase research on crop rotations to consider the inclusion of new major crops, including industrial crops, companion crops and crops which are likely to be displaced from other regions due to climate change. This would entail increasing plant yield in 'under-improved' crops, applying technologies that UK researchers employ overseas and taking account of improving crop plants not previously economically viable.
Success	Improved use of crop rotations, utilising integrated pest management principles and development of novel agronomic solutions to reduce risk of attack by pests, weeds and diseases.
Issue 6	Consider changing national and recommended listing criteria for new plant development to include reducing inputs as well as measuring yield. This would require a larger input for 'public good' in the plant breeding process but could realize major benefits in driving environmental benefits such as reduced N inputs.
Recommendation	6. Plant listing criteria
	Extend plant breeding testing to include reduced inputs as well / in place of increased output (yield) alone.
Success	A pipeline leading to new crop varieties better suited to a changing environment and reduced availability of inputs.

Theme 4 - Knowledge Transfer	
Issue 1	Focus of scientists primarily on peer-reviewed publications for their career development, absence of recognition by research councils of scientists involved with good high quality applied research, and lack of incentives for engagement in translating research into use.
Recommendation	1. Incentives for scientists in translation research
	Encourage change of culture to incentivise scientists to engage in research to solve practical problems relevant to industry, e.g. by acknowledging the contribution made to applied industrial R&D and associated dissemination to business; encourage inclusion of end-users on project steering groups; change rule for industry engagement in BBSRC Industrial Partnership Awards to allow in-kind as well as cash contributions, and encourage more input from venture capitalists.
Success	Two way flow of information between science and industry and better uptake of knowledge.
Issue 2	Need for better translation and subsequent transfer of crop production/protection science onto farm to meet practical needs of farmers and their consultants, leading by example, and spread of best practice through influence of innovative farmers on others.
Recommendation	2. National Knowledge Transfer Strategy
	Development of national strategy for knowledge transfer and translational research to fix broken pipeline and improve co-ordination across disparate and fragmented activities by different organisations (leadership from AHDB and input from Landex Colleges), with engagement of “non-agricultural” Universities where an enormous potential skill base resides.
Success	Stakeholders signed up to national strategy and implementation, and working to the same objectives. National Translation Centre established with national and regional roundtable events with researchers and users, and network of regional experts (using universities, institutes and existing knowledge transfer organisations). Researchers are actively engaging directly with local farmers and crop associations.
Issue 3	Lack of co-ordination and communication between stakeholders engaged in crop protection science and translation into use.
Recommendation	3. Communication / Engagement with Users
	Establishment of networks, whilst embracing current mechanisms, to promote better coordination and communication between stakeholders through existing demonstration farms, agronomy / farmers clubs, engagement with users during development and implementation of research to tailor outputs to user needs, and establishment of register of expertise and projects.
Success	Better links and more effective knowledge exchange between researchers and farmers/ other users of research.

General Recommendations	
Issue 1	Lack of joined-up delivery of crop protection tools
Recommendation	1. Delivery of a National Crop Protection Strategy
	Development and implementation of a national crop protection strategy founded in the principles of integrated management (i.e. using all the tools and developing more) to provide durable control of those pests, diseases and weeds causing the largest losses in UK major arable and horticultural crops; and sufficiently robust and far-sighted to enable adaptation to climate change.
Success	Continuing reduction in yield gap.
Issue 2	Slow speed of product approvals and re-registration, and cost, time taken and uncertainty to meet regulatory requirements. Uncertainty for the industry regarding future EU pesticide legislation, and lack of new pesticide actives offering solutions.
Recommendation	2. Better Regulation
	Joined up action between government and its regulators with adequate resource, to ensure new active ingredients are approved in timely manner, biological controls are fast tracked, and more effective approaches to regulation of new technologies are developed; with continued engagement in EU to try to ensure EU regulation is proportionate.
Success	Encouragement of continued investment in new control measures.
Issue 3	Insufficient skills in some areas, particularly bioinformatics, chemistry of plants, weed science, entomology, plant pathology, knowledge transfer and translational research.
Recommendation	3. Skills Capacity and Expertise
	Investment in training provision among researchers and users to improve use of new technologies and innovation.
Success	Vibrant well skilled sector.
Issue 4	Improve public awareness and understanding of new technologies to avoid the public perceptions that have impeded the application of GM in agriculture.
Recommendation	4. Public Debate
	Development of a communication strategy with carefully thought-out narrative and nomenclature for new technologies (e.g. 'omics').
Success	New technologies are available for uptake by users.

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