WORKSHOP REPORT

Alternatives to conventional pesticides: understanding the efficacy and unintended consequences of a change in practice

Global Food Security
Sustainable, healthy food for all

Executive summary

Pesticides provide numerous benefits - they reduce food losses, reduce labour costs, limit pest damage and control pest populations, reduce weed numbers, and control diseases, all of which could lead to unnecessary waste. However, there are many pressures on the use of pesticides, including regulatory restrictions, potential ecological and environmental damage, emergence of pesticide resistance in pests and weeds, and social pressures from consumers around potential contamination and food safety concerns.

New products and strategies are being developed that use less conventional pesticides. Biopesticides and Integrated Pest Management strategies (IPM) have been suggested as viable solutions to sustainably replace conventional pesticides. Biopesticides are pest management solutions based on living micro-organisms, which include microbials (bacteria, algae, protozoa viruses, fungi), pheromones and semiochemicals, macrobials (insects and nematodes), and plant extracts. IPM is a systems approach that combines different crop protection practices with monitoring of pests and their enemies, including biopesticides.

The Global Food Security programme (GFS) held a workshop, to identify knowledge gaps and priorities for research for alternatives to pesticides.

Understanding trade-offs in the food system is imperative and can help to mitigate the effects of unintended consequences on local and global food markets. The food system is global, meaning that unforeseen circumstances can create systemic shocks. A greater understanding is needed of the interconnected environmental risks of a reduction in conventional pesticide use – for example a reduction in the use of glyphosate could lead to an increase in GHG emissions if increased ploughing was necessary.

Technological advancement has led to possible game-changing solutions in agriculture. There is potential in the fields of CRISPR, and RNAi, and the potential of GM to reduce food insecurity, however public dialogue is vital in understanding how we should integrate these techniques in agriculture, and the wider food system.

It is a lengthy process from scientific development to commercialisation of biopesticides, and it is difficult to market a concept such as IPM. Communities rely on conventional pesticides to work as and when they are needed, and there are concerns around the scalability and cost efficacy of biopesticides and IPM. There is also a need to understand how biopesticide efficacy is impacted by extreme weather and climate change. It is possible that unless suitable alternatives are found, it may no longer be economically viable to grow certain crops in the UK. Simply restricting the use of certain pesticides when there are no proven alternatives could have a detrimental impact on yields, as farmers would be unable to defend crops from the threats posed by certain pests, weeds and diseases.

Research and evidence is needed on how to successfully use IPM techniques in large-scale agricultural production, without compromising on yield and quality. There is an urgent need for new interventions for managing problematic pests, weeds and diseases such as cabbage stem flea beetle, black-grass and yellow rust. The pace at which pests have evolved resistance, and rates at which pesticides have been restricted by legislation, has been much faster than the pace at which alternatives are made available.

Research into the underpinning science of how pesticides work at a micro-level, at specific target sites, could provide insight into selecting the right pesticide for each crop, and may lead to better utilisation of other techniques. Precision agriculture also has the potential to heavily reduce the amount of pesticide needed to combat weed resistance, and more work is needed to provide affordable engineering solutions for large-scale agricultural practice.

More research is needed on how climate change and extreme weather events will impact on ecosystems and farm-level services, and subsequently how this will impact on pests, weeds and diseases in the UK and globally.

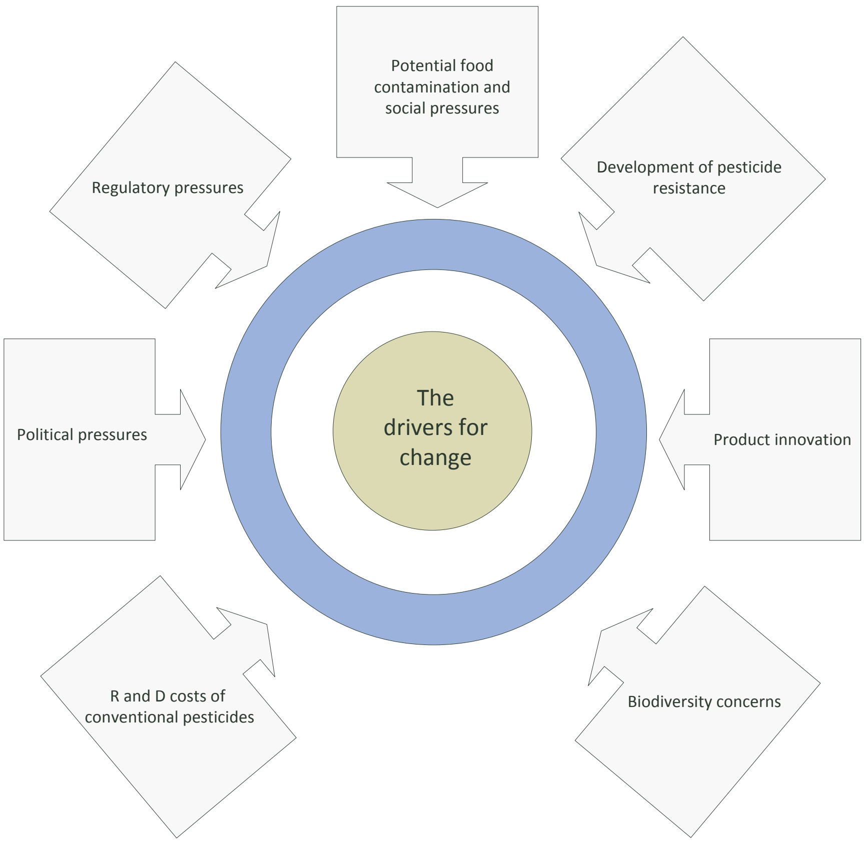
A systems approach is needed to understand how to optimise trade-offs, to ensure a more resilient food system, and the GFS programme has a key role to play in facilitating this.

What are the current and future challenges around the use of conventional pesticides in food production?

The global population is expected to increase to over 9 billion by 2050[1], which presents a challenge to both sustainable development and sustainable food production, not least in the context of diminishing land availability and losses of crops through pest and diseases. The UK has a small land area and a large population to feed, increasing the reliance on well-functioning markets, and a productive food and farming industry[2].

Pesticides[3] are used to maximise yields through minimising losses and reducing labour costs. Pesticides also continue to benefit lower middle income countries (LMICS) – for example, pesticide use in Kenya means a four-fold income increase for small-scale passionfruit farmers and extra income for avocado farmers[4]. However, repeated use of the same pesticides over time leads to an evolutionary selection of pest organisms with developed resistance, and cases of herbicide resistance are becoming increasingly common - for example herbicide resistance in the weed black-grass has been confirmed in 35 counties in England[5].

The EU Directive (91/414) aimed to curb negative effects of pesticides by implementing maximum acceptable concentrations and threshold concentrations for individual compounds in specific environments and on pesticide application routines and techniques. Pressure on the agri-food system to become more sustainable and to reduce risks has intensified in recent years, with the formulation of the sustainable use directive (Directive 2009/128/EC). Legislation and strict guidance on the use of plant protection products has left some in the agricultural sector asking what alternatives are available that could sustainably replace pesticides without compromising on yield and quality. Consumers are increasingly concerned about transparency in food supply chains, and there is also greater demand for minimising or avoiding pesticide use in agricultural production, both from a health perspective (e.g. concerns regarding pesticide residues in food), and a biodiversity perspective (e.g. potential impact on pollinators). This has led to some commentators, including food producers, suggesting a need to prepare for a post-pesticide world.



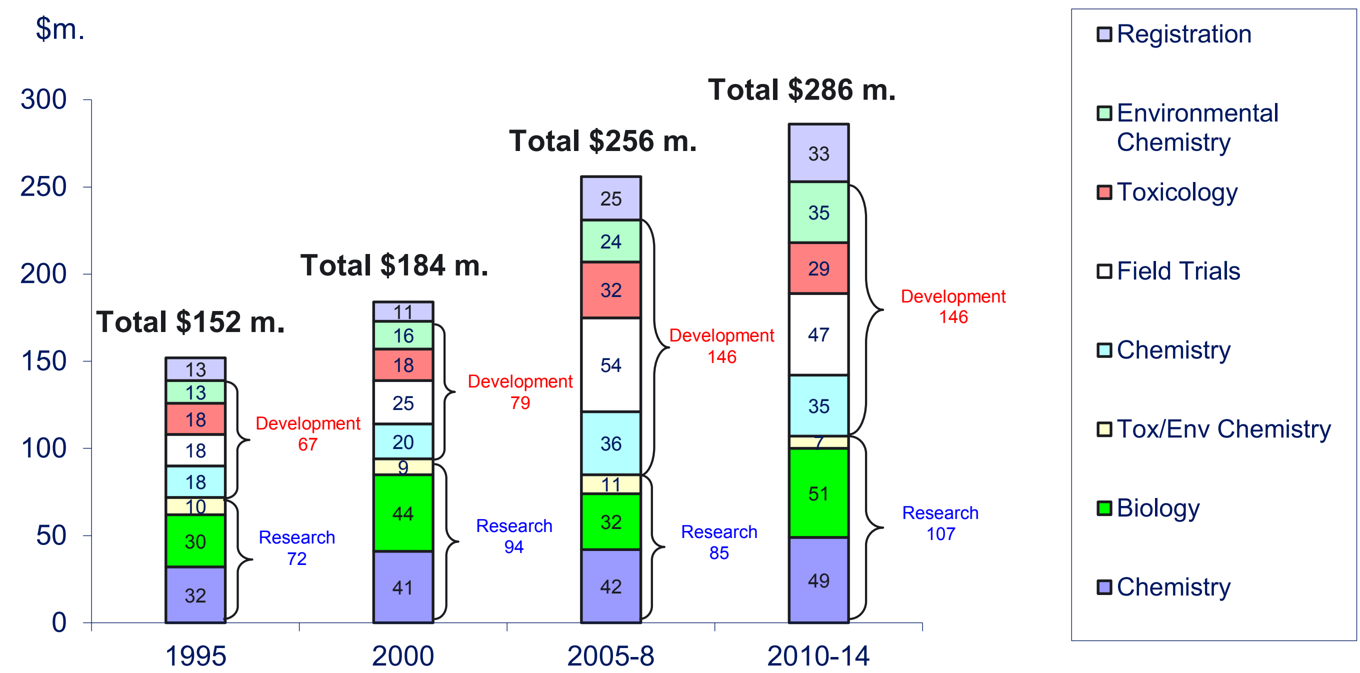
What are the potential technologies that can replace conventional pesticides?

Biopesticides and Integrated Pest Management strategies (IPM) have been suggested as viable solutions to sustainably replace conventional pesticides. Biopesticides are pest management solutions based on living micro-organisms, which include microbials (bacteria, algae, protozoa viruses, fungi), pheromones and semiochemicals, macrobials (insects and nematodes), and plant extracts. IPM is a systems approach that combines different crop protection practices with monitoring of pests and their enemies, including biopesticides. Other techniques used in IPM include cultivation practices such as crop rotation and intercropping, physical methods such as mechanical weeders, using natural enemies of pests, and decision-support tools to inform farmers[6].

A recent report by the UN suggests that agroecology is capable of delivering sufficient yields to feed the world, without using pesticides[7] but it would require a significant change in practice. There is increasing pressure on industry from regulation, and from the consumer, to reduce conventional pesticide use, this has led to mergers and acquisitions, and smarter agriculture through for example targeted applications. Certis Europe has developed IPM programmes to achieve no pesticide residues in fresh fruit and vegetables, demonstrating that industry are increasingly focusing their efforts on IPM strategies as a way of managing the challenges associated with conventional pesticide use.

Larger organisations, such as Syngenta and Monsanto, heavily invest in bringing conventional pesticide products to market, spending up to $286 million, and on timescales of up to 11 years between the first synthesis and the first sale of the product[8].

The end of the 21st Century saw a paradigm shift, from producer-led politics to consumer-led politics, with consumers increasingly demanding goods that are unblemished as well as "cleaner". Therefore, if biopesticides are going to be widely adopted, it is crucial that they maintain visual quality; otherwise food waste could increase.



The rising costs of R and D - Courtesy of Phillips-McDougall, 2016

What are the risks and challenges around alternatives to pesticides?

Understanding the interconnected environmental risks of reducing pesticide use

Greater transparency is needed to understand the interconnectedness of risks associated with a reduction in pesticide use. For example, in order to control weeds, farmers apply glyphosate and other herbicides. A reduction in pesticide usage would lead to other methods of weed control, such as ploughing, which can subsequently reduce the ability of soil to store carbon, increasing emissions, and depleting the micro-organisms in the soil. Furthermore, the global food system is vulnerable to climatic shocks – including extreme weather events and mean temperature increases as a result of climate change, all of which will influence food production. These risks can impact on levels of pests and diseases at certain latitudes, availability of natural capital, nutrient availability, and provision of ecosystem services. Climate change will also increase the risk of flooding. Industries need to be resilient to environmental factors that may have an adverse effect on agricultural yields, and further clarity is needed on how interconnected environmental risks will affect agriculture. A systems approach is needed to capture direct and indirect effects of a reduction in conventional pesticide use, and further understanding is needed on the efficacy of biopesticides in an evolving 21st Century climate.

Public acceptance of novel technologies

Recent advances in genome engineering could offer game-changing potential for agriculture, by both building plant resistance and potentially creating biopesticides. CRISPR is a gene editing tool that has the potential to edit genomes with unprecedented precision, in an efficient and flexible way[9]. The use of CRISPR in an emerging technology known as “gene drive” allows a mutation made by CRISPR on a chromosome to copy itself to its partner in every generation, so that nearly all offspring will inherit the change. RNA interference (RNAi) – the process by which small interfering RNAs bind to and cleave complementary mRNA sequences – is another potent tool for fighting common crop pathogens[10]. Commercial cultivation of virus-resistance papaya and field testing of virus-resistant plum has shown that the pathogen-derived RNAi technology can deliver very effective and durable resistance. Despite the scientific success of these techniques, public dialogue will be imperative prior to the commercial use of any novel technology.

Complexity of IPM strategies and cost efficacy

It is a lengthy process to take scientific discoveries and turn them into profitable and marketable products. IPM is a collection of different strategies, and therefore marketing a seemingly intangible product is difficult, and without a single solutions approach, they may not be considered a viable option for farmers. Growers can rely on pesticides as and when they need them, with reliable action when applied, which makes them a desirable ally in the fight against crop pests and diseases. There is a fundamental need to involve growers at all stages of technology development, to ensure effective knowledge transfer, and new solutions need to be effective and time-saving if they are to be adopted in the current business environment. Further clarity on best practice and alternatives to conventional pesticides is needed, to ensure yield and produce quality does not decrease. There are issues around the complexity of IPM, and the scalability of biologicals that are currently used in greenhouses and controlled environments, to their usage in fields and in large-scale agricultural practice.

Interconnected risks to food markets

The price of food is determined by shifts in supply (production) and demand (consumption). Globalisation of commodity markets has resulted in greater connectivity; however it has also led to increased exposure to price volatility in the food system. For example, a food production failure in a specific exporting country, due to increased restrictions on pesticides or a reduction in use, may lead to an increasing reliance on imports from other countries. Should production shocks occur in major production regions, prices may rise and the exporting nation may restrict supply.[11] Therefore, reduction in the use of pesticides could make the UK less resilient to price volatility. Understanding trade-offs and unintended consequences of a change in agricultural practice will be crucial in safeguarding the UK food system from production shocks.

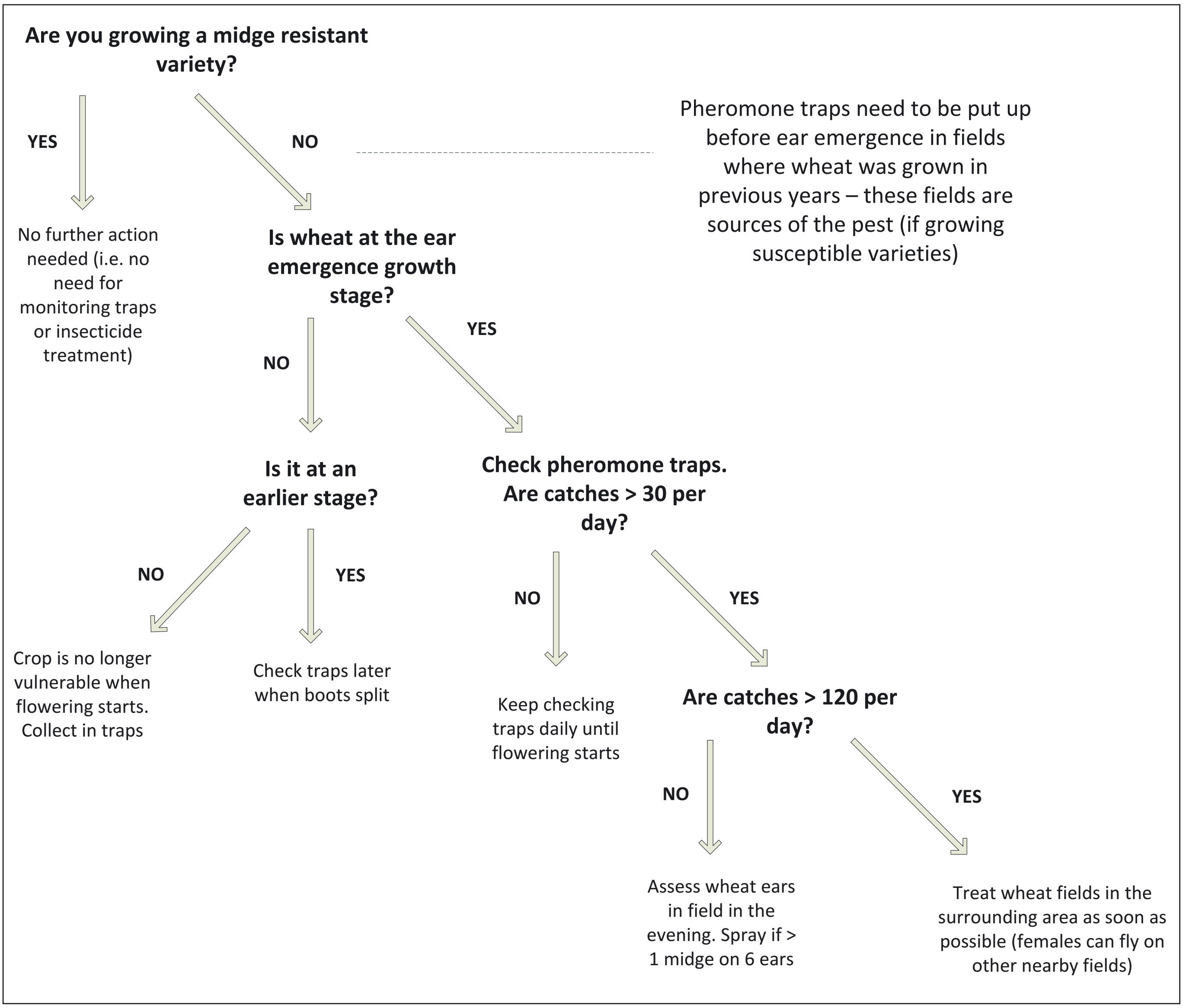
What current research is underway?

Professor Toby Bruce of Rothamsted Research, presented his previously funded BBSRC work, examining the ability of cis-Jasmone, a volatile organic compound emitted by flowers or leaves of several plant species, to act as a plant defence activator that makes plants less attractive to aphids but more attractive to natural enemies of pests[12]. cis-Jasmone can act as a signalling molecule in the plant thale cress, inducing the expression of a suite of genes involved in metabolism and defence response. This indirect defense can attract natural enemies of pests, including parasitic wasps. Furthermore, research has shown that parasitic wasps spend twice as long foraging on treated wheat. cis-Jasmone can therefore 'switch on' plant defence prior to attack, and its potential application has already been demonstrated in field experiments[13].

Previous AHDB-Defra funded research on orange wheat blossom midge was also described. This led to the commercialisation of highly effective resistant wheat varieties that do not require insecticide treatment. This resistance has now been bred into many UK wheat varieties, arguably timely, as the main insecticide that was used against the midge, chlorpyrifos, was banned in March 2016. The project also developed highly sensitive pheromone traps that are widely used by wheat growers for midge monitoring and avoiding unnecessary insecticide applications, which could be an important decision-making tool for farmers.

Professor Bruce also presented the Agri-Tech Catalyst project that is developing a "lure-and-kill" approach to manage agricultural pests. Currently blanket spraying of insecticide

An example of a decision-support tool that can be used to treat Orange Wheat Blossom Midge



are used against pea and bean weevil, which attacks nitrogen fixing root nodules of field beans and peas, and used against the bruchid beetle, which severely reduce the quality of field beans[14]. Instead of blanket spraying, pests will be lured to a bait station containing small amounts of bioinsecticide which stick to the body of the pest. This technique has the potential to protect agriculture and control pest populations.

Professor Tariq Butt, of Swansea University, presented on black vine weevils, which are pests of container and field grown nursery crops in the UK. Professor Butt discussed the use of *Metarhizium anisopliae*, an Entomopathogenic fungus, as a biocontrol agent, used with sublethal doses of insecticide, to control black vine weevil (BVW) larvae. Although not completely eliminating conventional pesticide use, this technique could eradicate BVW larvae on strawberry plants, whilst reducing the amount of insecticide needed by 90%.

Professor Rob Edwards, of Newcastle University presented on new strategies to control weeds, and outlined how the Black Grass Research Initiative (BGRI), will look to control black-grass. Black-grass has proved problematic in Northern Europe over the last 30 years due to the evolution of herbicide resistance[15]. Target site resistance, whereby weeds developing tolerance to herbicides due to mutations in proteins, is fairly well understood, however metabolism-based resistance, whereby weeds enhance their ability to detoxify crop protection agents, is poorly understood. The project uses a combination of molecular biology and biochemistry, ecology and evolution, modelling and integrated pest management to develop better tools to monitor and manage both target site resistance and metabolic or multiple herbicide resistance in black-grass under field conditions.

What are the research gaps and future priorities?

Promising research projects are being undertaken to control pests, weeds and diseases, however there are a number of future research priorities.

Demonstrating how IPM works to the user and developing skills to implement IPM strategies

IPM strategies have to be attractive to the end-user, and therefore evidence, and further research, is needed on how to successfully use these techniques in large-scale agricultural production. Providing a portfolio of evidence for farmers, growers, and consumers, and simple methods of implementation could help to demonstrate the potential of IPM. There is not currently a universal portfolio for IPM, or clear guidance on how it should be implemented on a temporal and spatial scale, with systems appropriate to each farm, for each season.

Understanding modes of action at a micro-level

Modes of action currently describe how a pesticide works at the molecular level. Research into the underpinning science of how pesticides work at a micro-level, at specific target sites, could provide insight into selecting the right pesticide for each crop, and may lead to better utilisation of other techniques. In the case of biopesticides this may lead to significant improvements in efficacy.

Precision agriculture in the arable and horticulture sectors

Precision agriculture could have a profound impact on how we produce food in the future, with robotics and autonomous vehicles having the potential to reduce the need for the amount of conventional pesticide used in the food system. Vehicles are being developed that can detect early signs of disease in crops[16], and machines that can use low-power lasers to remove weeds from field crops.[17] If we can farm 'smarter' there is the potential to significantly reduce the amount of pesticides needed in future. Further development of precision agriculture solutions to combat pests, weeds, and diseases, and making them commercially accessible to end-users, is needed.

Studying the effects of climate change on pests, weeds and diseases, both in the UK and globally

Interactions between climate change, crops and pests are complex, and therefore more evidence is needed on how climate change will impact on ecosystems and farm-level services in the UK, It is likely that global supply chains will be impacted by increasing levels of pests, weeds and diseases at certain latitudes. Increasing average temperatures, warmer winter minimums, or changes in the levels of rainfall, could contribute to pest and disease invasions[18]. Agriculture, and the wider food system, needs to be resilient in adapting to climate change, and further research is needed in order to understand how climate change will impact on the severity and distribution of pests and diseases.

Interdisciplinary, systems-based research

It is important to break-down silos and encourage researchers to work together to combat threats of pests, weeds and diseases. A systems approach is therefore needed to understand how to optimise trade-offs, to ensure a more resilient, sustainable and healthy food system.

Annex 1: Attendees List

Dr Steve Ellis – ADAS
Dr Caroline Nicholls – AHDB
Debbie Harding – BBSRC
Sadhana Sharma – BBSRC
Bryony Taylor – CABI
Professor Bill Symondson – Cardiff University
Dr Wynand Van Der Goes Van Naters – Cardiff University
Dr Helen Hesketh – Centre for Ecology & Hydrology
Jennifer Lewis – Certis Europe
Stephen Coleman – Defra
Professor Xiangming Xu – East Malling Research
Christina Baskaran – Food Standards Agency
Dr Richard Binks – FreshTec
Professor Tim Benton – GFS
Riaz Bhunnoo – GFS
Evangelia Kougioumoutzi - GFS
Dave O'Gorman – GFS
Sian Williams – GFS
Dean Cook – Innovate UK
Professor Adrian Newton – James Hutton Institute
Professor Ken Wilson – Lancaster University
Tony Vallance – Mack Multiples
Matt O'Hagan – Marks and Spencer
Professor Rob Edwards – Newcastle University
Dr Emma Hamer – NFU
Andrew Burgess – Produce World
Dr Roma Gwynn – Rationale Biopesticide Strategists
Professor Toby Bruce – Rothamsted Research
Dr Paul Neve – Rothamsted Research
Dr Fiona Burnett – Scotland's Rural College
Dr Andy Evans – Scotland's Rural College
Geoff McBride – STFC
Professor Tariq Butt – Swansea University
Dr Dave Hughes – Syngenta
Dr Les May – Syngenta
Professor Nic Lampkin – The Organic Research Centre
Dr Dave Chandler – University of Warwick

References

[1] UN – World population prospects

[2] GFS Strategic Plan 2011-2016

[3] ‘Pesticides’ is a colloquial term that encompasses many types of plant protection products, many of which are used to control pests, weeds and diseases. Examples include: insecticides; fungicides; herbicides; molluscicides; and plant growth regulators.

[4] Feeding Nine Billion: The issues facing global agriculture

[5] Hull et al (2014) Current status of herbicide-resistant weeds in the UK

[6] Chandler et al (2011) The development, regulation and use of biopesticides for integrated pest management

[7] UN Human Rights Council – Report of the Special Rapporteur on the right to food

[8] Phillips-McDougall The Cost of New Agrochemical Product Discovery, Development and Registration in 1995, 2000, 2005-8 and 2010 to 2014

[9] CRISPR: gene editing is just the beginning (Nature)

[10] Improving crops with RNAi (The Scientist)

[11] GFS Extreme weather and resilience of the global food system

[12] Bruce, Toby JA, et al. (2008) *Proceedings of the National Academy of Sciences* 105: 4553-4558.

[13] Bruce, Toby JA, et al. (2003) *Pest management science* 59: 1031-1036.

[14] ‘Lure and Kill’ technology to manage beetle pests

[15] BBSRC-HGCA Black-grass Resistance Initiative

[16] https://www.precisionfarmingdealer.com/articles/1497-uk-university-research-may-lead-to-robotic-broccoli-harvester

[17] Automation - Smart farming

[18] Bebber, D, Ramotwoski, M and Gurr, S (2013) Crop pests and pathogens move polewards in a warming world

Global Food Security Workshop: Alternatives to conventional pesticides: understanding the efficacy and unintended consequences of a change in practice

Prepared by David O'Gorman on behalf of the Global Food Security programme

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