Final Project Summary

Project title	Combating insecticide resistance in major UK pests		
Project number	RD-2012-3780	**Final Project Report**	PR584
Start date	January 2013	**End date**	July 2016
AHDB Cereals & Oilseeds funding	£74,993	**Total cost**	£550,003

What was the challenge/demand for the work?

Despite substantial progress with developing non-chemical methods of crop protection, pesticides remain essential for effective suppression of pests, pathogens and weeds in many cropping systems. Reliance on pesticides introduces a number of risks, including the appearance of resistance in target organisms to insecticides, fungicides and herbicides. Combating resistance remains a significant challenge for researchers and regulators, as well as the farming and agrochemical industries. The loss of a single compound or an entire pesticide group (through a shared resistance mechanism) can threaten the productivity and competitiveness of an agricultural system. Attempts to predict and forestall resistance encounter two formidable challenges. Firstly, the need to take account of the very large number of factors (henceforth termed ‘traits’) that can potentially influence whether resistance occurs, and the speed at which it is selected. These traits relate to the biology of a pest organism (e.g. host range, reproductive rate, dispersal capability), agronomic aspects of a cropping system (e.g. species of crop, acreage, protected or unprotected), and the pesticide itself (e.g. mode of action, persistence, method of application). Secondly, it is usually very difficult, and sometimes impossible, to perform experiments to unravel these interactions or compare the outcome of alternative resistance management tactics on different pest species, over appropriate spatial and temporal scales.

Further, there are substantial differences in the guidance for managing insecticide resistance compared with guidance for fungicide resistance. For example, mode of action (MoA) mixtures are widely advocated for resistance management in fungicides, but not for insecticides. The use of lower than label recommended doses is also widely practiced for fungicides and has been shown to slow the evolution of resistance, whereas use of full label doses is advocated for resistance management in insecticides. Some of these differences in practice may be driven by other considerations (such as efficacy or environmental impact) rather than resistance management, but is it helpful to be clear whether particular practices are being advocated and are justified for resistance management or for other reasons. In the work reported here, we focus on whether the guidance for managing insecticide resistance is a logical result of the particular characteristics (traits) of the biological system, and whether different traits between pest species might require different strategies.

This project aimed to address these challenges and clarify the need for different approaches to insecticide and fungicide resistance by: (i) identifying effective insecticide resistance management strategies, and (ii) developing an objective method for resistance risk assessment. The overall aim was to maintain effective control of major UK pests. The work was undertaken by ADAS and Rothamsted Research, with support from grower levy organisations (AHDB, BBRO and PGRO), Defra and the Chemicals Regulation Directorate (CRD).

How did the project address this?

Objective 1: Compare the net benefit of different insecticide resistance management strategies for insects with contrasting life-histories and damage implications. Models were developed to compare the effectiveness of resistance management strategies for delaying the development of target-site resistance for groups of pest species sharing similar traits.

Objective 2: Develop a method to assess insecticide resistance risk based on objective and measurable criteria. A database was constructed consisting of documented resistance cases alongside information on relevant biological and agronomic traits. This data set was statistically analysed to develop a risk assessment scheme relating combinations of easily defined traits to the speed at which resistance (target or metabolic) is predicted to develop.

Objective 3: Transfer the new knowledge of anti-resistance strategies and risk assessment to the relevant end user communities. Results were translated into messages and communicated to stakeholders throughout the project.

What outputs has the project delivered?

Objective 1 - Resistance management modelling

A mathematical model was developed that allowed a range of resistance management strategies to be compared. The model simulated the development of resistance caused by a mutation in the target site for the insecticide, as this type of resistance can cause high levels of insensitivity, leading to loss of pest control. Different management strategies were compared for a diverse set of pest traits, including diploid or haplodiploid species, sexual or asexual reproduction, single or multiple generations per year, varying degrees of immigration (from untreated refuges) and varying dominance of insensitivity (which determines the sensitivity of strains which are heterozygous for resistance).

The model was used to explore two aspects of pest management that have an effect on the development of target-site insecticide resistance. Firstly, if a single insecticide MoA is being used to control an insect pest with no previous exposure to that MoA, is it better to apply a full label dose or reduce the dose (where this is possible whilst still obtaining effective control)? The results showed that the optimal dose for slowing the development of target site resistance to an insecticide depends largely on two factors for all insect species: the rate of immigration of less resistant individuals into the insect population being treated, and the mortality achieved by a label dose of insecticide. In most biologically plausible scenarios a high dose of insecticide was shown to lead to the fastest selection for resistance, and reducing the dose of insecticide reduced the speed with which target-site resistance builds up. Only in exceptional circumstances in the model (with very high immigration rates from an unselected population, a recessive resistance gene, and high insecticidal efficacy) can a high dose be an optimal resistance management tactic, and these circumstances are seldom expected to occur in most realistic scenarios.

Secondly, the model was used to explore the optimal combination of two insecticides with different MoA. Two potential combination methods were considered, whether to alternate (rotate) insecticide MoA, or to combine the two insecticides into a mixture and apply them together. When two insecticides with different MoA were mixed together with both components at their full label dose, target-site resistance developed considerably faster than when the insecticides were alternated each year. However if the dose of each insecticide was adjusted so that the mixture provided the same control of the insect population as a label dose of a single MoA product, mixtures often resulted in resistance building up slower. When the resistance resulted in substantial fitness costs in the insect species, however, alternating two insecticides at their label dose led to slower resistance development than reduced-dose mixtures.

The resistance management model explored the management traits in relation to their ability to slow down the development of target-site insecticide resistance in a pest previously unexposed to that insecticide. The above results must be considered within the larger context that any pest management programme must also maintain pest densities below economically-damaging thresholds and have an acceptable environmental profile.

Risk assessment model

Most case-histories of insecticide resistance used in the study were extracted from the ‘Arthropod Pest Resistance Database’, a resource maintained by the University of Michigan in the USA as a global compendium of reports of resistance in insects and mites. Various filters were applied to eliminate likely duplicate case histories, and limit analysed cases to ones originating in European and Mediterranean Plant Protection Organisation (EPPO) member countries and where scientific integrity could be assessed. For 125 cases used in the final analysis, data from the original report as well as primary, peer-reviewed literature, national or online databases and expert judgement were used to calculate an FDR (first detection of resistance) time: defined as the time in years from first exposure of a pest species to an insecticide with a specified MoA, until the year when resistance was first detected in that pest. Data for 44 traits were also obtained for each case. Some traits (e.g. crop area) were analysed as numerical variates with a continuous distribution, others (e.g. crop type) consisted of discrete categories to which cases could be assigned. Seventeen traits were found to be significantly associated with FDR time, accounting for between 3.4% (number of crop hosts) and 32.8% (crop type) of the variation in FDR values. These significant traits were then used in a forward stepwise regression analysis, to identify the combination of traits with the greatest power to predict observed FDR times. A model incorporating five traits and accounting for 45.9% of variation in FDR was found to be optimal for this purpose. These five traits were, in descending order of importance: crop area, crop type, number of crop hosts, mode of reproduction and taxonomic Order. Other traits that were significantly associated with FDR time when analysed individually did not figure in the final model due to correlations with other traits that masked their contribution in the multivariate analysis.

The resulting model is potentially of broad application. It can be used to assess resistance risk (target or metabolic) for novel pest/crop/insecticide combinations since all the key traits are relatively easy to quantify without knowledge of prior resistance history. There is nonetheless still considerable uncertainty, as in any biological system, and it is unlikely that we will ever be able to predict the number of years for resistance to evolve with complete accuracy. However, the model provides an objective means of ranking pest-crop combinations from high to low risk, allowing proportionate and effective resistance management strategies to be put in place.

Who will benefit from this project and why?

The ultimate beneficiaries of the work are UK growers, supported by levy organisations and the regulatory framework for pesticides administered by CRD. The project will strengthen resistance management and contribute to maintaining effective chemical control of key pests.

Some of the findings of this project differ from current guidance. Experimental validation of those specific findings (guided by the modelling) will be required to provide confidence for the industry to change practice.

Levy payers benefit via outputs from the direct users of the work, namely:

Levy organisations: Will disseminate guidance (in liaison with the Insecticide Resistance Action Group; IRAG).

IRAG: Will incorporate project findings into their guidance on resistance management, where relevant.

Crop consultants: Will interpret IRAG guidance and messages into practical advice which is appropriate for individual growers.

CRD: Will use improved risk assessment techniques and assessments of the effectiveness of anti-resistance strategies, to underpin regulatory decisions. A stronger evidence base for such decisions ultimately benefits the industry.

If the challenge has not been specifically met, state why and how this could be overcome

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Lead partner	ADAS UK Ltd (Sacha White/Neil Paveley/Catriona Walker)
Scientific partners	Rothamsted Research (Joe Helps/Frank van den Bosch), University of Hertfordshire (Ian Denholm)
Industry partners	None
Government sponsor	Defra/CRD