The Future Availability and Efficacy of Plant Protection Products – Potential On-Farm Implications

for

AHDB
CEREALS & OILSEEDS

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EXECUTIVE SUMMARY

- Plant Protection Products (PPP) are key to growing healthy, profitable crops of wheat, barley and oilseed rape.
- The availability and efficacy of PPP are under the twin threats of non-authorisation of key products, and the growing resistance of pests to the products that remain.
- The approvals process of active substances is undertaken at EU level. (*Despite 'Brexit' this is likely to remain the key source of regulation for some years*.) The regulatory environment has become more challenging in recent years with the move from risk-based, to hazard-based assessments. New criteria, such as endocrine disruption, also decrease the likelihood of actives being re-approved.
- In addition, water quality issues mean that restrictions or outright bans may be imposed on some PPP.
- This process is not new; it is calculated that seventeen actives used in UK combinable crop production have already been lost since the turn of the millennium. However, with a large number of re-approvals due in the next few years, the pace of loss could well increase.
- Fourteen key insecticides (plus molluscicides and nematicides) were identified as being used in the main UK combinable crops (2014 year). Of these three were under 'high' threat of being lost – i.e. almost certain not to be re-approved. Of the 31 key fungicides 5 were under severe threat. Out of the 38 herbicides identified, nine were deemed likely to be lost. These loss figures could be much higher depending on the precise implementation of the EU approvals rules – particularly those on endocrine disruptors.
- Resistance to pesticides is the other major threat. As the number of approved actives decreases, the likelihood of resistance build-up increases as the number of Modes of Action in use decreases.
- Examples of resistance can be found across the categories of PPP in the UK. The most obvious, and the one with the largest economic impact is herbicide resistant blackgrass. But examples of resistance can be found against fungicides and insecticides as well.
- Being a biological process, the future development of resistance is not easy to predict. It interacts in complex ways with the 'toolkit' of PPP available, and the farming practices employed. However, the trajectory of build-up is unlikely to improve from that seen over recent years and could well get worse.
- Due to uncertainties around the regulatory environment and progress of resistance it is very difficult to state categorically that a certain active substance (or group of them) will no longer be available, or no longer be effective at a certain point in the future. To deal with this uncertainty, three scenarios have been created as to what the crop protection environment might look like in the future.
- A precise date has not been set out, but it can be thought of as the likely circumstances around 5 to 8 years in the future.
- Scenario A is the most 'mild' outcome. However, even under this forecast some well-known active substances such as cypermethrin, thiacloprid, a number of azoles, mecoprop, quinmerac and

metazachlor all fail to secure re-approval for all current uses. In addition, the rise of resistance makes remaining actives less effective.

- For Scenarios B and C, the regulatory impacts become progressively more severe, and the growth of resistance is quicker. To take the example of glyphosate, under Scenario B the product remains available, but its uses are restricted – e.g. it cannot be used for pre-harvest desiccation. Under Scenario C it is not re-approved at all.
- There are a range of practical effects on-farm depending on which Scenario is chosen. Under Scenario A, the production of wheat, barley and oilseed rape can continue to a large extent as it is now, with some amendments to spray programmes and cultural control. Some yield decreases may well be seen however, which will place profitability under pressure.
- Under Scenario B the changes are greater. A greater focus on varietal resistance to pests and disease is likely to be required, rather than the use of PPP. There is likely to be a trade-off in terms of yields. A change in rotations and cultivation methods may be forced on the sector.
- Under Scenario C the loss of PPP results in large changes in combinable cropping. In certain circumstances it will be impossible to grow oilseed rape profitably and it will drop out of the rotation. For wheat and barley, the reduction in the number and efficacy of PPP will mean that crops are being grown under 'semi-organic' conditions in many cases.
- Farmers need to be aware of these changes. It is always difficult to plan for something of uncertain timing, and uncertain severity. But spending some time thinking 'what if . . .' as it relates to their own farm will make them more prepared and resilient when changes in PPP do occur.

CONTENTS

1. INTRODUCTION

1.1. BACKGROUND

The UK combinable crops sector is threatened by the loss of key plant protection products (PPP). This is both from regulation on the authorisation of PPP, and increasing resistance of weeds, pests and diseases to existing active substances.

With an uncertain regulatory environment (being subject to political pressures), and the progress of resistance difficult to forecast, the overall effect of these trends is unclear. The lack of clear information on what the future situation might look like has meant that it is difficult for businesses to engage with the issue and to start making plans on how to cope with possible changes.

This report aims to summarise the current state-of-play on PPP approvals and resistance levels. It will then use this information to set out three possible scenarios for the future. This information will be used on an AHDB Monitor Farm to assess the practical and financial effects of such scenarios.

Overall, the aim of the project is to stimulate and facilitate discussion among farmers (and advisors) about the changes that might result from future changes in the availability and efficacy of PPP. As a consequence, the industry will already be thinking about the issue, and investigating potential mitigation strategies, ahead of any actual changes.

1.2. PROJECT SCOPE AND APPROACH

The project looks at the three largest crops by area in the UK combinable cropping industry – wheat, barley and oilseed rape. It includes all types of plant protection products - fungicides, herbicides, insecticides and molluscicides. It is based on the active substances currently available, no attempt has been made to forecast any new chemistry which may be in the product development pipeline. The scenarios are not related to a specific year or season in the future, due to the inherent uncertainty around many of the issues involved. However, they are based on a medium-term outlook of around 5 to 8 years in the future. For simplicity, the scenarios will refer to *active substances* rather than specific branded *products*. It is assumed that there will be no significant improvements from plant breeding over and above what is currently available.

This report is based on the best available information. Where possible, the basic data is sourced from publicly-available, referenced, information. There is a requirement for a number of assumptions to be made in attempting to forecast the future development of policy and biology. These are clearly stated. Although the research is comprehensive and detailed, the aim has been to summarise it in a number of 'high-level' statements within the scenarios that can be easily digested.

The project has been undertaken primarily as a desk-based research exercise. It has gathered data from a variety of sources. This has been supplemented with interviews with a number of key individuals within the crop protection and farming industries.

1.3. Structure of this Report

The following Chapter provides a summary of the legislation that is threatening the continued use of some PPP. It then outlines which active substances are most under threat from these pressures.

Chapter 3 looks at the issue of resistance. Then, it summarises which active substances (or groups of active substances) may lose efficacy in the future, and to what degree.

Chapter 4 sets out three scenarios based on the information gathered. These are in the form of a series of statements. Three different scenarios are presented, based on a range of possible outcomes. None of these is thought of as more likely than any of the others, a broad perspective is presented to illustrate the potential future situation and to stimulate discussion. In practice, a mix of elements from all three scenarios are likely to occur.

In Chapter 5, the effects of the changes on a real-life farm are investigated. These cover possible changes in cropping, growing regimes, mitigation strategies, and the effect on profitability.

Finally, in Chapter 6, a summary of the project and a set of conclusions is presented.

1.4. Definitions

Within this report the chemical that provides protection to the plant is referred to as a 'pesticide' or alternatively the 'active substance'. Whilst not used in this report, an alternative term often used is 'active ingredient'.

A Plant Protection Product (PPP) is the formulation that is used in agriculture or horticulture. It may be made up of one or more active substances. 'Product' is used interchangeably with PPP.

'Pests' is used to mean all weeds, insect pests, molluscs and fungal diseases.

Insect is also used generically to refer to all aphids, moths, flies, midges, and all arthropod pests including mites, centipedes etc.

1.5. A Note On 'Brexit'

This study was commissioned, commenced and largely completed before the UK voted in the referendum on the 23rd June 2016 to leave the EU. With the authorisations of pesticides being conducted at an EU-level, this obviously has the potential to significantly alter the regulatory landscape. However, it is still too early to know what the long-term effect may be.

The following factors must be borne in mind;

- Until the UK formally leaves the EU it will continue to be bound by EU laws. Any negotiations for exit are unlikely to be concluded before 2018, and could stretch through to 2020. Therefore, the current EU regime will continue to apply in the short-term.
- The future trading relationship between the UK and EU is uncertain. If the UK negotiates to maintain tariff-free access to the Single Market for agricultural produce, then it is likely to have to implement many of the rules of the Single Market. This could (depending on final outcomes)

include EU rules on the regulation of Plant Protection Products. It should be noted that, being no longer a member of the EU, the UK would have no say in setting these rules.

- Even if the UK were to have a more 'arms-length' trading relationship with the EU, domestic regulators (and the industry itself) may not wish to depart too far from EU standards in terms of which PPPs are authorised and used. This is because Europe will continue to be a key market for UK cereals and oilseeds exports. Crops grown to very different production standards may not be acceptable to EU regulators or buyers.
- Lastly the UK has a huge legislative task replacing EU laws with UK ones in many areas. The regulation of pesticides may not be top of the agenda, and therefore the existing EU rules would be 'rolled-over' in the medium term, pending more fundamental reform in the long term.

Therefore, for the purposes of this project, and in the absence of better information, it will be assumed that the current regulatory environment for PPP will be the one operating at the point in the future looked at in this study.

2. REGULATORY PRESSURES

2.1. Previous Research

The basis of this section is a report previously published by the author in October 2014 – 'The Effect of the Loss of Crop Protection products on UK Agriculture and Horticulture and the Wider Economy'. This work was funded jointly by the AIC, NFU and CPA. A full copy of the report can be found at - https://www.nfuonline.com/andersons-final-report/. The findings of this earlier report relating to the availability of PPP have been summarised and updated in the sections that follow.

2.2. Summary of the Regulatory Environment

The threat to PPP comes from a variety of sources. These can be summarised as;

- The approvals process at the EU level
- The implementation of the Water Framework Directive at national level
- Various other polices in specific areas such neonicotinoid seed treatments, national authorisations, residue levels etc.

Each of these is looked at in more detail in the following sections. This section aims to provide a brief overview of the issues, but the science and regulatory environment is complex.

2.2.1. The Pesticides Approval Process

Before the 1990s, individual Member States were responsible for approving pesticides in their own countries. Directive 91/414/EEC was implemented in 1993 to harmonise the approvals process across the EU. Any active substance approved for use on the European market was placed on 'Annex I' to 91/414 EEC for a period of ten years. After that period, they need to be re-approved (or 'renewed'). By 2009, around 230 active substances were approved for use in the EU.

Renewals are grouped into batches. The Annex I Review number 1 (AIR-1) saw seven active substances successfully renewed under Regulation EC 737/2007[1]. At present AIR-2 has 31 active substances under review[2]. Decisions on this batch were due by the end of 2015, but delays mean that they have not yet been completed. For example, glyphosate is within the AIR-2 programme. Finally, there is an AIR-3 group of 150 active substances whose approval expires between 1st January 2013 and 31st December 2018. Generally, once an application for re-approval has been made, there is an extension of the expiry date for products containing it whilst the application is processed.

Directive 91/414/EEC was replaced by Regulation 1107/2009 on the Placing of Plant Protection Products on the Market[3] in June 2011. It has more stringent requirements for active substance approval. Various 'cut-off criteria' apply with approval not being granted if the active substance has the following properties;

- Mutagenic
- Carcinogenic or have Reproductive Toxicity (unless the exposure is 'negligible')

- Endocrine Disruptors (ED)[4] which cause adverse effect [*]
- Persistent Organic Pollutants (PoPs)
- Persistent Bio-accumulative and Toxic (PBT)
- Very Persistent / very Bio-accumulative (vPvB)

There is a derogation allowing pesticides to be approved for five years in exceptional circumstances, even if they fall within the above criteria, if they are necessary to 'control a serious danger to plant health that cannot be contained within other means'. Asulam, an important herbicide for bracken control in the uplands, had gained approval for use under this derogation because there are no alternative products.

A key point about 1107/2009 (widely referred to in the sector as 'eleven-oh-seven') is the move from a risk-based to a hazard-based approvals system. Under the previous rules, even if the properties of a pesticide deemed it to be classified as hazardous (e.g. carcinogenic) the way it was actually used would be looked at. Exposure when correctly used was considered, the risk was assessed and, if considered acceptable, the pesticide could be registered for sale. Under the new 1107/2009 rules, any level of exposure to a substance that is deemed as hazardous is considered unacceptable. It is the intrinsic properties of an active substance that are now key.

Companies wishing to get an active substance approved (or re-approved) are required to submit a 'dossier' proving that all the necessary risk assessments have been undertaken. The European Food Safety Authority (EFSA) provides technical guidance on how these risk assessments should be undertaken. The amount and complexity of this guidance continues to grow, increasing the costs and timescales for gaining authorisation. The guidance is also subject to regular revision which makes for an uncertain regulatory environment. In certain cases, pesticides already approved and on Annex I can lose their approval (or face additional restrictions) if EFSA changes its guidance. This is what happened with three neonicotinoid seed treatments in oilseed rape.

Under 1107/2009 some active substances may be approved, but deemed to be 'candidates for substitution'. This means that products containing these pesticides may have their approval removed if a safer alternative is available to control a particular weed, pest or disease problem on a crop. Candidates for substitution will only be approved (or re-approved) for a reduced, seven-year, period. The candidate for substitution assessment is made on products and is undertaken at individual Member State level. Therefore, an active substance that is a candidate for substitution is unlikely to lose its approval entirely – but the uses to which it can be put may be restricted. The definitive list of pesticides that are candidates

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[*] *ED's can interfere with an endocrine (hormone) system in animals. Following much delay, the EU Commission published draft criteria for defining EDs on 15th June 2016. An impact assessment released alongside the draft legislation identified 26 active substances that were potential ED's under the new definition. A revised report was issued on the 30th June 2016. This resulted in some re-categorisations (e.g. boscalid was no longer deemed to be a potential ED) but the number of potential EDs identified rose to 27. These results came from a 'screening' process of existing scientific work. Not all pesticides were screened (348 out of 482 active substances - so around two-thirds). Therefore, additional pesticides may be included. Conversely, some of the substances flagged as EDs may not, in fact, fall foul of the criteria when a full scientific assessment is made. For the purposes of this report, the results of the 30th June assessment have been used.*

for substitution was due to be published in December 2013. This has not yet been done. This element of Regulation 1107/2009 is relatively new, so it remains to be seen what long-term effect it has on the number of active substances and control mechanisms; especially where this part of the legislation may conflict with resistance control strategies.

Even when a pesticide is approved at EU level, there may be restrictions placed on products containing it that make its use on farm impractical. An example of this is the product methiocarb. This has been widely used as a slug control product within slug pellets. The active substance is still approved, but the EU decided to withdraw approval for its use in slug pellets from mid-September 2014. This is due to the potentially hazardous effect on grain-eating birds that frequent farmland (this was a result of criteria contained in the Birds and Mammals Guidance document). Methiocarb's use in other situations, such as seed treatments, can continue.

2.2.2. The Water Framework Directive

The Water Framework Directive (WFD)[5] (2000/60/EC) is EU legislation that requires all rivers, lakes, ground and coastal water to reach good ecological and chemical status. In addition, the Drinking Water Directive (DWD) (1998/83/EC) sets limits on the amount of pesticides and other chemicals that are allowed in drinking water. Finally, the Groundwater Directive (GWD) (2006/118/EC) sets out quality requirements for the protection of groundwater. DWD and GWD are 'daughter directives' of the WFD.

The WFD is implemented in six year 'cycles'. The second cycle runs from 2015 to 2021. The WFD is implemented on the basis of 'River Basin Districts' (RBDs) – simplistically the catchments of major rivers or groups of rivers. New River Basin Management Plans have been drawn up for each RBD for the period 2015 to 2021[6].

In terms of the effect on pesticides availability, the WFD impacts in three main ways. Firstly, a small number of chemicals that have the biggest impact on water quality are identified at EU-level. The 2013 Priority Substances Directive[7] sets out 45 such chemicals. Two categories of these are defined. Priority Hazardous Substances (PHS) are deemed to have the greatest threat and are being phased-out. 'Priority Substances' (PS) have a lesser, but still significant, threat and Environmental Quality Standards (EQS) are mandated at EU level. Examples of pesticides that appear as PHS/PS are chlorpyrifos, isoproturon, bifenox and cypermethrin. Any active substance on these lists is in danger of being withdrawn completely from use (in the EU and UK). *The EU Commission has also instituted a 'watch list' of chemicals. These are not on the official Priority (Hazardous) Substances list, but are those that are judged to be of possible concern for the future. Methiocarb has been placed on this list. The widely-used herbicide glyphosate was an initial candidate for the watch list but after analysis[8] was found not to be of sufficient concern.*

Secondly, at Member State level, chemicals that have certain intrinsic properties and are used widely in that country are identified. In the United Kingdom these are known as 'UK Specific Pollutants'. Relevant ones in terms of pesticides for the 2015 to 2021 cycle are carbendazim, chlorothalonil, cypermethrin, diazinon (*although diazinon is not approved for use in the UK*), dimethoate, glyphosate, linuron, mecoprop, methiocarb, pendimethalin and permethrin.

Lastly, Article 7 of the WFD requires that the quality of water intended for drinking should not be allowed to deteriorate from a baseline level and thus require additional treatment. Whilst there is no specific 'list' of substances that come under Article 7, the Environment Agency (EA) has identified those active substances most likely to lead to an issue with Article 7 compliance. Currently (2015 data), the ten most frequently detected by water company and EA monitoring (in order of frequency of detection) are metaldehyde, MCPA, propyzamide, carbetamide, mecoprop, clopyralid, chlorotoluron, 2-4D, glyphosate, quinmerac, metazachlor and isoproturon.

Voluntary 'stewardship' schemes have been adopted by the industry and agri-environmental schemes also contribute to water quality improvements. Should voluntary approaches not deliver the required results, then restrictions on the use of active substances may be imposed to meet rules on UK Specific Pollutants or Article 7 limits. These are unlikely to be a complete withdrawal across the UK. Restrictions could be implemented only in catchments or in Drinking Water Protection Areas where there was an identified problem. These are more likely to take the form of limits on timings, dose rate or crop use rather than an outright ban. This makes it somewhat difficult to model the possible future effect of the WFD on UK agriculture as the geographical scope could be mixed.

2.2.3. Other Policy Issues

On 1st December 2013 EU-wide restrictions on three neonicotinoids were imposed - clothianidin, imidacloprid and thiamethoxam[9]. The restriction comprises a prohibition of use on the three pesticides as a seed dressing on flowering crops and spring planted cereals. The active substances can continue to be used as a seed dressing on crops such as sugar beet and winter cereals, and as a foliar spray. Although often reported as a two-year moratorium, the ban is open-ended and will remain in place and will only be reviewed in light of further scientific data. The ban was a result of a report from the European Food Safety Authority (EFSA)[10] which concluded that the actives posed a risk to bee health. The technical guidance relating to risk assessments for bees had been updated since the pesticides had last gained approval. It was concluded that the existing risk assessments were no longer robust and the authorisations for the active substances should be withdrawn for certain uses.

Whilst approvals for ***active substances*** are undertaken at an EU level, ***product*** (PPP) authorisations are conducted at a national level. In the UK, the Chemicals Regulation Directorate (CRD) is the competent authority for PPP approval. The CRD is an agency of the Health and Safety Executive and operates on clearly laid-out standards[11]. The EU has made efforts to harmonise and streamline the product review process by creating three zones within Europe in which countries mutually recognise each other's approvals. This system is still bedding-in.

Whilst an active substance may remain authorised, the conditions for use (i.e. label guidelines) for the products containing it can change substantially. For example, the product may be restricted to use at certain times of the year, on specific crops, or for a limited number of applications. This reflects the fact that an active substance may pose a higher potential risk to the environment when it is used under one set of conditions rather than another. The total quantity of active substance applied can also be an issue and restrictions are imposed on usage to prevent a build-up of pesticide residues in crops.

The CRD is also responsible for '***extension of authorisation for minor uses***' (EAMU) in the UK. Minor uses are crops grown on relatively small areas or very specific uses on major crops. As this study is looking only at wheat barley and oilseed rape, EAMU will not be covered, but this is a significant issue for low-area but high-value crops. The CRD can also propose the approval of ***emergency use authorisations***.

These allow the use of a specific active substance which is otherwise not authorised, or extends the scope of its use, to deal with an identified threat. The authorisation lasts for a maximum of 120 days, and can only be granted if the danger cannot be contained by any other means. An example of this was the approval to treat a limited area of oilseed rape seed with neonicotinoid seed treatments in the UK for autumn 2015 plantings.EU Regulation 396/2005 sets harmonised standards for ***Maximum Residue Levels*** (MRLs) across the EU. The main issue in regulatory terms is the time that it takes to set MRLs for an active substance. This can delay authorisation and thus prevent access to useful PPP (often products that have already been used elsewhere in the world). It also adds cost to the authorisation process.

A number of retailers have grower protocols which impose additional restrictions on the use of PPP. Even when an active substance or product is authorised a retailer may choose not to buy produce treated with it. This is more common in the horticulture sector than for broadacre arable crops because many horticultural crops are presented to the consumer with minimal processing.

2.3. What Has Been Lost Already?

As approvals for active substances are renewed (or not) on a piecemeal basis, it is quite easy to underestimate the cumulative total of pesticides that have already been lost to the farming industry. This section goes back to the millennium and looks at the active substances no longer available to combinable crop growers. Note that it only looks at pesticides used on wheat, barley and oilseed rape as that is the scope of this project. There are further losses on actives used on other crops (e.g. atrazine for maize). *It should be stressed that this report does not intend to imply that the actives listed below should have remained available – there may well have been good scientific reasons not to authorise them. The list is merely intended to highlight the scale of losses already seen.*

2.3.1. Combinable Crop Insecticide, Nematicide and Molluscicide Losses

The following have been lost for use on wheat, barley and oilseed rape (OSR) since the turn of the millennium. They include insecticide seed treatments;

- Clorpyrifos – wheat, barley, OSR – all uses restricted apart from brassica modules
- Clothianidin – OSR seed treatment – use restricted by EU
- Dimethoate – wheat – still approved but restrictions limit use
- Imidacloprid – OSR seed treatment – use restricted by EU
- Methiocarb – wheat, barley, OSR – no longer authorised for use in slug pellets
- Pirimicarb – wheat and OSR – withdrawn from sale July 2016
- Thiamethoxam – OSR seed treatment – use restricted by EU

2.3.2. Combinable Crop Fungicide Losses

The following have been lost for use on wheat, barley and oilseed rape since the turn of the millennium;

- Carbendazim – wheat, barley and especially OSR – no longer approved
- Fluquinconazole – minor wheat use – withdrawn for commercial reasons
- Flusilazole – wheat, barley and especially OSR – no longer approved

- Vinclozolin – OSR – no longer approved

2.3.3. Combinable Crop Herbicide Losses

The following have been lost for use on wheat, barley and oilseed rape since the turn of the millennium;

- Cyanzine – minor use on wheat, barley and OSR – no longer approved
- Ioxynil – wheat and barley – no longer approved
- Isoproturon – wheat and barley – was banned in the UK, had returned but restricted to low dose only, but was subsequently not re-approved for use at EU level in June 2016. Its use is currently being phased-out
- Paraquat – v minor use on wheat, barley, OSR – no longer approved
- Tepraloxydim – OSR – no longer approved
- Trifluralin – wheat, barley, OSR – no longer approved

2.4. The Threat of Regulation to Key Actives

In the sections below the most widely used[12] pesticides for each of the crops wheat, barley and oilseed rape are listed. Then, an assessment of the threat of regulation limiting their use is made – 'low' means it is thought unlikely that the active would be lost within the timescale of this study. Those classed as 'medium' have a higher chance of being lost through regulation. They will be assumed to disappear in the more testing scenarios set out in Chapter 4. For those classed as at 'High' risk it is considered quite likely that they (or a large majority of them) will be lost as a result of regulation during the timescale of this report.

It must be stressed that this list is the author's own estimation, and cannot be regarded as definitive. It should be noted at the outset that this list draws data from a large number of sources and attempts to present a realistic picture of the situation as at summer 2016. *The 'Example Products' are simply intended to provide an illustration and are in no way a recommendation or preference. Where possible, a product containing only the active substance in question has been shown. Where this has not been practical, a mixed product is shown in italics. In the 'UK Treated Area' column a ' - ' either means that none of the active substance was used on the crops in 2014, or the use was too minor to appear in the Pesticides Usage Survey.*

2.4.1. Combinable Crop Insecticide, Nematicide and Molluscicide Threats

Combinable Crop Insecticide, Nematicide and Molluscicide Threats						
Active Substance	Example Product	UK Area Treated 2014 - Ha		Date of Reauthorisation	Risk of Loss	Reason
		Cereals	Oilseeds			
Alpha-cypermethrin	Astound	137,240	101,574	31/07/2017	Very Low	
Beta-cyfluthrin (inc. seed treatment	Gandalf	18,017	212,227	31/10/2016	Low	minor ED evidence
Clothianidin (as seed treatment)	Deter	837,488	-	31/01/2018	Low/Medium	suspected ED
Cypermethrin	Contest	697,034	387,588	31/10/2017	High	WFD Priority Substance / ED
Deltamethrin	Decis	26,771	10,958	31/10/2016	Low/Medium	suspected ED
Dimethoate	Perfekthion	2,789	-	31/07/2018	Low/Medium	suspected ED
Esfenvalerate	Sven	193,326	-	31/12/2022	High	Persistent Bio-accumulative and Toxic (PBT)
Ferric Phosphate	Sluxx HP	28,056	-	31/12/2030	Very Low	
Lambda-cyhalothrin	Hallmark Zeon	804,382	437,905	31/03/2023	Low/Medium	suspected ED
Metaldehyde	Certis Metaldehyde 3	389,853	461,955	31/05/2021	Medium/High	WFD Article 7
Pymetrozine	Plenum WG	804	4,774	30/06/2017	Very Low	
Tau-fluvalinate	Mavrik	34,134	262,437	31/05/2021	Low	minor ED evidence
Thiacloprid	Biscaya	-	12,653	30/04/2017	High	Cut-off criteria
Zeta-cypermethrin	Fury 10 EW	147,249	92,537	30/12/2019	Very Low	

In summary, three active substances in the insecticides category are at high risk of loss. This rises to four if the medium/high classification is included.

2.4.2. Combinable Crop Fungicide Threats

The following list includes fungicide seed treatments.

Combinable Crop Fungicide Threats						
Active Substance	**Example Product**	**UK Area Treated 2014 - Ha**		**Date of Reauthorisation**	**Risk of Loss**	**Reason**
		Cereals	**Oilseeds**			
Azoxystrobin	Amistar	529,807	312,013	31/12/2021	Low	minor ED evidence
Bixafen	*Variano*	1,098,437	62,192	30/09/2023	Low/Medium	suspected ED
Boscalid	Filan	442,383	251,381	31/07/2018	Low/Medium	suspected ED
Chlorothalonil	Bravo 500	3,518,709	-	31/10/2017	Medium/High	WFD UK Specific Pollutant / suspected ED
Copper-oxychloride	Cuprokylt	76,465	372	31/01/2018	Very Low	
Cyproconazole	Centaur	879,593	76,857	31/05/2021	High	Cut-off criteria / ED
Cyprodinil	Unix	226,265	-	30/04/2018	Low	minor ED evidence/ potential CfS
Difenoconazole	Difference	21,735	127,699	31/12/2018	Low	minor ED evidence
Dimoxystrobin	*Swing Gold*	-	-	31/01/2018	Very Low	
Epoxiconazole	Ignite	3,758,696	-	30/04/2019	High	Cut-off criteria / Endocrine disruptor
Fenpropimorph	Corbel	762,658	-	30/04/2019	Very Low	
Fludioxonil (as seed treatement)	Beret Gold	254,177	311,796	31/10/2018	Low	minor ED evidence
Fluopyram	*Recital*	-	-	31/01/2024	Very Low	
Fluoxastrobin	*Fandango*	552,632	-	31/07/2018	Low	minor ED evidence
Fluxapyroxad	Imtrex	1,098,127	-	31/12/2022	Very Low	
Folpet	Arizona	352,731	-	31/07/2018	Low/Medium	suspected ED
Isopyrazam	Reflect	398,488	-	31/03/2023	Low	potential Candidate for Substitition (CfS)
Mancozeb	Quell Flo	77,717	-	31/01/2018	High	ED
Metconazole	Caramba	722,729	297,866	30/04/2018	Medium	ED*
Penthiopyrad	Intellis	566,461	-	30/04/2024	Low/Medium	suspected ED
Picoxystrobin	Galileo	100,885	97,722	31/10/2016	Low	minor ED evidence
Prochloraz (inc. seed treatment)	Poraz	1,207,281	187,770	31/12/2021	High	ED
Proquinazid	Talius	282,788	-	31/07/2020	Low/Medium	suspected ED
Prothioconazole (inc. seed treatme	Proline 275	4,951,034	829,626	31/07/2018	Low/Medium	suspected ED
Pyraclostrobin	Comet 200	951,889	-	31/01/2017	Low	minor ED evidence
Silthiofam	Latitude	142,561	-	31/10/2016	Low/Medium	suspected ED
Spiroxamine	*Cello*	710,813	-	31/12/2021	Low/Medium	suspected ED
Tebuconazole	Folicur	2,911,126	880,034	31/08/2019	High	ED
Thiram (as seed treatment)	Thyram Plus	15,314	95,713	30/04/2017	Low/Medium	suspected ED
Trifloxystrobin	Swift SC	-	-	31/07/2016	Very Low	
Triticonazole (as seed treatment)	*Kinto*	556,317	-	30/04/2018	Low/Medium	suspected ED

* Metconazole is not on the EU Commission list, but has been identified as a potential ED previously. Not clear if it was part of the screening process.

For fungicides, it is forecast that six active substances are at high risk of not being re-authorised. This rises to seven if the medium/high classification is included.

2.4.3. Combinable Crop Herbicide Threats

Combinable Crop Herbicide Threats						
Active Substance	Example Product	UK Area Treated 2014 - Ha Cereals	UK Area Treated 2014 - Ha Oilseeds	Date of Reauthorisation	Risk of Loss	Reason
2-4D	Depitox	5,522	-	31/12/2030	High	WFD Article 7 / UK Specific Pollutant
Amidosulfuron	Squire Ultra	110,960	10,861	31/12/2018	Very Low	
Aminopyralid	*AstroKerb*	-	65,478	31/12/2024	Very Low	
Bifenox	Fox	2,655	86,548	31/12/2018	High	WFD Priority Substance
Bromoxynil	Butryflow	108,404	4,863	31/07/2017	Low/Medium	suspected ED
Carbetamide	Crawler	-	74,917	31/05/2021	High	Cut-off Criteria
Chlorotoluron	*Tower*	175,772	-	31/10/2017	Medium	WFD Article 7
Clethodim	Centurion Max	-	132,549	31/05/2021	Low/Medium	suspected ED
Clodinafop-propargyl	Topik	227,761	-	30/04/2018	Very Low	
Clomazone	Gamit	-	146,197	30/10/2018	Low	minor ED evidence
Clopyralid	Shield	67,609	121,015	30/04/2018	Medium	WFD Article 7
Cycloxydim	Laser	-	35,647	31/05/2021	Very Low	
Dicamba	*Mircam*	112,391	-	31/12/2018	Low/Medium	suspected ED
Diflufenican	Hurricane	2,286,614	-	31/12/2018	Low/Medium	suspected ED/potential CfS
Dimethenamid	*Springbok*	-	264,798	31/10/2016	Very Low	
Florasulam	Lector	679,196	-	31/12/1930	Very Low	
Fluazifop-P-butyl	Fusilade Max	-	100,985	31/12/2021	Low/Medium	suspected ED
Flufenacet	Sunfire	1,789,595	-	31/10/2016	Low/Medium	suspected ED/potential CfS
Flupyrsulfuron-methyl	Lexus SX	364,843	237	30/06/2017	Very Low	
Flurtamone	*Movon*	-	-	31/10/2016	Very Low	
Fluroxypyr	Starane	1,172,253	-	31/12/2021	Medium	WFD Article 7
Glyphosate	Clinic Ace	1,297,402	557,742	30/06/2016	Medium/High	EU Cut-off Criteria / WFD UK Specific Polluta
Iodosulfuron-methyl-sodium	Hussar	986,092	8,281	31/10/2016	Very Low	
MCPA	Easel	124,058	-	31/10/2017	Medium/High	WFD Article 7
Mecoprop-P	Duplosan KV	671,590	-	31/01/2017	High	WFD Article 7 / UK Specific Pollutant
Metazachlor	Butisan S	47	557,703	31/07/2019	High	WFD Article 7
Metsulfuron-methyl	Jubilee SX	1,039,819	2,632	31/03/2023	Low	potential Candidate for Substitition (CfS)
Pendimethalin	Stomp Aqua	1,288,864	-	31/07/2016	High	ED
Pinoxaden	Axail	501,100	-	30/06/2026	Very Low	
Propaquizafop	Falcon	3,369	337,635	30/11/2019	Low/Medium	suspected ED
Propyzamide	Kerb Flo	1,177	415,429	31/01/2017	High	WFD Article 7 / ED
Prosulfocarb	Defy	241,141	-	31/10/2018	Low	
Quinmerac	*Shadow*	-	159,644	30/042021	High	WFD Article 7
Quizalofop-P-ethyl/tefuryl	Leopard 5EC	-	131,717	30/11/2019	Low/Medium	suspected ED
Thifensulfuron-methyl	*Harmony M*	-	-	31/10/2017	Low/Medium	suspected ED
Tri-allate	Avadex	128,561	845	31/12/2019	Low	potential Candidate for Substitition (CfS)
Tribenuron-meythl	Thor	519,031	-	31/10/2017	Low	minor ED evidence
Triflusulfuron	Debut	-	-	31/12/2019	High	ED

Seven key herbicides currently used in UK combinable cropping systems are at high risk of being lost. This could be as high as ten if those with a slightly lower risk of loss are included.

2.4.4. Combinable Crop Seed-Treatment Threats

It is assessed that the threat to all growth regulators used in wheat, barley and (to a lesser extent) oilseed rape is low. These include 2-chloroethylphosphonic acid, chlormequat, mepiquat and trinexapac-ethyl.

3. PESTICIDE RESISTANCE

3.1. GENERAL

Resistance to pesticides in the field occurs through natural selection. Some members of a species, either insect, fungus or plant, may have a genetic mutation that means they are affected to a lesser degree, or not at all, by the active substance. Often such mutations are very rare at the outset of the process. Once the pest population is subject to chemical control the non-resistant strain is killed or supressed by the active substance. This confers a competitive advantage for the resistant individuals. This advantage is passed-on to their offspring. Over time, if the selection pressure is maintained through continual use of the pesticide, the resistant members of the species come to dominate the population. The active substance then becomes ineffective in controlling the pest.

There may be a good evolutionary reason why the genetic mutation conferring resistance is initially found at a low level within the population – it may confer a disadvantage in normal circumstances. Therefore, if the selective pressure is removed (i.e. the active substance is not used), then the pest population can regain susceptibility as the 'standard' members of the species regain a competitive advantage and become a larger portion of the population once more. However, this reversing of resistance is not always the case.

Pesticides have specific Modes of Action (MoA) – the way they react with their target organism to kill it. For example, this may be interfering with nerve signals in insects, blocking cell formation in fungi, or inhibiting enzyme activity in weeds. Active substances have a target site within the pest where their chemical has its effect (a biochemical pathway). Modern pesticides tend to have a single-site Mode of Action. This tends to have a lower potential for unintended environmental damage, such as affecting non-target organisms (it can perhaps be thought of as a precision-guided missile). However, a single site MoA only provides one chance for the active to work. Therefore, more modern, safer and 'sophisticated' pesticides are often at greater danger of developing resistance than older chemistry. This is one of the reasons resistance has become a growing problem in combinable crop farming.

A single genetic mutation at the target site can completely block the activity of the active substance and the organism becomes completely resistant. Control cannot be regained by higher rates or more frequent pesticide applications. This type of resistance is referred to as qualitative resistance. Some genetic differences can lead to partial blocking of the active substance; there is variation in sensitivity within the population. Resistance in this case is a reduction of control and it can be regained (at least in the short-term) by using higher rates or more frequent fungicide applications. This type of fungicide resistance is referred to as quantitative resistance.

Organisms that develop resistance to one active substance also become resistant to other closely-related pesticides, even when they have not been exposed to them. This is because 'families' of active substances have the same Modes of Action. This is called cross resistance. MoA classifications are produced for insecticides, fungicides and herbicides to help with resistance management. Resistance risk for a new MOA can be difficult to predict.

Managing resistance is critical to controlling pests in combinable crops. Rotations, cultural control, and variety choice can all play a part. However, resistance has already developed to a number of key active substances and it seems highly probable that this trend will continue, making control through purely chemical means more problematic. The following sections look at specific issues for insecticide, fungicide and herbicide resistance.

3.2. Insecticide Resistance

3.2.1. General

The Insecticide Resistance Action Committee (IRAC)[13] is an international organisation dedicated to preventing or delaying the development of resistance in insect and mite pests. In the UK, the Insecticides Resistance Action Group (IRAG)[14] does similar work. More information on the subject of resistance to insecticides is available from these sources.

Resistance in insects can be divided up into two main types. ***Target site resistance*** is when a mutation blocks the specific biochemical pathway the insecticide uses to attack the insect. More general resistance comes through ***non-target site*** routes. Of these, ***metabolic*** resistance is the most important; this is where the insect creates a greater-than-usual amount of enzymes which break down the active substance before it can reach its target site.

Insects are more mobile than both weeds and fungi. This has both advantages and disadvantages in terms of resistance. It means that resistant strains can spread more easily. But is also means that there is a greater mixing of populations so that 'pure' resistant populations do not become so established in certain locations. This, in turn, can have the effect that individual farmers are less likely to take ownership of resistance management.

3.2.2. Wheat and Barley Insecticides

The main insect pests that cause economic damage in cereals are, aphids, wheat bulb fly and orange wheat blossom midge. Of the aphid species, bird cherry-oat aphids and grain aphids are important. As well as direct feeding the latter two also transmit Barley Yellow Dwarf Virus (BYVD). More minor insect pests include wireworms, frit fly, gout fly, yellow cereal fly, rose grain aphids, leatherjackets, and saddle gall midge.

Of these pests, only grain aphids have so far developed resistance to insecticides. Grain aphids have demonstrated a type of resistance to pyrethroids known as knock-down resistance (kdr) since 2012. The impact of widespread grain aphid resistance has the potential to be severe as they carry BYDV which causes losses of 2.5 tonnes per hectare[15]. At present, although the resistance is reported to be widespread in the grain aphid population, it is currently at a relatively low level and pyrethroids still provide satisfactory control in the majority of situations.

The other insect pests have not, to date, shown any resistance. Therefore, for the purposes of this project, it will be assumed that they will remain controllable using present active substances.

Slugs have the potential to cause major economic harm. However, no resistance is reported to molluscicides.

3.2.3. Oilseed Rape Insecticides

In general, oilseed rape suffers more from insect pests than cereals. The main economic pests are cabbage stem flea beetle (CSFB) and peach potato aphids, followed by pollen beetles, brassica pod midge and cabbage seed weevil. More minor pests include cabbage root fly, leaf blotch miner, mealy cabbage aphid and rape winter stem weevil. The 'lesser' pests tend to cause more sporadic, localised damage – this can be severe on an individual farm basis but tends not to have a large overall effect on the sector.

In terms of aphids, the main problem is not direct damage but the transmissions of viruses. The peach potato aphid transmits the turnip yellows virus (TuYV) – as well as other viral diseases. It is already estimated that 60% of UK OSR is affected by TuYV. The average yield loss from TuYV in oilseed rape is 15% but it can be as high as 30%[16].

Until 2013 both CSFB and peach potato aphids were largely successfully controlled by neonicotinoid seed treatments. CSFB can now only be controlled by applying pyrethroids in the autumn. Knock-down resistance (kdr) to pyrethroids has been confirmed in Germany. Recent work in the UK[17] has found this type of resistance in beetles is present domestically as well. Beetles have also been found to have a metabolic based resistance as well as kdr; this type of resistance has so far only been confirmed in the UK. Active substances within the pyrethroid family include cypermethrin, zeta-cypermethrin, and lambda-cyhalothrin.

The peach-potato aphid has developed resistance to a variety of insecticides[18]. Target site resistance to pirimicarb and pyrethroids are conferred by specific mutations. Metabolic resistance also serves to make these active substances less effective and confers resistance against organo-phosphorous chemicals (although this is now a moot point with the loss of clorpyrifos – the only approved OP spray).

As with cereals, slugs, whilst a large potential economic threat, show no resistance to current control methods.

3.3. Fungicide Resistance

3.3.1. Background

Most modern fungicides have a single-site mode of action and are generally at medium to high risk for resistance development. Modern fungicides move into the leaf tissue (fungicide is not toxic to the plant), making them more rain-resistant than contact-based fungicides and have higher activity levels as they move from where they are deposited on the upper leaf surface to the lower surface where pathogens tend to develop. Some modern fungicides are systemic meaning they move widely throughout plants. Older fungicides, such as copper and chlorothalonil, have low potential for resistance to develop because they have multi-site mode of action.

Fungicide Group Codes designating chemical groups were developed to facilitate managing resistance by the Fungicide Resistance Action Committee (FRAC). These codes are usually on the front of labels or in the resistance management section. Fungicides with the same Group Code have similar mode of action and therefore likely will exhibit cross-resistance. Thus, it is critical for managing resistance to know the group code for the fungicides being used for a particular disease to avoid alternating among chemically similar fungicides. Codes for all fungicide active substances (e.g. common names) can be downloaded from www.frac.info.

3.3.2. Examples of Resistance

Various examples of the build-up of resistance to fungicides in combinable crops can be found around the world. In Australia the use of fungicides is relatively recent. Combinable cropping is characterised by low and intermittent rainfall with poor soil fertility meaning yields are comparatively low by international standards. The need and financial justification for fungicides has therefore been low. Use of fungicides only really started at the turn of the millennium with a small group of actives (mainly triazoles) that had come off patent. Even in this relatively short timescale resistance has been seen in mildews, septoria and botrytis strains. The large areas of monoculture and repeated cropping is likely to have added to the selection pressure speeding up the development of resistance.

In ***Ireland*** the key fungal disease is septoria (due to the wet climate). In 2015, researchers[19] found strains of the disease that were highly resistant to the SDHI group of active substances (which include bixafen and fluxapyroxad). Although not yet widely prevalent this would cause severe problems for Irish wheat production. Strobilurins have become ineffective against septoria due to resistance. The other main familyof chemicals used to control the disease, azoles (such as epoxiconazole and prothioconazole), still have some control. But the loss of SDHIs would make resistance management much more difficult.

In the UK, strobilurins were a great success when they were introduced in 1996, but fungal resistance to them spread quickly. They had a single site MoA which made the chemistry vulnerable to resistance. Stobilurins once provided good protection from most cereal fungal infections but this is no longer the case. Septoria, mildew, ramularia and *Microdochium nivale* should be considered to be resistant to strobilurins, as isolates are now widespread across the UK and dominate the population. Net blotch still has some sensitivity to Strobilurin fungicides, although resistant isolates are widespread. No resistance has yet been identified in rusts.

3.3.3. Wheat Fungicides

The most economically damaging fungal disease in the UK wheat crop is septoria tritici (also sometimes known as leaf blotch). According to an HGCA publication[20] losses can be as high as 30-50%, with susceptible varieties seeing average losses of 20% when left untreated.

The azole group of fungicides has been the main treatment for septoria. Almost all crops are treated and CropMonitor data (2010) suggests that an average of 2.85 azole treatments per crop is undertaken. The effectiveness of many older azole products has declined as septoria has developed resistance to them. The main azole control options in the UK are now epoxiconazole and prothioconazole.

Alternative control options are chlorothalonil, mancozeb and folpet which are protectant, but provide no curative action. A group of newer succinate-dehydrogenase inhibitors SDHI fungicides including biaxfen, boscalid, fluxapyroxad and isopyrazam also provide control against septoria. In 2016 it was reported that the strains of septoria that are highly resistant to SDHIs, as found in Ireland (see above), had also been seen in the UK[21]. However, they have not increased for the 2016 crop, suggesting a high fitness penalty (i.e. the fungus experiences a strong trade-off for its high SHDI resistance in other negative attributes).

Low to moderately SDHI resistant strains in both the UK and Ireland are increasing however. SDHIs only have one site of action, and so the probability of resistance developing further if not used in conjunction with the azoles is high. FRAGUK considers that the SDHI fungicides are at a medium/high risk of resistance development in cereal pathogens.

Strobilurins now offer little or no result against septoria.

Other fungal diseases that affect wheat plants are yellow rust, brown rust and (powdery) mildew. The rusts are currently well-controlled with azoles, SDHIs and the strobilurin group of fungicides. Wheat powdery mildew is considered a high risk pathogen because of the number of disease cycles in a season. It can therefore evolve quickly. However, its effect on yields is less than many other diseases. Strobilurins no longer control the disease and some resistance to azoles has been seen.

Eyespot has the potential to severely affect yields and it is difficult to control completely with fungicides. Azoles and SDHIs have an effect of reducing the severity and no resistance issues have been reported to date.

3.3.4. Barley Fungicides

In barley rhynchosporium is the most damaging disease, especially in the north and west of the UK[22]. Strobilurins continue to provide good control of rhynchosporium. The disease is developing resistance to the azoles (although prothioconazole continues to have some control). The SDHIs show no field level resistance as yet but, as outlined in the wheat section, are thought to be susceptible.

Ramularia is an important disease in the north and increasingly in the south of the UK. Strobilurins have lost their effectiveness against this disease but SDHIs and azoles still provide control as does chlorothalonil, which offers a different MoA. Mildew is another economically important disease. There is a wide range of chemical options to treat the disease which should, hopefully, prevent or slow resistance build-up to any one active. Strobilurins no longer control mildew due to disease resistance. Partial resistance to some specific mildewicides has developed meaning they have reduced efficacy.

The key active substances remain effective against rusts (brown and yellow). Net blotch can also be important in barleys. Strobiluron chemistry has activity against the disease although partial resistance and reduced efficacy is common. Azoles and SDHIs show no signs of resistance build-up in net-blotch.

3.3.5. Oilseed Rape Fungicides

In oilseed rape the main foliar fungal diseases are phoma leaf spot and light leaf spot[23]. Phoma has historically been more prevalent in south and eastern England whilst light leaf spot was more common in Scotland and northern England. However, the diseases now overlap to a large extent with 90% of the oilseed crop potentially affected by phoma and three-quarters by light leaf spot. Phoma can invade the stem and cause cankers. The main treatment for both diseases are the azole fungicides. An alternative treatment option for phoma is an SDHI plus strobilurin mix. None of these actives appears to be losing effectiveness due to resistance at present. Light leaf spot can also be controlled by tebuconazole and shows no signs of building resistance. The disease does appear to have developed some resistance to older triazoles.

Sclerotinia stem rot (inc. stem canker) is the major disease in oilseed rape at flowering. Affected plants can suffer up to 50% yield loss[24] but attacks are very variable from season to season. Treatments provide good control for about three weeks. Two sprays may therefore be required to protect crops at high-risk sites throughout the flowering period. Prothioconazole is the main active substance used to control the disease although other azoles such as metconazole and tebuconazole are also used). SDHIs (e.g. fluopyram and bixafen) are used, as well as boscalid. Sclerotinia shows no resistance as yet to these active substances in the UK, but the usual approach of using mixtures, co-formulations and products with different MoA should be adopted.

The fungi alternaria and powdery mildew also infect oilseed rape, but tend to be controlled by the pesticides used for the leaf spots and sclerotinia. Again, resistance is not reported to be a problem at present.

3.4. Resistance to Herbicides

3.4.1. General

Unlike insects and diseases, weeds tend not to be specific to particular crops – they are simply within the arable rotation. They reduce the yield of the crop by competing for space, light, water and nutrients. For this reason, this section is not organised by crop, rather by weed type – split into grass and broadleaved weeds.

The UK Weed Resistance Action Group (WRAG) and the international Herbicide Resistance Action Committee[25] both publish guidance on minimising resistance to herbicides.

There are three key types of herbicide resistance[26]. The most common is Enhanced Metabolic Resistance (EMR). Like the metabolic resistance previously described in insects, the organism is able to break down and de-toxify the active substance to some effect. Most herbicides can suffer from EMR to some extent, but it only increases slowly so the active substance continues to have an effect.

The second type of resistance is target site resistance (TSR). In the UK TSR to the ACCase inhibitor group of herbicides. blocks the activity of the following categories of active substances;

- 'fop' – e.g. clodinafop, fenoxaprop, fluazifop-P, propaquizalofop, quizalofop
- 'dim' – e.g. cycloxydim, tepraloxydim
- 'den' – pinoxaden

ALS target site resistance is also found in the UK and inhibits the action of sulfonylurea herbicides such as flupyrsulfuron, mesosulfuron, iodosulfuron, and pyroxsulam.

Unlike resistance in insects and fungi, plant species tend not to lose resistance over time – once resistance to an active is prevalent the usefulness of the chemical is lost permanently.

3.4.2. Grass Weeds

The most high-profile grassweed in UK combinable crop production is blackgrass. It has spread out of its traditional heartlands of south and eastern England further west and north. It is also becoming more prevalent on soil types other than the heavy clay soils with which it has historically been associated. Its spread has been caused by the increasing area of autumn cropping, and a move to earlier planting (before the end of September). This means more of the blackgrass plants emerge with the autumn cereals crop, rather than beforehand where they can be more easily destroyed. The geographic spread has likely been mainly through the movement of seeds in hay and straw and also on agricultural machinery. Although there is good evidence that resistance has also developed separately at multiple locations.

A number of active substances used for blackgrass control have already been lost including trifluralin, isoproturon, and chlorotoluron. This has led to a reliance on a smaller group of pesticides to control the weed and resistance has built up as a consequence. According to a recent study[27] herbicide resistant blackgrass is now very widespread and is estimated that some degree of resistance occurs on at least 80% of farms that spray regularly to control the weed.

There is a focus on making more use of pre-emergence herbicides which have lower resistance risks. These include flufenacet, pendimethalin, prosulfocarb and tri-allate. All these are affected to some extent by EMR; flufenacet appears the most effective.

Of the post-emergence herbicides, ACCase resistance is now widespread. ALS resistant blackgrass is less prevalent, but increasing steadily. Mixtures or sequences of herbicides with different MoA should be used to reduce the spread of resistance[28]. Even so, this is likely to be a growing problem for UK cereals farmers in the coming years.

Blackgrass is less of a problem in oilseed rape. Carbetamide and propyzamide can both be used and are, as yet, unaffected by resistance. This can help clean the field for following cereal crops.

Of the other grass weeds commonly found in arable rotations, the most important are annual meadowgrass, ryegrass, wild oats and barren brome. Annual meadowgrass does not appear to have developed widespread resistance to any of the main classes of herbicide. Isoproturon (IPU) had been re-authorised at low-doses to control meadowgrass, but this active has now lost its authorisation at EU level.

Resistant ryegrasses are an increasing threat in the UK. This includes EMR and ACCase (but less severe than for blackgrass). ALS resistance has been confirmed but is not yet widespread. Wild oats exhibit less resistance issues. EMR resistance has been confirmed but is less prevalent in wild oats than in the grass species. ACCase resistance appears to be mainly an issue for the 'fop' herbicides at present and there is no ALS target site resistance reported. Resistant wild oats seem confined to patches in the UK. Wild oats are self-pollinating so resistant genetics will not be spread by pollen. However, the problem is very prevalent in other countries (e.g. Canada) so the possibility of increased resistance in the future is real.

Barren brome does not demonstrate resistance to the key herbicides in the UK, although there are anecdotal reports of increasing difficulty in controlling it. Historically, couchgrass was a major problem in domestic cereal crops. This problem has been controlled almost to the point of irrelevance with the current armoury of crop protection products, and resistance does not seem an issue.

3.4.3. Broadleaved Weeds

This category of weeds includes cleavers, charlock, mayweed, chickweed, poppies, thistles and others of less economic significance. Charlock and cleavers are particular problems in oilseed rape. All of these weeds compete with the crop for nutrients, water and light, so their presence in large numbers reduces yield. The presence of broadleaved weeds can create a micro-climate in the growing crop near the soil. This can favour the development of disease.

Up until now, the herbicides used to control grassweeds in cereals have also provided good control of broadleaved weeds. However, a recent publication by the AHDB[29] outlined that resistance is now appearing. Resistance has been found in chickweed, mayweed and poppies to the ALS inhibiting herbicide class (as well as in groundsel to the triazinone herbicides such as metribuzin and metamitron used on root crops). ALS resistant poppies are the most common followed by chickweed and mayweed. No EMR resistance has been found and there are presently good alternative control options for these weeds. For example, on poppies, pendimethalin; for chickweed fluroxpyr and ioxynil (although no longer approved for wheat and barley) and bromoxynil for mayweed. (Note that ACCase-type herbicides are not active on broadleaved weeds.)

None of the other broadleaved weeds is yet exhibiting any resistance traits. However, across Europe other broadleaved weed species, such as shepherds purse, cornflower and fat hen have developed resistance to herbicides including ALS and synthetic auxins. If cleavers, for example, became resistant to one, or all, of the key groups of herbicides this would cause a major problem for UK combinable crop growers.

3.4.4. Non-Selective Herbicides (Desiccants)

Non-selective herbicides control most vegetation to which they are applied. They are widely used to control volunteers and other weeds prior to planting and are also used to desiccate crops prior to harvest. This ensures an even level of crop maturity, reduces moisture content from growing weeds, and makes harvesting easier.

By far the most commonly used desiccant in the UK is glyphosate. This is a systemic herbicide in that it is absorbed by leaves, and translocated to all plant tissues (including the roots). It is a key part of the crop production process in the crops being looked at in this study.

No cases of resistance to glyphosate have been recorded in the UK. However, there are 35 glyphosate resistant species (including both broad-leaved and grass-weeds) seen in 27 countries around the world. It is far from inconceivable that resistant strains could appear in the UK in the future.

4. SCENARIOS

4.1. General

In general, it is assumed that the pest pressures are as currently seen, save for the development of resistance to certain active substances. No new diseases or pests are assumed (or currently minor ones having a 'breakout' into a major problem). This cannot be discounted in the longer term with the impact of climate change, and the inter-connectedness of the modern world increasing the potential for invasive species.

In the scenarios, wheat and barley have been grouped together as they share many of the same issues. Where there are differences these have been highlighted.

4.2. Scenario A

This scenario is the least-worst in terms of retaining the number and efficacy of pesticides. In terms of re-authorisations, only those deemed as at 'high' risk of loss in Chapter 3 are lost. There are also few, if any, 'label changes' resulting in the way products are used being restricted from the current situation. Resistance to key active substances does increase, but relatively slowly, helped by the industry working hard to manage resistance.

4.2.1. Wheat and Barley

Scenario A for wheat and barley is as follows;

- Cypermethrin and esfenvalerate are not re-approved. However, enough products remain to control insect pests on wheat (e.g. alpha-cypermethrin, lamda-cyhalothrin etc.). The resistance seen in grain aphids does not become more prevalent and no resistance build-up seen in other species. Therefore, insect pests and insect borne diseases are not a major problem.
- Due to the success of 'stewardship' efforts, no additional restrictions on the use of metaldehyde are imposed.
- Of the azole fungicides, cyproconazole, epoxiconazole and tebuconazole are not re-authorised. However, the remaining azole products (e.g. difenoconazole, metconazole, prothioconazole and triticonazole) have no additional restrictions on their use.
- Of the contact/multisite fungicides mancozeb is not reauthorized. Folpet remains as does chlorothalonil, although the latter is subject to restrictions on its use in certain water catchments.
- Of SDHIs, boscalid, bixafen, fluxapyroxad, isopyrazam and penthiopyrad remain. There are no additional restrictions imposed on the use of these products.
- In wheat, septoria resistance to SDHI's reduces their performance by 35% compared to current levels. Septoria resistance to azoles also continues to develop. Effectiveness is reduced by 20% compared to current levels.
- Strobilurins stay on the market. They are ineffective against septoria, but remain effective against rusts.

- In barley, the continued availability of chlorothalonil sees it remain an important option for rhynchosporium and ramularia control. Strobilurins and SDHIs also continue to be available and effective on rhynchosporium. SDHIs and azoles are available for ramularia.
- It is assumed that glyphosate remains available under this scenario. *There is a possibility that as a condition of its re-approval some additional restrictions could be placed on how it is used (for example, no pre-harvest desiccation uses). For the purposes of this scenario, it will be assumed that there will be no change from current label rules.*
- In terms of herbicides, the most important loss under this scenario is pendimethalin. However, other pre-ems such as flufenacet, prosulfocarb and tri-allate remain available. Metabolic resistance continues to rise in blackgrass, albeit slowly, reducing the effectiveness of control from pre-ems. However, some control is still possible – 65% effectiveness assumed, although the figure will be lower in 'hotspot' areas.
- ACCase resistance becomes endemic resulting in the 'fop', 'dim' and 'den' herbicides having no benefit on blackgrass. ALS resistance spreads but sulfonylurea herbicides continue to have a limited effect on blackgrass.
- The loss of mecoprop-p, in addition to pendimethalin, removes two widely-used active substances for broadleaved weed control. However, enough other actives remain to retain good control options. Widespread broadleaved weeds resistance to ALS herbicides does not occur.

4.2.2. Oilseed Rape

Scenario A for oilseed rape is as follows;

- No reversal of the ban on neonicotinoid seed treatments.
- Thiacloprid not re-approved, but pymetrozine remains for autumn aphid control. Pyrethroids still available to control peach potato aphids, but their effectiveness, as currently is very limited.
- Resistance of cabbage stem flea beetles to pyrethroids increases. This assumed to be at a reasonably high rate due to lack of alternative control options. Effective control drops by 30% from current levels.
- Cypermethrin and esfenvalerate not re-approved. However, a number of pyrethroids remain (e.g. alpha-cypermethrin, beta-cyfluthin, deltamethrin, lamda-cyhalothrin and tau-fluvalinate).
- No restrictions on use of metaldehyde (see wheat and barley section above).
- Tebuconazole (and cyproconazole) not authorised, but prothioconazole and metconazole remain to control phoma, light leaf spot and sclerotinia. No resistance issues develop.
- In terms of herbicides, key losses are carbetamide and propyzamide. This means that two options for grassweed control that have yet to develop resistance issues will be lost. This situation would be exacerbated by restrictions on metazachlor. Under this scenario, 'stewardship' measures mean that the amounts found in water reduce and no further restrictions are applied.
- Resistance to ALS herbicides in broadleaved weeds does not become prevalent. An alternative (EAMU) control option will be removed with the loss of bifenox.
- Glyphosate to remain available and no resistance issues develop. As outlined in the cereals section above, no restrictions placed on its use.

4.3. Scenario B

It should be pointed out that, whilst this is the 'middle' scenario, it does not necessarily make it more or less likely than the others; there is a wide range of possible outcomes. Under this scenario, the active substance rated as 'high' or 'medium/high' in terms of risk of loss are not re-authorised. Even some actives that remain have more onerous restrictions on their use imposed. Resistance to key active develops in line with the trend seen over the past decade or so.

4.3.1. Wheat and Barley

Scenario B for wheat and barley is as follows;

- As with Scenario A, cypermethrin and esfenvalerate are not re-approved. However, enough products remain to control most insect pests on wheat (e.g. alpha-cypermethrin, lamda-cyhalothrin etc.). Grain aphid resistance becomes more widespread with a reduction in the effect of pyrethroids. This begins to cause economic losses. No resistance build-up in other insect pests.
- Restrictions on the use of metaldehyde are imposed. However, these are only applicable in specific catchments. *Priority catchments are assumed to account for 21% of the arable land in England*[30]*. An earlier report suggested 20% of the land in this area could be affected. It is assumed that a simple ban on the use of the substance is imposed in these areas – although restrictions on the amount that could be used is also possible.*
- Of the azole fungicides, cyproconazole, epoxiconazole and tebuconazole are not re-authorised. Unlike under Scenario A, the remaining azole products are restricted in their use to only once per season due to concerns over their effect on the environment and human health.
- Of the contact/multisite fungicides only folpet remains (i.e. chlorothalonil and mancozeb are not re-authorised).
- Of SDHIs, boscalid, bixafen, fluxapyroxad, isopyrazam and penthiopyrad remain. But only one SDHI application is allowed per season, for resistance management reasons.
- In wheat, septoria resistance builds faster than under Scenario A (to an extent, this is due to the loss of the additional multisite chlorothalonil). For SDHI's this reduces their performance by 50% compared to current levels. Septoria resistance to azoles also continues to develop. Effectiveness is reduced by 30% compared to current levels.
- As with Scenario A, strobilurins stay on the market. They are ineffective against septoria, but remain effective against rusts.
- In barley, rhynchosporium remains controllable through strobilurins and SDHIs as does ramularia with SDHIs and azoles. Chlorothalonil will no longer be available.
- It is assumed that glyphosate remains available under this scenario. No resistance to the herbicide develops. *Readers may note that the risk to glyphosate is deemed to be 'medium/high' in the table in Chapter 3, and so might be thought to be lost under this scenario. However, the pesticide is so integral to modern farming methods it is believed that a reauthorisation will be forthcoming. However, restrictions on its use will be imposed.* It is assumed that pre-harvest desiccation will no longer be an approved use.
- Pendimethalin lost for grassweed control. Other pre-ems such as flufenacet, prosulfocarb and tri-allate remain available. Metabolic resistance continues to rise in blackgrass (at a faster rate than in

Scenario A) reducing the effectiveness of control from pre-ems. However, some control is still possible – 50% effectiveness assumed, although the figure will be lower in 'hotspot' areas.
- ACCase resistance becomes endemic resulting in the 'fop', 'dim' and 'den' herbicides having no benefit on blackgrass. ALS resistance spreads to the extent that sulfonylurea herbicides also have little effect on blackgrass.
- Broadleaved weeds become an increasing problem as resistance to ALS herbicides spread. An alternative control option will be removed with the likely loss of pendimethalin.

4.3.2. Oilseed Rape

Scenario B for oilseed rape is as follows;
- As with Scenario A, no reversal of the ban on neonicotinoid seed treatments.
- Thiacloprid not re-approved, but pymetrozine remains for autumn aphid control. Peach potato aphids assumed to be widely resistant to pirimicarb and pyrethroids.
- Resistance of cabbage stem flea beetles to pyrethroids becomes widespread. Effective control becomes difficult in over half of the crop.
- Cypermethrin and esfenvalerate not re-approved. However, a number of pyrethroids remain (e.g. alpha-cypermethrin, beta-cyfluthin, deltamethrin, lamda-cyhalothrin and tau-fluvalinate).
- Restrictions on use of metaldehyde in specific catchments (see wheat and barley section above).
- Tebuconazole not authorised, but prothioconazole and metconazole remain to control phoma, light leaf spot and sclerotinia. No resistance issues develop.
- As under scenario A, key herbicide losses are carbetamide and propyzamide. This means that two options for grassweed control that have yet to develop resistance issues will be lost. This situation is exacerbated by likely restrictions on metazachlor. This is a key product in controlling broadleaved weeds and provides an element in blackgrass control. It is assumed that rather than being lost completely, the use of this active will be restricted in certain catchments to address water quality issues. *Priority catchments are assumed to account for 21% of the arable land in England[31]. An earlier report suggested 20% of the land in this area could be affected. It is assumed that a simple ban on the use of the substance is imposed in these areas – although restrictions on the amount that could be used is also possible.*
- Broadleaved weeds become an increasing problem as resistance to ALS herbicides spread. An alternative (EAMU) control option will be removed with the loss of bifenox.
- Glyphosate to remain available and no resistance issues develop. However, the active substance will no longer be allowed to be used for pre-harvest desiccation.

4.4. Scenario C

This is the most extreme scenario. The regulatory restrictions imposed are the maximum thought likely. This means that all actives flagged from a 'low/medium' level of being at risk upwards are lost. This would require a very strict interpretation of the endocrine disruptor definition – all those place in Category II within the EU Commission's assessment as having 'some evidence' that they are EDs. Given the EU Commission's current proposals, this could be considered an unlikely outcome, but is not outside the bounds of possibility.

It is further assumed that additional restrictions on use are imposed on some of the key actives that remain. As the 'toolkit' of pesticides becomes less, it becomes harder to use pesticides with different modes of action. Therefore, the development of resistance accelerates in some cases.

4.4.1. Wheat and Barley

Scenario C for wheat and barley is as follows;

- As per Scenario B, but lamda-cyhalothrin and, less importantly, deltamethrin also lost. Alpha-cypermethrin becomes key in controlling insect pests in cereals. Some resistance starts to be found in the insect population to this active.
- More onerous restrictions on the use of metaldehyde are imposed. As with Scenario B, this is limited to Priority Catchments. However, a simple blanket ban on the use of metaldehyde in these areas is imposed. This leaves only ferric phosphate to control slugs in these areas. *Although clothianidin seed treatments in cereals do deter slug attacks, this active itself is likely to disappear under scenario C.*
- Of the azole fungicides only difenoconazole remains and it can only be used once per season.
- As with Scenario B, folpet remains, with chlorothalonil and mancozeb not re-authorised. Only fluxapyroxad and isopyrazam remain of the SDHIs under this scenario. All current strobilurins stay on the market.
- Resistance of septoria to the limited range of remaining fungicides becomes a major issue. In effect, chemical control of the disease becomes ineffective and control is only achieved through septoria-resistant varieties*.
- Rusts in wheat begin to develop resistance against the key chemical groups. But this does not develop sufficiently to be economically significant in the timescale covered by this report. Mildew also develops resistance to azoles and SDHIs, and at a faster rate due to its short life-cycle. It starts to become an economically important disease.
- In barley, rhynchosporium remains controllable through strobilurins and the remaining SDHIs. The limited suite of azoles/SDHIs means that ramularia begins to show resistance. The same effect is seen for mildew. The rusts remain adequately controlled by the actives available.
- Under this scenario glyphosate does not get re-approved for use in the medium term.
- Prosulfocarb and tri-allate remain as pre-emergent herbicides. The limited availability of other control options sees metabolic resistance accelerate in blackgrass. This gives pre-ems only very limited effect on controlling the weed.
- As with Scenario B, ACCase and ALS resistance becomes so widespread that sulfonylurea, 'fop', 'dim' and 'den' herbicides have no effect on blackgrass.
- In addition to the loss of pendimethalin, this scenario would see the loss of bromoxynil, diflufenican, flufenacet and fluroxypr. This would present significant problems in terms of broadleaved weed control.
- The limited range of active substances sees the resistant broadleaved weeds becoming and important economic issue.

** It is beyond the scope of this project to consider the introduction of any new active substances (and, in any case, this would be very difficult as it would require full knowledge of manufacturers' research pipelines). However, it is reported that an active substance with a new MoA for septoria may be launched shortly. A* *next-generation triazole is also in development.* ***If*** *these products reach market, then the situation regarding septoria control could be improved. However, any new azole may well face the same regulatory issues (especially around ED definitions) as current azoles. Also, without a suite of active substances available, any new pesticide may quickly face resistance issues..*

4.4.2. Oilseed Rape

Scenario C for oilseed rape is as follows;

- As with, Scenario A and B, no reversal of the ban on neonicotinoid seed treatments.
- Of the pyrethroids, only alpha-cypermethrin, beta-cyfluthin and zeta-cypermethrin remain approved.
- Pymetrozine remains for autumn aphid control. No lessening of the resistance of peach potato aphids to pyrethroids and thereforethey provide no effective control.
- Resistance of cabbage stem flea beetles to pyrethroids increases. Effective control drops by 50% from current levels.
- Strict restrictions on use of metaldehyde in specific catchments (see wheat and barley section above).
- Of the azoles, only difenoconazole remains to control phoma, light leaf spot and sclerotinia. Penthiopyrad is also lost. Even with this very limited control option, the development of resistance is very slow (azoles have been the main treatment for phoma and light leaf spot for many years, and there have only been slight shifts in resistance). Strobilurins could offer an alternative control route.
- In terms of herbicides, both carbetamide and propyzamide are lost. This will severely curtail the opportunity to control grassweeds (and especially blackgrass) in oilseed rape crops.
- The remaining herbicides for use in rape will be amidosulfuron, aminopyralid, clomazone, cycloxydim, dimethenamid, and possibly tri-allate (on an extension of use). Any sulfonylurea herbicide (e.g. amidosulfuron) is likely to be ineffective as it is assumed that resistance to ALS herbicides becomes widespread. The limited range of other actives under this scenario will see broadleaved weed resistance become a major issue in oilseed rape.
- As with wheat and barley, under this scenario glyphosate does not get re-approved for use in the medium term.

5. ON-FARM EFFECTS

5.1. METHODOLOGY

This section aims to provide a very simple example of the on-farm effects of the scenarios outlined in the previous section.

An example farm will be taken, and its current (standard year) spray programme will be set out. The losses in each of the three scenarios will be discussed, and the potential effect on the farm estimated. What the farm manager might do to offset the negative impacts will then be explored.

5.1.1. Loam Farm Background

Rather than use an actual farm, Andersons' Loam Farm model will form the basis of this analysis. Loam Farm is a notional business that has operated since 1991, and tracks the fortunes of British combinable cropping farms. It is run on a real-time basis and fully costed. The data is based on the prices, costs and yields experienced by Andersons' clients and the industry generally. A model farm is used rather than an actual example as it is completely anonymous.

Loam Farm comprises 600 hectares in a simple rotation. In the standard model this is milling wheat, oilseed rape, feed wheat and spring beans (150 Ha each). For the purposes of this report the cropping has been amended to include barley, so the effects of crop protection changes can also be illustrated for this crop. The rotation is therefore 100 Ha milling wheat + 100 Ha feed wheat → 100 Ha milling (2^{nd}) wheat + 100 Ha malting barley → 200 Ha oilseed rape.

The farm has a working proprietor, one full-time member of staff and employs harvest casual. It undertakes most operations in-house. As the name suggests, it is sited on good-quality loam soils. Whilst the farm is notionally located somewhere in East Anglia, it is typical of many modern combinable cropping businesses across the UK. The technical performance of the farm is good, and it would be in the top half of businesses. However, it is not the very best (i.e. not in the top 25%).

5.1.2. Loam Farm Spray Programme

The standard spray programme for the four crops on Loam Farm is set out in the tables below. Obviously this is only indicative, and there will be variations between seasons depending on pest pressures. *An example of this is that no T0 fungicide was used in 2016 – Loam Farm would tend to use a T0 in about 50% of seasons.* Note also that this is ***not*** a recommendation for a spray programme. However, it is designed to be representative of the programme a commercial farm of this type will be likely to be adopting.

FEED WHEAT (1st Wheat)	Area - 200 Ha	Yield - 9.0 t/Ha
Insecticide / Nematicide / Molluscicide Programme		
Slug Pellets	metaldehyde @ 7kg per Ha[1]	*Generic*
Insecticides	Lambda-cyhalothrin @ 50 ml per Ha	*Hallmark Zeon*
Fungicide Programme		
Seed Treatment	triticonazole + procholoraz	*Kinto*
T0 Timing	*N/A in 2016 - Depends on Season / Disease Pressure*	
T1 Timing	Chlorothalonil @ 1.109 L per Ha	*Sinconil*
	Kresoxim-methyl + Epoxiconazole + Fenpropimorph @ 1.0 L per Ha	*Mantra*
	Metconazole + Epoxiconazole @ 0.333 L per Ha	*Brutus*
T2 Timing	Epoxiconazole + Fluxapyroxad @ 1.250 L per Ha	*Adexar*
T3 Timing	*N/A in 2016 - Decision based on cost Vs market reward*	
Herbicide Programme		
Pre-emergence	Flufenacet + Diflufenican + Flurtamone @ 1 L per Ha	*Movon*
Post-emergence	Mesosulfuron-methyl + Iodosulfuron-methyl-sodium @ 0.4 kg per Ha	*Pacifica*
	Alkylamine ethoxylate propoxylate @ 0.15 L / Ha	*Zeal (adjuvant)*
Dessicant	*N/A - Depends on Season*	
Other		
Trace Elements	Manganese @ 1.0 L per Ha	*Nortrace Mensa*
	Magnesium + Nitrogen 1.071 L per Ha	*Magnor*
Growth Regulator	Trinexapac-ethyl @ 0.2 L per Ha	*Cleancrop Cutlass*

[1] depending on the season

MILLING WHEAT (2nd Wheat)	Area - 100 Ha	Yield - 8.2 t/Ha
Insecticide / Nematicide / Molluscicide Programme		
Slug Pellets	metaldehyde @ 7kg per Ha[1]	*Generic*
Insecticides	Lambda-cyhalothrin @ 50 ml per Ha	*Hallmark Zeon*
Fungicide Programme		
Seed Treatment	Silthiofam	*Latitude*
T0 Timing	*N/A in 2016 - Depends on Season / Disease Pressure*	
T1 Timing	Chlorothalonil @ 1.109 L per Ha	*Sinconil*
	Kresoxim-methyl + Epoxiconazole + Fenpropimorph @ 1.0 L per Ha	*Mantra*
	Metconazole + Epoxiconazole @ 0.333 L per Ha	*Brutus*
T2 Timing	Epoxiconazole + Fluxapyroxad @ 1.250 L per Ha	*Adexar*
T3 Timing	Prochloraz + Tebuconazole @ 1.031 L per Ha	*Agate*
Herbicide Programme		
Pre-emergence	Flufenacet + Diflufenican + Flurtamone @ 1 L per Ha	*Movon*
Post-emergence	Mesosulfuron-methyl + Iodosulfuron-methyl-sodium @ 0.4 kg per Ha	*Pacifica*
	Alkylamine ethoxylate propoxylate @ 0.15 L / Ha	*Zeal (adjuvant)*
Dessicant	Glyphosate @ 4 L per Ha - due to following crop immediately with OSR	*Roundup*
Other		
Trace Elements	Manganese @ 1.0 L per Ha	*Nortrace Mensa*
	Magnesium + Nitrogen 1.071 L per Ha	*Magnor*
Growth Regulator	Trinexapac-ethyl @ 0.2 L per Ha	*Cleancrop Cutlass*
	Chlormequat @ 1.0 L per Ha	*Adjust*

MALTING BARLEY (after wheat)		Area - 100 Ha	Yield - 7.2 t/Ha
Insecticide / Nematicide / Molluscicide Programme			
Slug Pellets	*N/A*		
Insecticides	Lambda-cyhalothrin @ 50 ml per Ha		*Hallmark Zeon*
Fungicide Programme			
Seed Treatment	triticonazole + procholoraz		*Kinto*
T0 Timing	-		
T1 Timing	Prothioconazole + Trifloxystrobin @ 0.60 L per Ha		*Mobius*
T2 Timing	Prothioconazole + Trifloxystrobin @ 0.48 L per Ha		*Mobius*
T3 Timing	-		
Herbicide Programme			
Pre-emergence	Flufenacet + DFF + Flurtamone @ 0.50 L per Ha		*Movon*
	Flufenacet + DFF @ 0.3 L per Ha		*Liberator*
Post-emergence	Amidosulfuron + Iodosulfuron		*Chekker*
	Pinoxaden		*Axial*
	Methylated rapeseed oil		*Adigor (adjuvant)*
Other			
Trace Elements	Manganese @ 1.0 L per Ha		*Nortrace Mensa*
	Magnesium @ 1.199 L per Ha		*Cropsure MAG-S*
Growth Regulator	Chlormequat @ 1.25 L per Ha		*Adjust*

OILSEED RAPE		Area - 200 Ha	Yield - 3.7 t/Ha
Insecticide / Nematicide / Molluscicide Programme			
Slug Pellets	Metaldehyde @ 7kg per Ha[1]		*Generic*
Insecticides	Lambda-cyhalothrin @ 75 ml per Ha		*Hallmark Zeon*
	Lambda-cyhalothrin @ 75 ml per Ha		*Hallmark Zeon*
Fungicide Programme			
Seed Treatment	Prochloraz + Thiram		*Hy Pro Duet*
Autumn	Metconazole @ 0.8 L per Ha		*Sunorg Pro*
Stem Elongation	Prothioconazole @ 0.63 L per Ha		*Proline*
Early Flowering	Picoxystrobin @ 1.0 L per Ha		*Galileo*
Mid-Flowering	Fluopyram + Prothioconazole @ 0.80 L per Ha		*Propulse*
Herbicide Programme			
Pre-emergence	Metazachlor + Quinmerac + Dimethanamid-P @ 2.5 L per Ha		*Shadow*
Post-emergence	Propyzamide @ 2.0 L per Ha		*Kerb Flo*
	Carbetamide @ 3.0 KG per Ha		*Crawler*
Dessicant	Glyphosate @ 4 L per Ha		*Roundup*
	Ammonium Sulphate + Polyacrylamide @ 0.50 L per Ha		*Companion Gold*
Other			
Growth Regulator	Metconazole + mepiquat-chloride @ 0.7 L per Ha		*Caryx*
	Fungicides also used as Growth Regulators as have PGR properties		

5.2. Effect of Scenarios

5.2.1. Scenario A

Under Scenario A, the effects on Loam Farm are reasonably limited. In terms of cereal active substances that are no longer available, then epoxiconazole is the obvious loss. To some extent, this can be 'worked-around' with other azole products being bought into the programme in place of it. However, epoxiconazole provides effective control of rust, which other azoles, such as prothioconazole, do not. There may be cost implications as additional actives may have to be deployed to counter the risk of rust.

Whilst septoria becomes a greater problem in wheat as resistance rises, there remains enough active products to retain sufficient control. However, there is some economic loss in years with very high disease pressures. This is not enough to warrant a fundamental change in the cropping on Loam Farm though.

Like many farms the issue of grassweeds will be important for Loam Farm in the future, even under the relatively benign conditions of Scenario A. At present the pre-emergence herbicides in cereals, plus a 'clean up' in oilseed rape using carbetamide and propyzamide is just about keeping on top of the problem. The loss of the latter two under this scenario would make the control of grassweeds in rape far more problematical. Alternative chemistry such as clethodim may be used, and other 'fop', 'dim' and 'den' products which still have some effect under this scenario. However, overall some yields loss is likely as grassweeds (particularly blackgrass) competes with the crop.

With less opportunity to clean up grass weeds in the oilseed rape break crop, there will be greater grassweed pressure within the cereals crops too. With rising resistance problems within the timeframe of this scenario, this will be key issue that Loam Farm is grappling with.

In oilseed rape the continued absence of neonicotinoid seed treatments will see additional autumn sprays of insecticides. These are only likely to be partially successful in controlling peach potato aphids which have resistance to pyrethroids. There will be additional economic losses and also increased costs over what has been seen historically for the crop.

To use a medical analogy, the problems for Loam Farm are chronic rather than acute. As the build-up is gradually, and the losses generally not severe, then the farm is likely to try and continue with its current system, with which it is familiar and has been successful in the past, and try and manage any changes. Indeed, possibly the biggest threat within this relatively 'subtle' scenario is that farms keep on doing the same thing because there is no single change in conditions large enough to prompt a thorough re-appraisal. Effectively, the ability to use plant protection products to grow good quality crops deteriorates slowly. Against the usual volatility in returns, the decline in profitability due to reduced pest control almost goes unnoticed.

5.2.2. Scenario B

For Loam Farm, scenario B means that additional problems present themselves. In terms of fungicides for wheat, the loss of chlorothalonil is an important loss. Folpet would be the only similar replacement. The losses of a number of azoles, and the restricting of the remainder to one application per season would require a radical re-formulation of the fungicide programme. This would be amplified by the loss of control of septoria from SDHI's and the restriction on their use to once a season too. A strobilurin might well be added back into the programme for rust control – however these are protective rather than curative. Strobilurins would also do little to help against septoria. This disease would become difficult to control. In the absence of chemical alternatives then the focus would likely turn to varietal resistance. There would likely be some trade-off between yield and resistance attributes, leading to reduced returns.

In barley the restriction on the number of azole timings would mean the current programme would have to be adjusted. The use of stobilurins and SDHIs would rise to compensate. The complexity (and possibly cost) of the programme would rise, although control of disease would likely to remain reasonably robust. Indeed, the relative effect on wheat versus barley of the changes may see a greater role for barley in the rotation of Loam Farm.

The weed control situation deteriorates even as compared to scenario A above. Flufenacet remains available, but its efficacy declines as metabolic resistance (particularly in blackgrass) increases. Although Loam Farm does not currently use pendimethalin, its loss does remove an alternative option for the farm.

In terms of oilseed rape, the main difference between scenarios A and B is the growing problems treating cabbage stem flea beetle. This is a combination of rising resistance and a more limited armoury of pyrethroids. There will be seasonal variations but some fields in some years may see severe damage and not be viable to take through to harvest. More generally, the damage will impact yields and reduce the profitability of the crop on Loam Farm.

Also for oilseed rape, the likely restrictions on pre-harvest use of glyphosate will make combining more problematical and potentially affect the quality of the crop. There could be a reversion to swathing the crop to achieve even ripeness. This will add to crop costs and reduce profitability.

Perhaps the key question under this scenario is whether oilseed rape can continue in the rotation given the difficulties in achieving good yields and quality, and thus the level of output required. Even if the crop remains, the area devoted to it would probably drop – purely as a risk-management exercise. This, in turn, begs the question of what might replace it in the rotation. Such issues are considered in the 'Mitigation Strategies' section below.

5.2.3. Scenario C

If scenario C occurs, then this poses many questions for the proprietors of Loam Farm (and the many combinable cropping farms like it).

Slug control in all crops would be more difficult if restrictions on the use of metaldehyde were imposed. Plough-based cultivation techniques rather than minor no-till might be favoured if there was a high degree of risk. This would have a cost implication.

Insect pests in cereals become more of a problem, but the economic effect is not hugely significant (especially compared to other pest and disease issues that arise).

In wheat, the very limited range of active substances remaining (one multisite, two SDHI's etc.), plus rapidly rising rates of resistance makes septoria all but untreatable. With yield losses of up to 20% in susceptible varieties, there is a strong move on Loam Farm to growing only those strains with strong resistance traits. There is a yield penalty for this.

Other cereals diseases start to have an economic effect on Loam Farm. This includes mildew and ramularia in barley. Again, the focus will shift to growing varieties that have good disease resistance characteristics rather than the maximum yield (or even grain quality).

The control of weeds would also become more difficult than under scenario B. As well as accelerated resistance to the main active substances in grassweeds, some broadleaved weeds also start to develop resistance.

The failure of glyphosate to gain re-approval will impact on all areas of combinable crop production. The inability to 'clean-up' fields before planting, and take out patches of persistent weeds will be added to the issue of not being able to desiccate crops pre-harvest. It is very likely that the weed burden will grow over time, having an adverse effect on crop yields through competition.

In oilseed rape, despite the loss of most of the azoles, increasing resistance of diseases such as phoma, light leaf spot and sclerotinia is not a major trend. The ability to use strobilurins as an alternative is assumed to mean that these diseases do not have a significant economic impact.

Broadleaved weed control in oilseed rape crops will become problematical.

5.3. Mitigation Strategies

Given the relative effects of each Scenario outlined above, then Loam Farm will have to make adjustments.

Note that the overall profitability situation in combinable cropping will have a bearing on the level of change that the availability and effectiveness of plant protection brings about. For example, if overall profitability is good, then a small drop in margins due to lower yields, reduced quality or higher costs could be absorbed relatively easily. Then, given that inertia is a powerful force in most human decision-making, the farming system will probably carry-on relatively unchanged. However, if the profitability situation is difficult, even a small change in margins could put Loam Farm into an unsustainable position. In this case, major changes in approach to combinable cropping would come about far more swiftly.

Mitigation strategies for Loam Farm fall into two broad categories. Firstly, the way the current crops are grown can be altered to offset some of the losses in capacity from Plant Protection Products (this would include changes in the varieties grown). Secondly, the rotation employed could be altered to help mitigate the impacts. For every farm this will involve weighing up a complex (and interlocking) set of pros and cons. The bullet points below provide a brief summary of what could be done on Loam Farm. They are not designed to be either in-depth or exhaustive, but are designed to prompt further thought and discussion;

- As indicated in section 5.2 above, variety selection may have to be increasingly on the basis of disease resistance traits, rather than focusing on crop yield and quality.
- Loam Farm already tries to delay drilling of its first wheats to generate a window to control grassweed (blackgrass). This practice will have to be retained and even extended.
- At present all the oilseed rape, and around half of the cereals are established under a min-till system. With restrictions on glyphosate, slug issues, and the need to control blackgrass, this may not be possible in future. A more 'traditional' plough-based system would have consequences for costs, timeliness of operations and machinery and labour requirements.
- There is a question over oilseed rape's continued place in the rotation. Even if it continues to be grown, the area of the crop is likely to decline. Without a robust pest control programme, it will be too risky to devote large areas of the farm to rape production. Loam Farm will move away from its

predominant wheat-oilseed rotation. Oilseed rape may become far more of a niche crop, both on Loam Farm and in UK agriculture more generally.

- A change in rotation begs the question of what might replace some of the oilseed rape area. Spring cropping is likely to be favoured - it allows a longer window for weed control, and allows some of the establishment workload to be spread away from the peak autumn period.
- On the type of soil seen on Loam Farm, spring beans are an obvious option (indeed, they are grown under the 'standard' Loam Farm model). Spring barley would be another alternative.
- In light of the fact that barley seems to have fewer potential disease issues than wheat, then there may also be a switch from winter wheat to winter barley. All these rotational changes need to be considered in the context of the market as well, however. *If, like Loam Farm, many UK cropping businesses switch to pulses or barley then oversupply could see the price fall – amplifying the effect on profitability.*
- As an aside, cover crops are gaining in popularity in UK farming, particularly combined with a shift to spring cropping. If restrictions were placed on glyphosate, then the ability to destroy such crops before the establishment of the following crop would be far more difficult.
- It may simply not be profitable to grow any crop on certain parts of the farm. These may be areas with particularly heavy weed burdens, or just inherently less productive due to topography, soil-type, drainage etc. If margins are under pressure generally on the unit, then there is less ability for the better land to cross-subsidise such underperforming areas. Therefore, Loam Farm may well look at greater use of fallow.
- The move to spring cropping and/or increased fallow produces a more low-output business. To make the economics work then the cost structure would have to be re-worked. This would mainly be looking to make savings in labour and machinery overheads, but all overhead costs would have to be challenged.
- In order to get 'clean' ground, some of Loam Farm's land could be taken out of combinable cropping completely. Depending on local demand, it may be possible to rent land out for potato, sugar beet and vegetables on short-term agreements. In a similar way, maize could be bought into the rotation. Although Loam Farm is not in a livestock area, the growth in the number of anaerobic digestion plants across the country has widened the scope for this option.
- The lack of livestock also means that the option to put fields into grass leys to assist in weed control looks unlikely for Loam Farm. At the extreme this is one way of dealing with particularly intractable grassweed problems. The farm neither has the skills, infrastructure, or desire to start a livestock enterprise. However, UK farming may well see more livestock coming back to arable areas in the future. New businesses, rearing sheep or cattle on short-term leys, may help deal with weed issues whilst offering new opportunities within the sector.
- Under the most extreme scenario outlined combinable crops will be grown under 'semi-organic' conditions simply because the plant protection options have dwindled to such an extent. This will pose serious problems for the industry, particularly if growers in other, competing, countries are not subject to the same restrictions.

6. CONCLUSIONS AND RECOMMENDATIONS

It is impossible to be prescriptive in terms of the future availability and efficacy of plant protection products. If it were feasible to outline that '*product A will be withdrawn in 20XX, and product B will cease to be effective in Y years' time*' then the task of planning ahead would be immeasurably simplified. Unfortunately, the future of plant protection products will be governed by both political and biological processes. Neither of these is easy to predict – hence this report outlines a range of scenarios.

The eventual outcome probably sits within the extremes set out. But where exactly it might be is a matter for conjecture. Scenario B, whilst setting out a 'middle way' is not necessarily the most likely, and the other examples should also be considered.

Despite the uncertainties, the direction of travel for the combinable cropping sector is fairly easy to see. The approvals process (whether run at EU or UK level) is likely to result in a decreasing number of active substances being available. Whilst not within the specific scope of this report, the pipeline of new actives does not seem likely to deliver a wide range of replacement active substances. New technologies such as biological controls, or robotic weeding may hold out hope for the future. But the successful deployment of these technologies in UK 'broadacre' farming in the short-to-medium terms must be questionable. In any case, the cost implications when compared to the relatively cheap and simple chemical control options currently available may be considerable.

In addition, the effectiveness of many of the current active substances is only likely to decline in future. Increasing resistance of weeds, insect and diseases to pesticides will only be exacerbated by the reduction in the number of active substances.

Whilst it is difficult to plan for uncertain events, it is recommended that combinable crop producers spend some time thinking about how they might adapt to the possible scenarios outlined in this research. It is tempting to wait and see what actually happens before addressing the issue. However, thinking about how to respond before the event means that any decisions made will be better-informed and more considered.

UK farmers may have to adopt a more 'integrated' and 'holistic' approach to combinable crop production, and perhaps even look to the organic sector for some inspiration. It is likely to be a more complex and challenging environment than the sector has seen for the past forty or fifty years.

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