Farming wheat without neonicotinoids

Ruth Levene Courtesy of A Field of Wheat

Acknowledgements

This report is produced by Friends of the Earth based on research by Ellie Crane.

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Executive Summary

In 2013, following a thorough scientific review by the European Food Safety Authority (EFSA) and a vote by Member States, the European Commission restricted the use of three neonicotinoid pesticides (clothianidin, thiamethoxam and imidicloprid) which posed a "high acute risk" to honey bees. Honey bees are one of over 260 bee species in the UK and since 2013 evidence has mounted that neonicotinoids also harm bumblebees and solitary bees. There is now evidence that these wild bees, which are responsible for most crop pollination, are even more sensitive to neonicotinoids than honey bees. The new scientific evidence of impacts on all species is now being reviewed by EFSA which is due to report again in 2017.

The existing restrictions only apply to flowering crops attractive to bees so wheat is not included. But in its review EFSA will consider evidence relating to the use of neonicotinoids on other crops including wheat. In 2014 neonicotinoid seed treatments (clothianidin) were used on over 700,000 ha of wheat in the UK. Although wheat itself is not bee pollinated, most (around 95%) of the chemical from a neonicotinoid seed treatment enters the soil and can then be taken up by plants which are attractive to bees. Clothianidin has been found to remain in the soil for up to 7,000 days.

Neonicotinoids on wheat are a risk to bees

Ahead of its 2017 report EFSA has already concluded that use of clothianidin as a seed treatment for wheat does pose a high risk to bees because of the way neonicotinoids persist and move in the environment. Firstly the chemical's ability to remain in the soil and its systemic nature means that it can be taken up in succeeding crops (like oilseed rape), grown after wheat, resulting in residues in the nectar and pollen of that crop. Secondly there is a risk of exposure from the dust which spreads when the seeds are drilled and can end up on adjacent crops or flowers in field margins.

Further evidence that the use of neonicotinoids on wheat will lead to exposure for bees in field margins was published in 2016. Residues of neonicotinoids, including clothianidin, were found in the pollen of wildflowers adjacent to wheat fields in the UK.

Risks to other wildlife

EFSA will only consider the impact of neonicotinoids on bees. Friends of the Earth considers that this evidence alone backs the need for a comprehensive ban on all crops. In addition to this there is now evidence that neonicotinoids are a risk to other wildlife. Butterflies, like bees, are exposed through nectar and pollen in crops and wildflowers, birds by eating treated seeds, and some species of beetles are eating slugs that come with a dose of neonicotinoids. Earthworms can be exposed for long periods of time because of the way neonicotinoids persist in the soil. Studies have shown impacts on all of these, and overall data shows that farmland wildlife is in decline. This is bad news for farmers too as the use of neonicotinoids may be harming the creatures that provide services to farmers for free including soil health, pollination and natural pest control.

Neonicotinoids have also been found in streams and wetlands around the world where they pose a risk to aquatic invertebrates. Monitoring of neonicotinoids in rivers and streams in the UK is inadequate but we do know that many of them are in poor condition and declines in species like freshwater shrimp will have a knock on effect on salmon and trout.

Extending the ban

After EFSA reports on the science in 2017 the European Commission may recommend a permanent and comprehensive ban on the three neonicotinoids which would apply to farmers in the UK whilst we are still in the EU. Friends of the Earth is urging the UK Government to commit to a comprehensive ban now that will apply whatever our future relationship with the EU. An extension of the ban to all crops will mean that farmers currently using neonicotinoids on wheat would have to find effective alternatives. Research for this report has found that there are many actions that farmers can take now, and many are already taking, to effectively manage pests without neonicotinoids.

What are the alternatives?

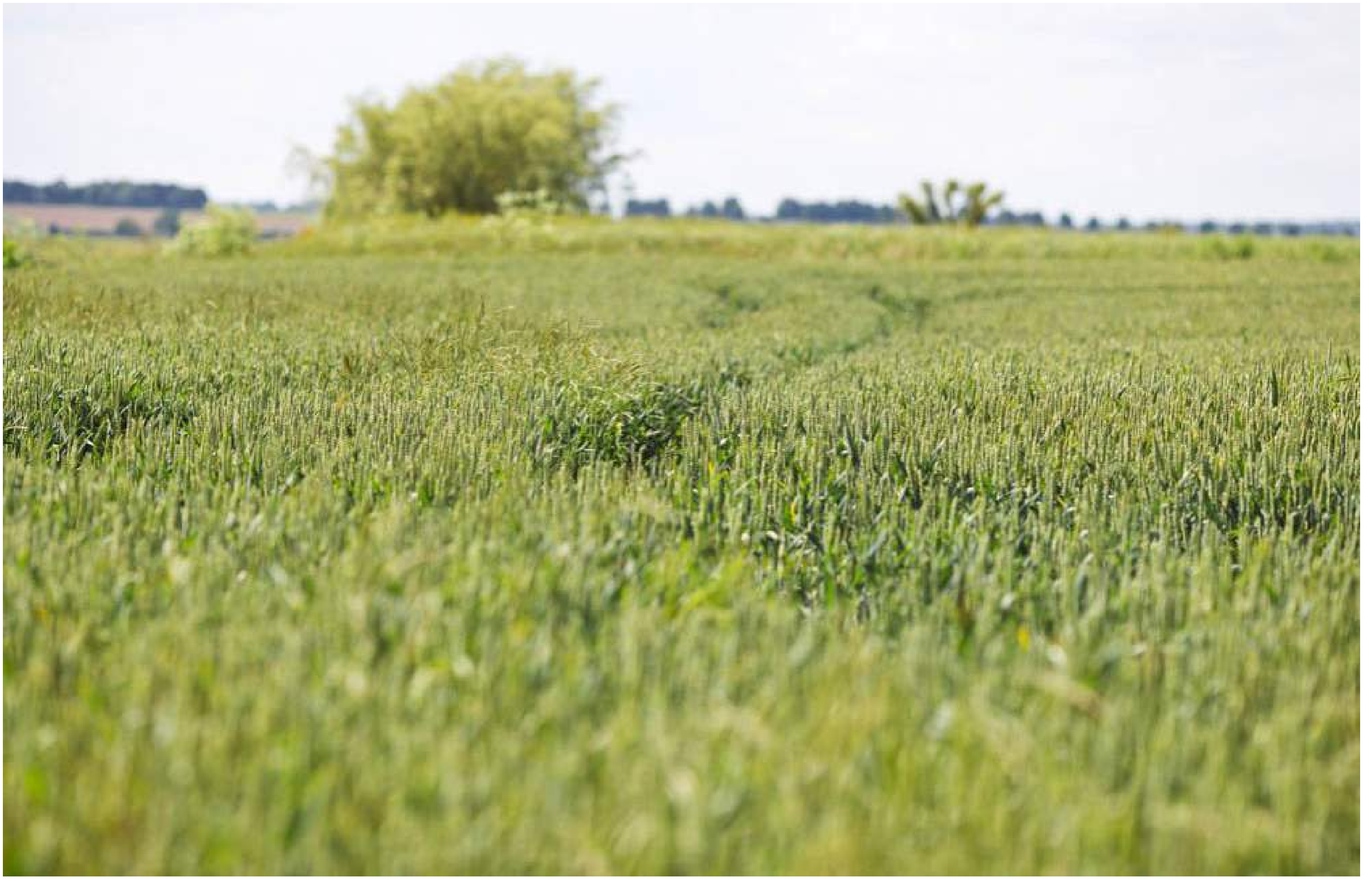
The main chemical alternative to neonicotinoids in wheat is pyrethroid sprays. Pyrethroid sprays are already used regularly on wheat in addition to neonicotinoid treated seeds, and use is probably higher than necessary for pest control as sprays are used as insurance against damage. Farmers are actually being advised by the statutory levy board, the AHDB, that prophylactic use of insecticides does not make economic sense to control aphids due to the sporadic nature of the pest attacks. Pyrethroids have their own risks to wildlife so it is clearly desirable to find safer alternatives. The priority should therefore be to promote non-pesticide approaches to pest management, as part of Integrated Pest Management and organic strategies. This also makes sense given that options for alternative chemical control are reducing. Resistance to pyrethroids is not yet at a level which would threaten control of key wheat pests but wider uptake of IPM with pesticides only used as a last resort will help to avoid resistance getting worse in the future.

This report finds that a wider take up of non-chemical approaches to tackling the pests currently targeted by neonics would also bring wider benefits to farmers – such as improving soil health.

Neonicotinoid seed treatments are currently used on less than half of the UK wheat area. This indicates that neonicotinoids are not essential to UK wheat production. Control of aphids is the main reason for using neonicotinoid treated seeds – primarily to avoid Barley Yellow Dwarf Virus (BYDV) which is spread by aphids. Neonicotinoids are also used to control Wireworms and Orange Wheat Blossom Midge (OWBM) although the incidence of OWBM has been decreasing.

Drawing on the detailed research for this report plus anecdotal evidence from farmers we conclude that the following non-chemical methods have the strongest evidence for being an effective alternative to control wheat pests, while recognising that the most effective techniques may vary from farm to farm and year to year.

- **Natural enemies** – All insect pests of wheat which neonicotinoids are used to control are known to have natural enemies. Available evidence from research and the experience of the farmers featured in this report points to the need to use a range of techniques to encourage natural enemies from providing a range of habitats to cutting insecticide use and minimising soil disturbance by using a no-till or minimum-till approach.



Nathan Gibson Courtesy of A Field of Wheat

- **Spring Cropping** – The key pest challenges in wheat have been made worse by the change to winter cropping. Although yields for Spring sown wheat are more variable it rarely experiences problems from aphids or Orange Wheat Blossom Midge (and has fewer problems with black grass) so inputs can be much lower.

- **Crop Variety** – Resistant crop varieties are readily available for Orange Wheat Blossom Midge.

- **Monitoring and thresholds** – Monitoring methods and thresholds have been developed for aphids, slugs, and OWBM, and could be used more widely (although it is acknowledged that for BYDV a very low number of aphids can lead to infection).

In addition there is good evidence that farmers practising no-till or minimum till have had positive results with improving natural pest control. Although it can take time for pest control to become effective in these systems the other proven benefits for soil health and reduced fuel use mean it is worth including in the list of measures that should be taken up more widely now.

It is important to note that to be most effective Integrated Pest Management approaches employ a range of techniques to complement each other rather than relying on one single approach.

Further Research needed on alternatives

This report shows that if the current restrictions on neonicotinoids were to be extended to wheat farmers would not have to increase their use of other pesticides. However it also acknowledges the challenges that will be faced by some farmers and the need to continuously improve and refine IPM approaches to ensure they are as effective as possible. The impending loss of more chemical products could act as an incentive for innovation but the investment in R&D should happen now not wait until there is confirmation that a product is being withdrawn or restricted.

Individual farmers who are already innovating and are willing to share their experience with others will be crucial. But trade organisations such as AHDB, the Government, research institutions and funding bodies all have a responsibility to further the state of knowledge and facilitate the uptake of IPM and organic approaches by more farmers. This responsibility stems from the linked needs to reduce the impacts of farming on biodiversity and ensure that farmers have access to effective crop protection as pesticides are withdrawn.

The need for more R&D into non chemical methods of control was also highlighted in our report Farming Oilseed Rape without Neonicotinoids, and the same demand has been put to the Government by research institutions such as Rothamsted.

Areas specifically needing more research for their potential to reduce insecticide use on wheat include:

- Non GM wheat varieties resistant to BYVD – this needs to be an ongoing area of research.
- Companion cropping – an innovative approach to pest management which is already known to provide other benefits particularly regarding soil health.
- Developing clarity on some aspects of crop husbandry including seed bed preparation, plant density, and impacts of crop choices in the rotation.
- Development and testing of biopesticides – these have potential to reduce impacts, and are less likely to lead to pest resistance but need careful testing.
- Further research on encouraging natural enemies to continue to improve knowledge of and therefore effectiveness of this approach.

The wider benefits that will accrue from investment in R&D in sustainable farming methods for our future food security and environment should make it a common sense area for research funding.

Importance of Independent Advice

For farmers who are currently following a strategy based on the routine use of pesticides, a switch to IPM would involve a change in approach, and farmers may need support to make these kind of changes.

A common theme that has emerged from contributors to this report is that there is a conflict between the need to help farmers find alternatives to chemical pesticides (driven by the need to protect nature and the reduction in available products) and the affiliation of many agronomists with companies selling pesticides. In order that farmers are well placed to deal with loss of neonicotinoids without simply using more of a different pesticide there is a clear need for more independent advice to be available to farmers.

The future direction of farming

This report shows that there are readily available solutions to the very specific challenge of growing wheat without neonicotinoids. It draws on research and farmer good practice to show that a much wider move towards reduced insecticide use is possible and desirable and works best when linked to other sustainable farming techniques such as habitat creation.

As the UK Government and farming industry considers what will replace the Common Agricultural Policy on our exit from the EU we have a unique opportunity to direct public spending towards a support system that will benefit both farmers and biodiversity. This includes the possibility to better support farmers to create habitats on farms that will help to reverse the loss of farmland biodiversity and provide crucial services to farming in terms of natural pest control. Redirection of public funding could support agroforestry, IPM or even independent advice to farmers.

Backround: why alternatives to neonicotinoids are needed

Friends of the Earth commissioned this research:

- To investigate the feasibility of growing wheat without the use of neonicotinoid insecticides
- To present evidence of the most effective alternatives to using neonicotinoids that are not harmful to bees and other wildlife, with a particular focus on methods that bring benefits for biodiversity
- To make recommendations on how the most beneficial and effective solutions identified could be taken up more widely by farmers.

Management of key pests in wheat has been thoroughly reviewed by Alan Dewar and colleagues in the 2016 ADHB report "Research Review No. 86: A review of pest management in cereals and oilseed rape in the UK". The current report highlights the relevant findings from this review and draws on additional sources from the published literature, grey literature and interviews with experts. It also includes case studies from farmers who are successfully growing wheat without neonicotinoids.

Evidence that neonicotinoid use on wheat poses unacceptable risks to wildlife and ecosystem services

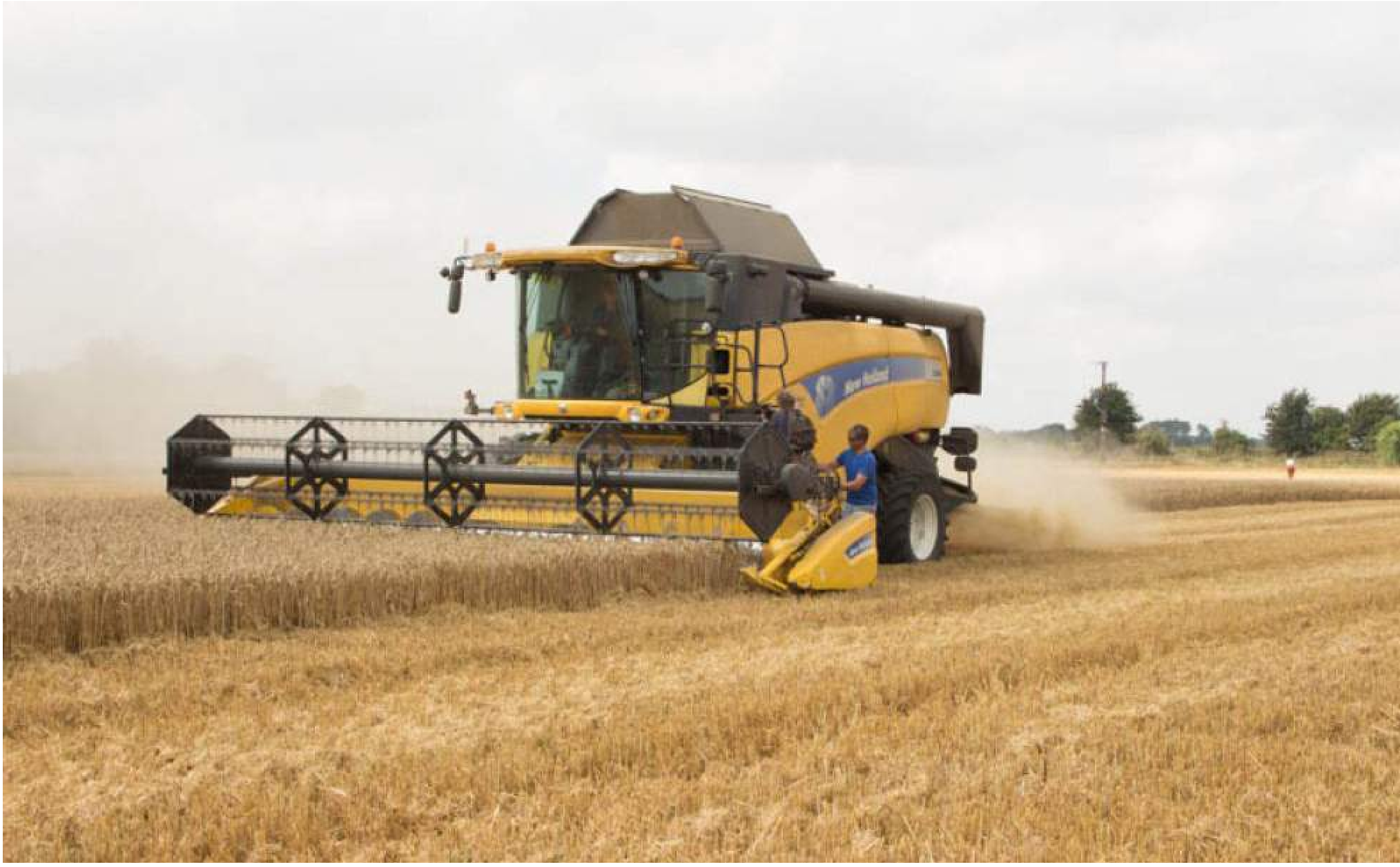
Three neonicotinoid insecticides (imidacloprid, thiamethoxam and clothianidin) are currently restricted for use on certain crops in the EU. These restrictions are intended to reduce the risks to pollinating insects of consuming contaminated pollen, nectar or guttation fluid and of exposure to contaminated dust during seed drilling (EFSA 2013). However, evidence continues to accumulate that neonicotinoids pose significant wider risks to wildlife and the environment which are not addressed by these restrictions, and in particular that exposure to neonicotinoids is not restricted to pollinators foraging on flowering crops (WIA 2015).

Far from being targeted treatments, studies on imidacloprid have estimated that only between 1.6 and 20 per cent of the active ingredient in a seed coating is actually absorbed by the crop (Sur & Stalk, 2003). There is increasing concern about the environmental fate of these chemicals (EASAC, 2015). Neonicotinoids are known to persist and move in soils. The calculated half-life of clothianidin in soil varies between 148 and ca. 7,000 days (BonMatin et al, 2014). Research in the UK found imidacloprid, thiamethoxam, thiacloprid, and clothianidin in wildflower pollen collected in oilseed rape and winter wheat field margins. (David et al 2016). The neonicotinoid imidacloprid has been found in soil in a year when no treated seed has been used (Bonmatin, et al, 2014) so it can be assumed that they can be taken up by a subsequent flowering crop such as oilseed rape. In 2016 EFSA published its review of further evidence on clothianidin, including its use on wheat, and concluded that for all field uses a high risk was identified or could not be excluded for exposure of bees via succeeding crops (EFSA 2016). EFSA also concluded that there was a high risk to bees from exposure via dust for the use of clothianidin as a seed treatment on winter wheat. This exposure is due to dust drift following seed drilling.

There are increasing concerns about impacts on other wildlife too. Earthworms, for example, are vulnerable to exposure to neonicotinoids used as seed treatments due to the amount of the treatment entering the soil (as described above). A major review of the impacts of systemic insecticides concluded that "Neonicotinoids can persist and move in soils thereby increasing the likelihood that earthworms will be exposed for extended periods of time" (WIA 2014). Although the impacts on earthworms have not yet been well studied there is evidence that they are more susceptible to neonicotinoids than other insecticides and that there are impacts on mortality, reproduction and behaviour (Wang et al 2012).

The presence of neonicotinoids in water is not well monitored in the UK. But studies elsewhere have found widespread presence in water. A study in Canada found clothianidin and thiamethoxam in most of the wetlands sampled in the intensively farmed Prairie Pothole Region (Main et al, 2014). And a study of global surface waters found that "strong evidence exists that water-borne neonicotinoid exposures are frequent, long-term and at levels which commonly exceed several existing water quality guidelines." (Morrissey el al, 2014). There is evidence that neonicotinoids have adverse impacts on aquatic invertebrates including mayfly, dragonfly, caddisfly and freshwater shrimp (Morrisey et al, 2014). The impact on shrimp has led to concerns about indirect impacts on fish such as salmon and trout which rely on shrimp for food. Salmon and Trout Conservation UK have found worryingly low levels of freshwater shrimp in the River Itchen: "This is particularly alarming as Gammarus are the foundations of the

Emily Wilczek Courtesy of A Field of Wheat



aquatic food web and a key element of fish diets. They are also known to be extremely sensitive to pollutants, in particular herbicides and insecticides such as neonicotinoids" (Salmon and Trout Conservation UK blog).

A strong negative association has been found for neonicotinoid use on UK farmland for 15 of 17 butterfly species (Gilburn et al 2015). A study in California found a negative association between butterfly populations and increasing neonicotinoid application while controlling for land use and other factors. The species most negatively associated with neonicotinoids are smaller bodied and have fewer generations per year, traits that may confer a reduced capacity for response to stressors (Forister et al 2016). Research in the USA found that Monarch butterfly caterpillars are harmed when eating the leaves of wildflowers growing near to crops treated with clothianidin (Pecenka & Lundgren, 2015). But the impact of contaminated wild plant leaves on caterpillars, beetles and other leaf eaters has been poorly studied. Further research is needed to show whether there is a causal link between neonic use and butterfly declines. But the studies described here indicate the need for a precautionary approach.

There is also evidence that neonicotinoids can harm birds such as house sparrows and grey partridge (Gibbons et al 2015), (Hallman et al 2014). Even though the law requires that treated seeds must be drilled into the soil, observations by the RSPB and others show that some seeds are inevitably left lying on the surface by accident (Martin Harper 2015). It is not known how many treated wheat seeds are consumed by birds or other wildlife, but for some species a few seeds would be enough to deliver a lethal dose of neonicotinoid pesticide. A recent field study in Spain has concluded that the use of seeds treated with pesticides (including fungicides as well as insecticides) poses "an unacceptable risk" to farmland birds (Lopez-Antia 2016).

A comprehensive assessment of the state of nature in the UK in 2016 found an overall decline in farmland species with farmland birds having declined by 54% since 1970 and butterflies having declined by 41% since 1976. The switch from spring to winter sowing, the increased use of pesticides and the loss of habitats such as hedges were all cited as key negative impacts resulting from the intensification of farming (Hayhow et al, 2016). The impacts of neonicotinoids and other pesticides on wildlife on and around farmland is of grave concern given that thriving biodiversity is crucial for our future food production. Farmers depend upon earthworms to improve soil structure and health, on bees for pollination, and on a range of other insects, such as beetles, for natural pest control. Encouraging natural predators is a key solution to emerge from this, and other reports on alternatives to insecticides. Yet the use of neonicotinoid seed treatments could be harming the very species that could help control arable pests like slugs. In a US laboratory study the pest slug Deroceras reticulatum was unaffected by thiamethoxam but transmitted the toxin to predaceous ground beetles (Chlaenius tricolor) feeding on the slugs impairing or killing >60% and decreasing soy bean yield (Douglas et al, 2015). New research from Pennsylvania State University in the US concluded that neonicotinoid seed coatings reduce populations of natural enemies by 10 to 20 percent (Pennsylvania State University, 2016).

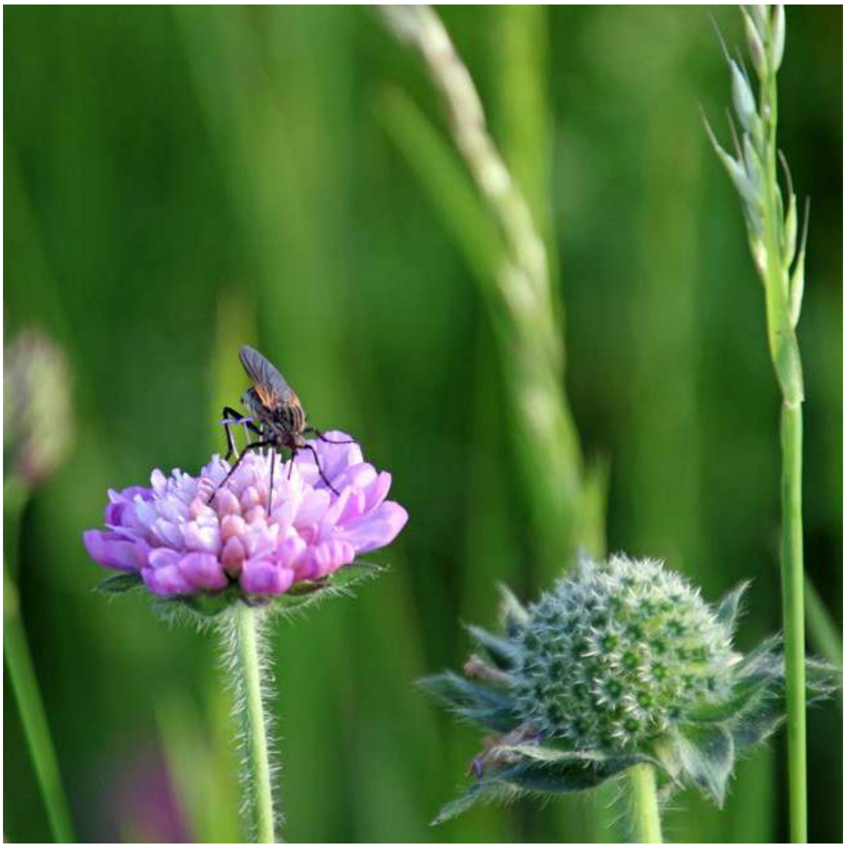
The highly respected European Academies Science Advisory Council (EASAC), which includes the UK's Royal Society, concluded that "There is an increasing body of evidence that the widespread prophylactic use of neonicotinoids has severe negative effects on non-target organisms that provide ecosystem services including pollination and natural pest control" and that "Widespread use of neonicotinoids (as well as other pesticides) constrains the potential for restoring biodiversity in farmland..." (EASAC, 2015).

Neonicotinoid review process

The European Food Safety Authority (EFSA) is currently reviewing new scientific evidence relating to the impact of the three restricted neonicotinoids on pollinators. In 2017 it will publish its conclusions about the need to maintain and expand the current restrictions. The final decision will be made by EU Member State governments. The UK will continue to be subject to EU-mandated restrictions on neonicotinoids until it has formally left the EU. Even then it is possible depending on the nature of the future agreement with the EU that the restrictions will still apply.

Friends of the Earth Position

Friends of the Earth considers that the mounting evidence of harm to bees requires that the current restrictions on three neonicotinoids should be made permanent. In addition, the evidence that is emerging about exposure to pollinators other than directly through flowering crops, and impacts on other wildlife and natural predators requires that the restrictions be extended to use on all crops in the UK, whatever the nature of the agreement with the EU. It will be important to ensure effective solutions are available to British farmers so that they can continue to grow key crops successfully without neonicotinoids. The current report deals with wheat. See also *Farming Oilseed Rape without Neonicotinoids, Friends of the Earth, April 2016*.



Current use of neonicotinoids on UK wheat

Wheat growing in the UK

In 2015, 1,832,000 ha of wheat were grown in the UK (out of a total 4,505,000 ha of arable crops). This produced 16.4 million tonnes of wheat worth £2,033 million. For comparison, the total gross output from farming (including subsidies) was estimated at £23,852 million. The UK both imports and exports wheat, but uses the majority of its production domestically and exports slightly more than it imports (Defra 2016).

The two major uses of wheat are as milling wheat (turned into flour for human consumption) and as animal feed. Milling wheat is grown to contract and must meet certain specifications, such as protein content and quality (HGCA, date unknown). It fetches a higher price: in 2015, milling wheat sold at an average of £138 per tonne and feed wheat £121 per tonne (Defra 2016). Different wheat varieties are recommended for different uses. In general, the varieties grown as feed wheat are higher-yielding than the varieties grown for milling, where more focus is placed on quality (AHDB 2016c, Farm-Direct website). If a crop intended as milling wheat fails to meet the specifications it may have to be sold as feed wheat at a significant cost to the farmer's profit margin, so growing wheat for milling can be seen as higher risk. This affects the economics of deciding when to treat with pesticides, and might be expected to lead to farmers applying more 'insurance' pesticides on milling wheat (Farm-Direct website). Certain diseases can cause wheat to be rejected for milling although they might be of less concern in feed wheat (AHDB 2016a). In the case of the insect pest Orange Wheat Blossom Midge, recommended economic thresholds for spraying are one midge per three wheat ears for feed wheat but as low as one midge per six ears for milling wheat (AHDB 2014a).

Another important distinction to be made is between spring and winter wheat. Winter wheat varieties require a period of cold to trigger flowering (vernalisation) so are sown in autumn and winter. Spring varieties have a low vernalisation requirement (KWS, date unknown) and may be sown at any time between about October and April (Dave Garthwaite, Pesticide Usage Survey Manager, Fera, July 2016, personal communication). In the UK, since the 1990s the large majority of wheat grown has been winter wheat (KWS, date unknown), although in recent years an increasing number of farmers have been planting spring wheat for agronomic reasons (Farmers Weekly, 9 January 2014). Compared with spring wheat, winter wheat generally has higher and more consistent yields but requires significantly higher levels of inputs (Dave Sheldon, DS Agronomy, August 2015, personal communication).

Use of neonicotinoids on wheat

In the early 2000s, imidacloprid was the neonicotinoid most commonly used on cereal crops, but its use has been declining since around 2008 in favour of clothianidin (Fera pesticide usage statistics). In 2014 (the most recent year for which these data are available), clothianidin seed treatments were used on 721,872 ha of wheat in the UK (about 38% of the total wheat area (Defra 2014)). Of this area the vast majority was winter wheat with only 5,353 ha being spring wheat. The current restrictions on neonicotinoids do not allow their use on cereals sown between January and June, so this must have been autumn sown spring wheat. Imidacloprid seed treatments were used on 2,740 ha of winter wheat (0.1% of the wheat area) (Dave Garthwaite, Fera, personal communication, August 2016). According to Fera, these were the only uses of neonicotinoids in wheat in 2014.

Imidacloprid seed treatments are no longer available for wheat in the UK as products have been withdrawn from the market in recent years. There are however several products containing clothianidin and thiacloprid currently authorised for use on wheat in the UK (HSE pesticides register).

Description of the key pests targeted by neonicotinoids

Bayer Cropscience markets clothianidin seed treatment for winter cereals under the brand name Deter. According to the product label, Deter controls aphids to prevent the spread of Barley Yellow Dwarf Virus. It reduces damage caused by wireworms and slugs and suppresses the activity of leafhoppers in early spring. Bayer also sells Redigo Deter, which is Deter plus the fungicide prothioconazole to control seed and soil-borne diseases (Bayer website).

Various companies market sprays containing thiacloprid, for example Biscaya, for use against Orange Wheat Blossom Midge (HSE pesticides register, Bayer website).

Aphids and Barley Yellow Dwarf Virus (BYDV)

Aphids are the most economically important pest of cereals around the world (AHDB 2016b). In the UK they reduce wheat yields both directly through their feeding activities (primarily between April and August), and because they are the vector of the cereal disease Barley Yellow Dwarf Virus (BYDV). The key period for virus transmission is from September to March (AHDB 2014a).

BYDV causes yellowing and severe stunting of wheat plants, resulting in yield losses of up to 2.5 tonnes per hectare (yield losses have been found to range from 5% – 80%, with an average of 30% (AHDB 2016b)). It is most damaging to plants infected in the early growth stages (i.e. in autumn for a winter wheat crop) and its effects may be exacerbated by other stress factors such as adverse weather conditions (AHDB 2014a). However, infection that occurs after the wheat stem elongation phase has begun have little impact on yield (Farmers' Academy 2015). Visible symptoms (yellowing of the crop) develop long after the infection has taken hold and yield loss is already determined (Foster 2004).

Different strains of BYDV exist and have different distributions. The parts of the UK generally at high risk from BYDV are coastal areas of the south, south east and south west (Foster 2004). In years with mild weather in autumn and early winter, however, almost any area of the UK can be at risk (Bayer website).

Two species of aphid act as vectors to BYDV: grain aphid and bird cherry-oat aphid. The adults of bird cherry-oat aphid are very frost-susceptible (HGCA 2003), so this species is a more significant pest in the mild south west of England (AHDB, 2014a). Bird cherry-oat aphids rarely cause significant direct damage through feeding, but are considered a threat to yield even at very small numbers because of the risk they will transmit BYDV to the crop (AHDB 2014a).

The grain aphid is the main vector of BYDV in the other regions of the UK (AHDB 2014a). Grain aphids can reproduce sexually or by parthenogenesis (producing clones). Most spread of BYDV is caused by the clone forms, which can survive mild winters as active individuals. If sexual reproduction takes place, aphids overwinter in the form of eggs. They are therefore inactive through the winter. It is only possible for these individuals to transmit BYDV to a wheat crop in spring, after hatching and becoming infected themselves through feeding on already-diseased plants. Such late infection with BYDV is less damaging to wheat yields than infection in autumn at the seedling stage, so sexually reproducing populations of aphids are much less of a concern for wheat yields. Such populations are more common in the north of the UK than the south (AHDB 2016b).

As well as being disease vectors, where grain aphids are present in sufficient numbers they can significantly decrease wheat yield and quality through their feeding activities during summer. This is both through direct damage to the plant and through the excretion of honeydew which encourages mould and attracts flies, including some pest species (AHDB 2014a, Croprotect website). There have not been any widespread damaging epidemics of summer aphids in the UK since the 1970s, although there have been localised outbreaks of grain aphid, especially in East Anglia (AHDB 2016b). Perhaps surprisingly, climate modelling predicts that the pest status of aphids in cereals in southern Britain will significantly decline by the end of the current century (Newman 2005).

A third species, the rose-grain aphid, can cause losses of 0.25 – 1 tonne per hectare (occasionally as high as 4 tonnes per hectare) through feeding. The rose-grain aphid is more likely to be a threat after hard winters, when grain aphids and their natural enemies are scarce and so it is easier for their population to become established. This species nearly always overwinters as eggs so is not a major vector of BYDV (AHDB 2014a).

Wireworms

Wireworms are the soil-dwelling larvae of click beetles. There are more than 9,000 species of wireworm worldwide, but in Europe the most significant crop pests are of the genus Agriotes

(Barsics 2013). In the UK, sampling indicates that the main species present are A. lineatus, A. obscurus and A. sputator (Barsics 2013, Furland 2007a). Different species are thought to dominate in different regions of the UK (AHDB 2016b).

Wheat crops are vulnerable to wireworm at the seedling stage. Wireworms move along the crop rows creating holes at the base of the plant stems, potentially killing seedlings. In severe cases they can cause overall yield losses of up to 0.6 tonnes per hectare (AHDB 2014a). Wireworms are widely distributed across the UK (AHDB 2016b). Crops sown within two years of ploughing out permanent pasture are at highest risk from wireworm infestation, but any rotation with mostly winter cropping is at risk (AHDB 2014a). Both autumn and spring-sown wheat is at risk as the seedling stages coincide with seasonal peaks in wireworm activity (AHDB 2016b).

Wireworms have only become a serious pest in arable rotations in recent decades. There are several hypotheses as to why this might be. The prevalence of winter cereals now provides wireworms with a year-round supply of food. The inclusion of set-aside in rotations, the sowing of grass margins and the adoption of reduced tillage can provide them with more hospitable habitat within the farmed environment (although such measures can also encourage natural enemies as outlined in the next section of the report on Integrated Pest Management).

Finally, the persistent organochlorine pesticides once used to control them have been withdrawn (HGCA 2003) because of environmental and health concerns (Barsics 2013). However, it is believed that, having increased, wireworm populations in arable rotations have now stabilised (AHDB 2016b).

Slugs

Slugs damage wheat both by hollowing out the seed before and during germination and by shredding the young leaves after emergence (AHDB 2016b). There are several important pest species, of which the grey field slug is considered the most injurious. Slugs are dependent on moisture and the optimum temperature for their activity, survival and reproduction is 17°c (AHDB, 2014a). Egg-laying peaks in March-April and September-October and the eggs are able to withstand freezing (AHDB 2016b). Slugs can cause damage at any time of year when conditions are suitable, but crops are most vulnerable at the early growth stages, when slug feeding on seeds and seedlings can prevent crop establishment (AHDB 2014a). Once wheat plants have reached the fourth leaf stage they are generally able to survive slug grazing (HGCA 2003).

Like wireworms, slugs have become a more serious pest in recent decades. According to AHDB, they have been favoured by various agronomic changes, especially the shift to winter cereal cropping, growing crops that have dense canopies in autumn (such as oilseed rape), and the adoption of minimum tillage (AHDB 2016b). However, some farmers' experience is that after an initial spike in slug populations minimum or no tillage can reduce the slug population over time by encouraging natural predators (see John Cherry case study).

Slugs are perceived to be an important pest in arable cropping, yet there is very little published evidence to show their effects on yield (AHDB 2016b).

Leafhoppers

The product labels for Bayer's neonicotinoid seed treatments (Bayer website) state that the products "suppress the activity of leafhoppers in early spring." However, leafhoppers are not apparently considered a pest of wheat (for example they are not mentioned as wheat pests in key AHDB literature (AHDB 2014a, AHDB 2016b)) and so will not be considered further in the current report.

Orange Wheat Blossom Midge (OWBM)

Female OWBM lay their eggs in emerging wheat ears, flying up to 3km to find ears in the right stage of development (AHDB 2016b). The larvae feed on the developing wheat grain, causing direct damage and increasing vulnerability to disease-causing fungi. This reduces both the quality and quantity of wheat yield (AHDB 2014a). After feeding, larvae fall to the ground and overwinter in the soil as a cocoon – they can survive in this state for more than 10 years (AHDB 2016b).

OWBM has a very patchy distribution and populations fluctuate greatly from year to year (Croprotect website). The insect only becomes a serious pest in peak conditions (Dave Garthwaite, Pesticide Usage Survey Manager, Fera, July 2016, personal communication), but on these occasions it can cause yield losses of 75% or more (Croprotect website). The last major outbreak in the UK was 2004, costing growers an estimated £60 million. The incidence of OWBM has been decreasing in recent years but it is still considered an important pest (AHDB 2016b).

An Integrated Pest Management approach to pest and disease control in wheat

IPM is a holistic farming approach that combines a variety of pest management techniques in a planned fashion, to achieve pest control while minimising risks to human health and the environment. The basis of IPM is farming systems that prevent the build-up of pest organisms. In IPM, potential pests are monitored closely, and the farmer only intervenes when the population exceeds a specific threshold. Sustainable, non-chemical interventions are preferred over pesticide applications. (EU Directive 2009/128/EC).

The following sections explore key steps of an IPM approach (choice of crop variety, crop husbandry, monitoring and thresholds, promoting natural enemies, biopesticides, and finally pesticides). The current and potential contribution of each of these factors to control of the insect pests of wheat is described. Table 1 provides a summary of the information in this section.

Adopting IPM should be viewed as a process of continuous improvement. Under an IPM regime a farmer still has the option of using a pesticide if required, but the aim should be to reduce or even eliminate this need.

Choice of crop variety

Introduction

The production of new crop varieties is largely driven by market demand – for example millers' requirements for particular nutritional or physical qualities in grain. Wheat is the most economically important crop in the UK and is the focus of many plant breeding programmes, but to date there has been more focus on fungal diseases than on insect pests. Demand for crops with pest tolerance traits can be driven by regulatory changes such as the withdrawal of a pesticide, or by the emergence of pests that are resistant to the pesticides on the market (Penny Maplestone, British Society of Plant Breeders, August 2016, personal communication).

Producing a new crop variety is costly (it costs £1.5 – £2 million per year to run a competitive wheat breeding programme) and can take 6 – 10 years from the first plant cross (once the genes of interest have been identified) to the commercial product. The profit from a new variety depends on how much money the breeder can collect in royalties, which in turn depends directly on how much seed of that variety is sold. Competition between breeders for market share is therefore fierce. Plant breeders will thus only invest in developing varieties which are likely to produce significant financial returns, bearing in mind possible future regulatory or market changes, and what their competitors are producing (Penny Maplestone, British Society of Plant Breeders, August 2016, personal communication).

Speculative research, for example searching for useful genes in crop wild relatives, is usually carried out by academic institutions working alongside plant breeders. Some funding is available from bodies such as BBSRC (see for example the BBSRC-funded Wheat Improvement Strategic Programme (WISP website)).

Penny Maplestone of the British Society of Plant Breeders (August 2016, personal communication) has stressed the importance to plant breeders of having clear market opportunities with sufficient predicted return on investment, a strong academic research community interested in working on real crop issues, with accessible sources of public investment for early stage research, and the availability of a library of well-characterised genetic resources from which to work, including crop wild relatives.

There needs to be a balance between breeders having access to these genetic resources and a clear framework for benefit sharing (currently governed by initiatives including the Nagoya Protocol and the International Treaty on Plant Genetic Resources). Maplestone also highlighted the need for research organisations to protect their investments with property rights, but at the same time enabling other researchers to further their research. For plant breeders regulatory certainty is also important particularly regarding the use of new technologies.

Aphids/Barley Yellow Dwarf Virus

It has long been known that different wheat varieties have different levels of resistance to aphid attack (Lowe 1984). The varieties currently grown in the UK have only limited resistance (Guan, 2015). Commercial varieties of wheat are also known to differ in their tolerance to BYDV (MASWheat website), but no varieties currently have commercially useful levels of tolerance or any true resistance (i.e. a reduction in virus concentration) (AHDB 2016b). Neither susceptibility to BYDV nor to aphids are currently mentioned in AHDB's recommended list for wheat (AHDB 2016c).

Developing varieties with true resistance to BYDV is seen by some as a key research need (Alan Dewar, Dewar Crop Protection Limited, August

2016, personal communication), and has been the goal of the International Maize and Wheat Improvement Centre for many years (AHDB 2016b). Resistance has been found in wheat relatives and successfully bred back into bread wheat (MASWheat website, Ohm 2007). However, concerns have been raised that this resistance will not prove durable in the face of rapidly-mutating strains of BYDV. Caution has been urged over use of these strains in breeding programmes (AHDB 2016b) as they exert strong selective pressure on the virus to overcome the resistance mechanism (Chain 2007).

In the past the availability of cheap pyrethroid insecticides to control aphids arguably reduced the market pressure to develop alternative strategies to control BYDV. The emergence of pyrethroid-resistant aphids may now make it economically more attractive to continue the quest to develop BYDV-resistant wheat (Peter Lundgren, White Home Farm, August 2016, personal communication).

There has been intensive research effort attempting to develop wheat with resistance or tolerance to the aphids themselves, with researchers investigating resistance mechanisms such as plant volatile chemicals and physical structure (AHDB 2016b). Aphid resistance is an active area of work in the UK, but is still at the 'speculative' stage of research described in the introduction to this section. A large number of different wheat lines have been screened for aphid resistance (Toby Bruce, Rothamsted Research, August 2016, personal communication). Some lines of Triticum monococcum, the domesticated form of Einkorn wheat, have been discovered to have partial resistance to grain aphids (Aradottir 2015). T. monococcum also appears to possess some resistance to transmission of BYDV (Tanguy 2009). This species is the most promising source of resistance found so far, even though the resistance is only partial. It is, however, an ancient relative of modern wheat, and it has proved difficult to incorporate its resistance characteristics into commercial varieties. Resistance genes are known to exist in other wheat relatives and could potentially be incorporated into commercial cultivars. Work continues to discover other genetic sources of resistance (AHDB 2016b). However, the current situation is that researchers are a long way from producing wheat lines that can be passed on to plant breeders to develop a commercial variety (Toby Bruce, Rothamsted Research, August 2016, personal communication). The fact that there are three key aphid species that need to be combated, each of which has a different feeding niche, presents a significant challenge to breeders (AHDB 2016b).

Scientists at Rothamsted Research, funded by the BBSRC have attempted to create aphid-repelling wheat using Genetic Modification. However, although this approach yielded promising results in the laboratory, the GM wheat did not repel aphids in the field (Bruce 2015). Given other concerns about genetic modification including contamination risks, cost to the farmer, and environmental impacts (Friends of the Earth, 2016) and evidence that non-GM methods can achieve the same ends (GM Watch) available research budgets would be better spent on other approaches including continuing research on non-GM varieties.

Wireworm

None of the commercial wheat varieties are believed to have significant resistance to wireworm. However, it is known that different wheat genotypes have varying susceptibility to wireworm damage (Barsics 2013) and different levels of tolerance to wireworm feeding (Higginbotham 2014). A promising area of research is volatile chemicals emitted by plant roots and how wireworms use these to select and locate the plants on which they feed (Barsics 2013). At the least, the cereal lines used by plant breeders should be screened for resistance to wireworm and other soil pests (AHDB 2016b).

Slugs

Resistance/tolerance to slugs is not mentioned on the AHDB Recommended List (AHDB 2016c). It has been claimed that some varieties of wheat are more palatable to slugs than others (Crop Protection Association 2002), but this does not appear to be an active area of research. Barley and oat seeds are less attractive to slugs than wheat seeds – finding out why could be a useful line of enquiry (AHDB 2016b). However, slugs are known to become less discriminating when there is little choice of food, so reduced palatability of crop in a monoculture might be of limited use (Bayer 2015).

Slow-growing crops are less able to recover from slug attack, so it could be expected that more vigorous varieties would be more tolerant of slugs, all else being equal. It is recognised that autumn crops are more vulnerable to slug damage than spring-sown crops because of their slow growth in the early stages (AHDB Information Sheet 04).

Orange Wheat Blossom Midge
Currently, 14 winter wheat varieties on the AHDB Recommended Lists are believed to be resistant to OWBM, including both milling and feed wheat varieties (AHDB 2016c). Growing one of these resistant varieties is the key non-chemical method recommended for OWBM management (AHDB 2014a).

OWBM resistance depends on a single gene, known as Sm1. When larvae begin to feed on a wheat kernel, Sm1 triggers an increase in naturally occurring acids in the kernel which prevent the larvae from feeding. This gene is present in all of the commercially available resistant wheat varieties. The fact there is only currently one mechanism of resistance makes it more likely that midges will become tolerant to it. In Canada, farmers growing resistant varieties are required to mix in 10% of a susceptible wheat variety to slow down the evolution and spread of resistant midge populations (Midge Tolerant Wheat website). The evolution of resistant midge populations has not yet been identified as a significant threat in the UK but more research is needed (Penny Maplestone, British Society of Plant Breeders, August 2016, personal communication).

If a susceptible variety is grown, choosing a variety with very early or very late flowering (and sowing very early/late) can reduce the chance that the crop is at the susceptible growth stage when the midges emerge. However, this approach needs to be balanced against other agronomic considerations (AHDB 2016b).

Crop husbandry and cultural control

Introduction
This section covers the decisions farmers make on how to manage their crop and how these can affect pest control. Farmers have access to a large volume of advice from sources including their farming peers, agronomists, academic and government institutions, the farming media and agrochemical and seed companies. Farmers need to weigh pest management considerations alongside other agronomic requirements and conditions on their particular farm, as well as potentially trading off improved control of one pest against increased risk from another.

For many cereal farmers, weeds such as black-grass are an important threat to the quality and quantity of crop yields. Advice on cultural control of weeds includes adding spring crops, fallow periods or grass leys to the rotation; ploughing every few years (in reduced tillage systems) to bury weed seeds; delayed drilling of winter crops and sowing at higher seed rates (HGCA 2010). In many cases this coincides with advice about insect control (see following sections and Table 1) but where this is not the case farmers will need to weigh up the risks and benefits of different options.

Aphids/BYDV
This section applies to winter wheat. Aphids are rarely a problem in spring wheat as the vulnerable phases of the crop do not usually coincide with peak aphid activity (AHDB Information Sheet 42).

Early-sown (August – September) winter wheat is at much higher risk of BYDV than later-sown crops (Foster 2004). Where practical, delaying sowing until the middle of October so that crops emerge after the end of the aphid migration (usually early November) reduces the risk from BYDV (AHDB 2014a, AHDB Cereal Disease Encyclopaedia). It should be noted, however, that later sowing dates can make the crop more vulnerable to the summer migration of aphids the following year if the crop matures later and so is exposed to the aphids at an earlier growth stage (AHDB 2016b).

Winter wheat can acquire the BYDV infection via wingless aphids overwintering on grass weeds within the field (so-called green bridge transmission). Such infections can be very hard to control because aphids feed on the roots of the new crop beyond the reach of either seed treatments or sprays (Farmers' Academy 2015). If there are high levels of aphid-infested grasses in the stubble, farmers are currently advised to consider using a herbicide or ploughing to remove or bury the grass (AHDB 2014, AHDB Cereal Disease Encyclopaedia). A gap of five weeks before sowing is then recommended (Farmers' Academy 2015). Green bridge transmission is most likely to happen in south west England, on early-sown crops and in mild, damp autumns (HGCA 2003).

In the UK overall, however, most infections are caused by winged aphids migrating from an infected source outside the field (AHDB 2016b). The initial infection spreads into patches within the crop as the offspring of the winged aphids reproduce and move to adjoining plants (Farmers' Academy 2015). The risk of infestation by winged aphids in autumn is known to be lower where minimum tillage is used, especially if the straw is left on the ground, compared with ploughing (AHDB 2014a). Farmers therefore have to weigh up the risks of the different routes of infection (green bridge versus invasion by winged aphids) before deciding what approaches to take. The effects of management on natural enemy populations and on other pest species must also be considered (see in natural enemies section of this report).

A growing number of farmers are advocates for zero-tillage. As an example, Andrew Barr runs a 700-hectare mixed conventional holding in Kent. Andrew has adopted a zero-tillage approach for the last five years, with only shallow tilling for the ten years before that. Since adopting minimum and zero tillage and with careful design of the crop rotation (which currently comprises milling wheat, spring barley, oilseed rape, beans, peas and oats), Andrew has been able to all but eliminate the use of foliar applied insecticides on his arable crops. He does however continue to use neonicotinoid seed treatments on his wheat. Since 2001, Andrew has only recorded one instance (in 2003) of BYDV infection in his winter cereals when managed under reduced tillage regimes. One field had to be ploughed in autumn 2013 and subsequently suffered significant BYDV the following spring, despite being seed-treated with a neonicotinoid and sprayed with a foliar insecticide. This provides observational evidence that, on this farm at least, minimum/zero tillage is an effective tool to help manage aphids and BYDV (Andrew Barr, East Lenham Farm, October 2016, personal communication). Other farmers using zero tillage have managed to avoid both neonicotinoid seed treatments and foliar sprays (see case studies at the end of the report).

A 3-year study of cereal crops across the UK explored a wide range of field characteristics and whether they affected numbers of aphids and incidence of BYDV (Foster 2004). The authors developed a model to predict BYDV risk. The most important predictors of risk were found to be:

- Sowing date (fields sown in August and September were at much greater risk than fields sown later in the autumn)
- Proximity to the sea (fields closer to the coast had higher virus incidence)
- Dominance of arable farming in the landscape (fields in a landscape dominated by arable farming had lower virus incidence)
- Aspect (fields facing east or southwest had higher virus incidence).

Several other factors were found to have a lesser effect. BYDV infection was highest in fields 2 – 4 ha in size, with smaller and larger fields having lower aphid densities. The authors hypothesised that the larger fields tended to be found in intensive arable areas with low aphid numbers (non-arable land use in the surrounding area was associated with higher aphid numbers), while the smaller fields could be expected to have increased predator penetration from the field margins. Aphid densities and (to a lesser extent) virus incidence were higher in fields associated with grassy areas. Surrounding land use was significant, with different land uses being associated with higher or lower virus incidence. This sort of detailed understanding of the factors affecting BYDV risk could help to focus monitoring effort and guide farmer and agronomist decisions, especially when weighing up different courses of action with conflicting outcomes.

Bi-cropping (where a **companion crop** is grown in the same field with the wheat crop) may offer an innovative approach to pest management while providing other agronomic benefits. Two studies in the 1990s (Jones 1993, Burke 1998) found that winter wheat grown with a white clover understory had lower levels of aphids and/or BYDV infection: in one case no pesticide use at all was needed. More recently, scientists at NIAB have successfully demonstrated the potential of bi-cropping winter wheat with clover to improve soil structure, yields and profit margins (Stobart 2014). However, an experiment set up within these trials found no impacts on natural aphid control (Samuel Leigh, PhD Student, University of Reading, September 2016, personal communication). The factors examined were bi-cropping (wheat with a clover bi-crop versus wheat alone), amount of nitrogen applied (50% or 100% of the usual dose) and cropping history of the plot (winter cropping or a mix of winter and spring cropping). None of these factors was found to have any effect on natural pest control. It was noted, however, that establishment of the clover was very poor, particularly in the 100% nitrogen plots where there were virtually no clover plants. Plots which received no synthetic nitrogen (where the positive effects of bi-cropping on yield were greatest) were not included in the natural pest control experiment – it would be worth looking at this in future trials.

Wireworm

The lifecycles of the different wireworm species can vary significantly, so in a wider European or global context it is vital to know which species is/are present when designing a pest management strategy (Barsics 2013). However, the three species present in the UK all have a similar life cycle (AHDB 2016b) and their larvae are impossible to tell apart with the naked eye, so current management strategies focus on wireworm in general rather than being species-specific (AHDB 2014a). Current advice to arable farmers is to consolidate seedbeds to restrict wireworm movement, and control grass weeds to reduce food sources. There is evidence that inversion ploughing can reduce wireworm populations. Including a spring crop in the rotation can be beneficial as it allows soil cultivations at times when eggs and larvae are vulnerable (AHDB 2014a, AHDB 2016b).

The sequence of crops in a rotation is well known to have an effect on wireworm populations. Crops that follow within two years of long-term grassland are most at risk of wireworm damage. Wireworms survive as well in wheat managed under minimum tillage as they do in grassland. Farmers should consider growing wireworm-tolerant crops such as linseed, flax or peas at high-risk points in the rotation (AHDB 2016b). To put it another way, a key cultural control method for wireworm is to avoid growing susceptible crops where there are known to be significant wireworm populations (Furlan 2007b, Barsics 2013).

The most intense periods of feeding activity for wireworm are March to May and September to October, so in theory risk could be reduced by not drilling crops during these times. However, this decision would need to be balanced with other agronomic considerations. The exact timing of these activity periods depends on weather and soil conditions, with the larvae requiring certain levels of warmth and moisture. Modelling tools could be developed to predict wireworm risk at regional or local scales, helping to guide farmer decisions (AHDB 2016b).

Isothiocyanates, naturally-occurring substances found in many brassica species, are known to be toxic to wireworms (Barsics 2013) (see also biopesticides section in the current report). The use of brassica species as green cover crops has been shown to reduce wireworm populations in Italy but the results have not yet been reproduced in the UK (AHDB 2014a). This could therefore be a valuable topic for further research.

A study of maize and sugar beet growers in Italy demonstrated that less than 5% of fields needed to be treated with an insecticide to control wireworm, but nevertheless the majority were treated. This appeared to be because the knowledge needed for an effective IPM strategy did not exist or was not known to the farmers (Furlan 2005). It is possible that the same is true of wheat farmers in the UK. The ready availability of effective chemical controls for wireworm stifled research into alternative control strategies and new chemistry until at least 1990 (Barsics 2013). There remain many questions about the ecology of wireworms, answering which could lead to improved control strategies in future (AHDB 2016b), for example innovations such as trap crops or push-pull approaches (Barsics 2013).

Slugs

Farmers are advised that the most important method of cultural control for slugs is the preparation of a fine, **consolidated seedbed** before sowing. Ploughing and tilling directly kills slugs, although some farmers have shown that over time a minimum or even no-tillage approach can help to control slugs by encouraging natural predators (see John Cherry case study and section on natural enemies below). A firm seedbed makes it harder for slugs to find safe resting places and to move around. A well-prepared seedbed will also help the crop establish and grow out of the vulnerable stages more quickly as will good crop nutrition and soil drainage. Drilling wheat down to 3cm (or deeper if the seedbed is cloddy) reduces accessibility of the seeds to slugs. The presence of weeds, crop residues such as straw, and manure applications (especially in autumn) can exacerbate slug problems by providing food and shelter (AHDB Information Sheet 04).

The advice about seed bed preparation appears to be based on anecdotal rather than empirical evidence (Defra Project PS2805). Given that this approach may conflict with many other objectives (for example retaining soil moisture, avoiding soil compaction by reducing traffic, conserving natural enemies of slugs and other pests), ascertaining its benefits or otherwise would seem to be an obvious research priority. Some farmers who are practising minimum tillage have found that, although slugs may be present in high numbers in their fields, they eat other material (such as volunteers from the previous crop) in preference to the wheat (see case study section of current report).

Some authors have suggested that sowing at **higher seed rates** where there is slug risk could help to ensure sufficient plants survive to compensate for losses. Seed rates have been reduced over the last 30 years as a result of industry advice. Wheat plants compensate for low crop density by producing additional tillers (stems) – in other words the surviving plants grow into the spaces. Plants growing closer together produce fewer tillers, meaning there is an optimum plant density for the best yield. This optimum density is generally lower for earlier sown crops because they have more time to produce tillers. There are other agronomic considerations, such as risk of lodging (where the crop falls over). Further research is needed to understand optimum plant density, and the seed rate needed to achieve it, under different levels of slug pressure and other conditions (AHDB 2016b, Defra Project PS2805).

One recent study found that boosting silicon levels in wheat seedlings (by applying soluble silicon) reduced feeding by slugs in laboratory conditions, suggesting a possible avenue for further research (Griffin 2015).

Orange Wheat Blossom Midge

This section refers to winter wheat: OWBM rarely affects spring-sown wheat because of its later flowering time (AHDB 2016b).

Cultural approaches do not currently form a major part of OWBM control strategies in the UK. There is some evidence that 'aggressive' cultivation techniques such as deep ploughing reduce numbers of OWBM; however, such techniques also harm natural enemies and have other environmental and agronomic disadvantages (AHDB 2016b). The presence of straw residues can reduce OWBM risk (and discourage invasion by winged aphids; see above), but may encourage slugs (AHDB Information Sheet 53). Crop rotation generally has little effect on OWBM risk (AHDB 2016b), although in more sheltered fields reducing the frequency of wheat crops in the rotation is believed to help reduce midge populations (AHDB 2014a). Farmers are advised that block cropping (where a particular crop such as wheat is all situated within one block rather than dispersed throughout the holding) can aid monitoring and control of OWBM in current crops and possibly reduce risk in future crops (AHDB Information Sheet 53). However, given that the simplification of the farmed landscape, including the shift to block cropping, is believed to be a key factor in farmland biodiversity decline (Boatman 2007) it may not be a desirable approach to promote.

Ryegrass is a good host plant for OWBM (AHDB Information Sheet 53), and it has been suggested that avoiding this species on arable farms and using alternative grasses (for example in grass margins and leys) could help to reduce crop infestation (AHDB 2016b).

Monitoring and thresholds

Introduction

Monitoring pests and setting evidence-based thresholds for intervention is a cornerstone of IPM. Without such monitoring, the benefits of improved cultural and biological pest management cannot be realised, because pesticides continue to be applied routinely even if the need for them has decreased. Monitoring protocols and thresholds have been devised for most of the key pests, as described below. It is important that these are continually reviewed and updated with new evidence. What can be harder to ascertain is to what extent farmers and agronomists are applying this advice in reality. If (as is often the case) pesticides are cheap compared with the costs of monitoring, there is a strong incentive to apply pesticides as an insurance rather than in response to need.

Aphids/BYDV

There is no threshold for aphids as regards BYDV risk, as very small numbers of aphids can infect the crop (AHDB 2014a). Farmers are advised to spray if aphids are invading outside the 4-6 week window of protection offered by neonicotinoid seed treatments, or when the first leaves appear in the case of aphids invading non-neonicotinoid treated crops (Croprotect website). This is regardless of the actual number of aphids present or whether they are believed to be carrying the virus. When viewed purely as an economic decision this appears logical: pyrethroid sprays are cheap and can be used in tank mixes with herbicides or fungicides during other autumn spray operations, whereas monitoring is time-consuming and the consequences of failing to treat an infestation could be severe (AHDB 2016b). However, it should also be considered that the indiscriminate use of pyrethroid sprays can harm populations of natural enemies and has hastened the emergence of resistant aphids (AHDB Aphid News).

Clearly there can be no thresholds to determine the use of seed treatments as these are prophylactic (AHDB 2016b).

The risk of direct feeding damage by grain aphids or rose-grain aphids in summer can be monitored by looking for aphids on the leaves of the wheat plants. The recommended threshold for spraying is half the tillers infested before flowering, or two-thirds infested after flowering. Aphid reproduction is dependent on temperature. A 'T-sum' system that calculates accumulated day degrees above 3°C can be used to predict best spray timings (Farmers' Academy 2015).

AHDB produces a free electronic newsletter, Aphid News, which provides weekly updates on regional aphid activity during key times of the year. Aphid News uses data from an aphid monitoring network run by Rothamsted and AHDB (which makes use of suction traps and water-pan traps located across the UK) to provide information on aphid migration and an assessment of risk to crops from BYDV and direct feeding (AHDB Aphid News). For some species including grain aphid, forecasts can be made at the beginning of the season based on correlations between activity and overwintering temperatures. This information can guide farmers and agronomists as to when to start monitoring their crops (AHDB 2016b).

Wireworm

Bait traps can be used to determine simple presence or absence of wireworms, and researchers have explored the potential to improve bait trap techniques so that they could be used to estimate the density of wireworms (Barsics 2013). The only method currently recommended for estimating wireworm numbers is examination of soil cores in a laboratory. Farmers are advised to use a seed treatment if there are more than 750,000 wireworms per hectare (if populations exceed 1.25 million per hectare, damage can occur even with a seed treatment). However, this method of monitoring is very costly, subject to large sampling errors, and is considered to be rarely justified in cereal crops (AHDB 2014a). Furthermore, it is not clear how these thresholds were arrived at, so they seem to be of limited use (AHDB 2016b).

Meaningful monitoring of wireworms and predicting risk of crop damage requires a more in-depth understanding of the species present, their population age structure, and interactions with risk factors at the field and landscape scale (AHDB 2016b, Barsics 2013). Regional or national surveys using soil cores could potentially be used to inform growers of the risk of wireworm attack (in a similar way to Aphid News – see elsewhere in the current report). If further research is carried out into the biology of wireworm species, it might be possible to construct a more sophisticated model of wireworm risk and incorporate this into a decision support tool for farmers (AHDB 2016b).

Slugs

Slugs can be monitored using refuge traps (non-toxic bait under a cover). Traps (nine per field) should be put out before cultivation, when the soil is moist and the weather is mild, and left out overnight. If there are at least four slugs per trap, and soil and weather conditions favour slug activity, there is a risk of crop damage (AHDB 2014a). Surveys and expert opinion, however, suggest that few growers are applying this approach. The time-consuming nature of putting out and checking traps means that many growers will apply insurance treatments, possibly after a basic risk assessment based on weather, soil type and past experiences (AHDB 2016b).

A Defra-funded study (Defra Project PS2805) aimed to investigate the tolerance of wheat and oilseed crops to slug damage. The authors concluded that, although wheat does have the ability to compensate for damage in early growth stages, there is a threshold for plant density below which the crop may be unable to compensate. Therefore, if the crop plant density is already low (for example because a low seed rate has been used, or because weather or other pests have affected growth), slug attack may reduce yields. This study also found variation in how the crop responded to leaf pruning (to simulate slug damage) – only 50% of study sites showed a significant reduction in yield. From this it appears that thresholds could be refined with a better understanding of which crops are vulnerable to slug attack. This will be challenging because compensatory growth responses are regulated by environmental factors like weather, which cannot be predicted sufficiently far in advance to guide slug control decisions. The authors called for further work to relate slug numbers observed in refuge traps with the amount of damage caused to the crop, and to determine how crops respond to a loss of leaf area.

Orange Wheat Blossom Midge

Outbreaks of OWBM are only likely in years when midge emergence and wheat emergence coincide, which in turn depends largely on the weather in winter and spring. However, it is extremely difficult to predict when this will happen and so monitoring and treatment thresholds are considered essential to OWBM control (AHDB 2016b).

Various methods are available for monitoring OWBM. Pheromone traps provide early warning of midge activity. Yellow sticky traps can be used to detect the presence of midges in crops at the susceptible stage, as can visual inspection of spider webs in the crop, or looking for adult midges laying eggs on the ears. A threshold for treatment is given for each of these methods. In the case of visual inspection of wheat ears, for example, 1 midge per 3 ears on feed wheat or 1 per 6 on milling and seed crops is considered the threshold for treatment (AHDB 2014a). A decision support model has been developed based on these monitoring methods to guide farmers in when to spray pesticides. This is relatively quick and simple for farmers to use, although some time and training are required to use the methods accurately (AHDB 2016b).

Natural enemies

Introduction
Natural enemies of pests are species naturally present in the environment that eat, parasitise or otherwise harm the pest species. Attempts to boost natural enemy populations are based on making the crop more hospitable (for example through minimum tillage or reducing pesticide use) and providing habitat for them in or around the crop (for example with beetle banks and arable margins).

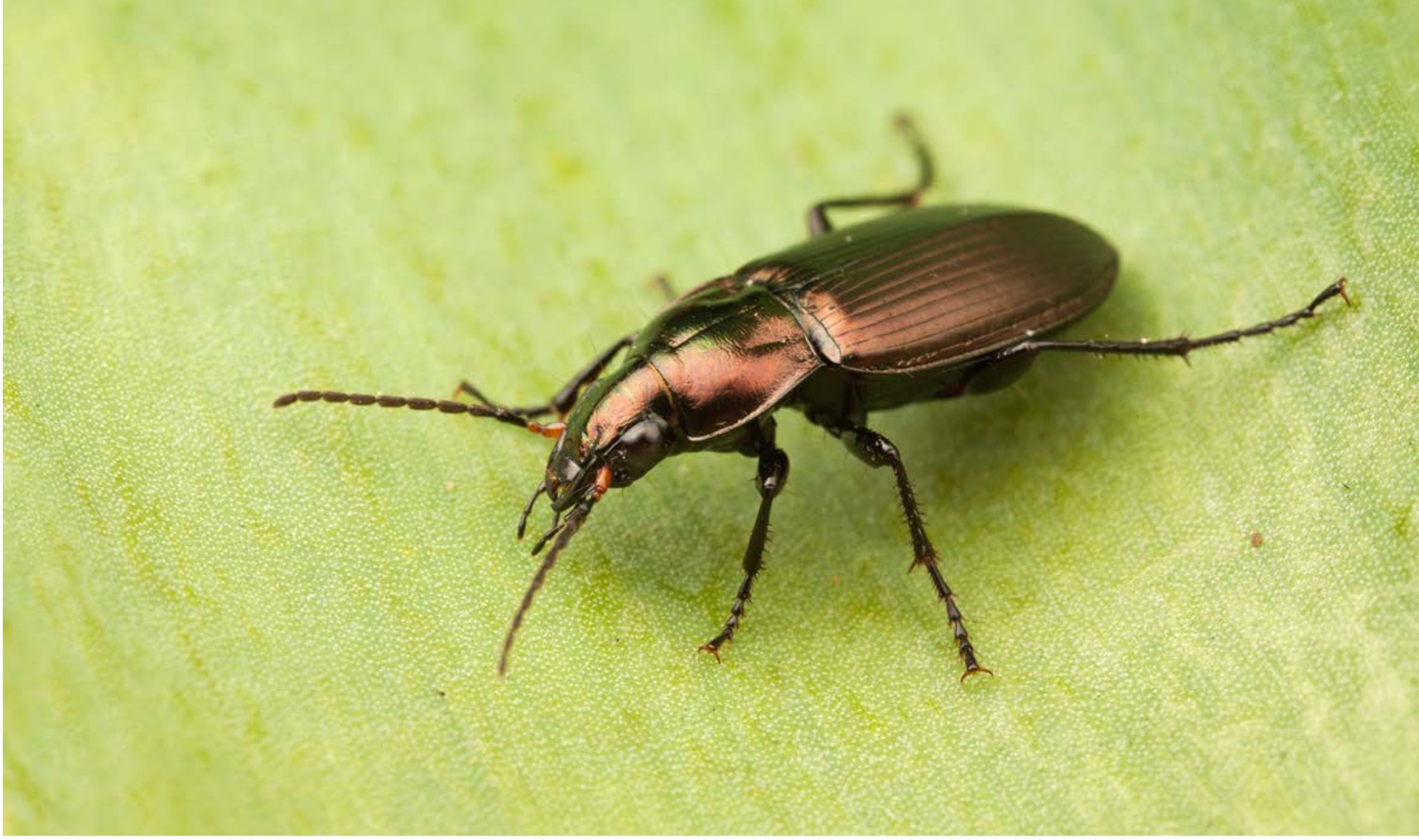
There is much evidence that particular habitat features support enhanced populations of natural enemies, but the actual impacts on pest populations or on crop yield have not always been quantified (Holland 2007, Fera 2012). It may be of limited use to draw general conclusions from individual studies, since the effects of an intervention on biological pest control can vary according to a number of factors including time, place, weather, farming system and wider landscape characteristics. Much work has been carried out and is ongoing to optimise the contribution of on-farm created habitats to biological control. In the meantime, it has been shown that in general there is a positive relationship between the **heterogeneity of a landscape** and pest control within crops (Bianchi 2006), and it has been proposed that encouraging a diverse range of natural enemies through habitat management is the best way to create a robust biological control system (AHDB 2016b, Holland 2008). This is also the experience of the farmers featured in the case studies in this report. To date, agri-environment schemes (such as Environmental Stewardship in England) have been important in supporting farmers to create and manage on-farm habitats. It is vital that such support continues in some form after the UK leaves the EU.

Aphids
Aphids are attacked by a wide variety of natural enemies including ground beetles, spiders, parasitoids, hoverflies, ladybirds and lacewings (AHDB 2014a). A recent study of cereal crops in south east England found that presence of natural enemies correlated with a reduction in pest population grown, indicating that natural enemies contribute significantly to pest control (Ramsden 2016). In one set of field trials in south west England, natural enemies provided almost complete control of aphids on winter wheat in summer. In this study, almost all of the control was provided by flying predators (a mixture of species, dominated by flies from the families Empididae and Dolichopodidae), spiders from the Linyphiidae family (money spiders) which can disperse on a long thread (ballooning), and rove beetles. Parasitism rates (as opposed to predation) were very low. However, this pattern does not appear to be universal: in other studies parasitoids, spiders and fly larvae were variously found to be the most important group of enemy species (Holland 2008).

Farmers are advised that conserving natural enemies can reduce the need for insecticide use against aphids (Croprotect website). Specific management options recommended to encourage natural enemies are minimum tillage, beetle banks in fields of 20ha or more, and field margins (especially if sown with wildflower mixtures (Croprotect website)) (AHDB 2014a).

There is also one study providing evidence that beetle banks increase aphid control by generalist predators up to 58m into the field (though the effect was greater nearer the bank) (Collins 2002). Grass banks, field margins and flower-rich habitats provide resources, overwintering sites and refuges for natural enemies and alternative insect prey species (AHDB 2014a).

Minimum tillage both allows greater survival of natural enemies and helps provide the structures between which spiders build their webs (AHDB 2014a). A study from Ireland provides evidence



Ground beetle © Matt Cole

that minimum tillage enhances control of aphids: the numbers of aphids in wheat and barley were smaller under minimum cultivation compared to conventional ploughing in two out of six seasons between 2001 and 2006 (Kennedy 2012).

There are potential trade-offs to be considered: for example, grassy areas can harbour aphids as well as their enemies, and minimum tillage can increase the risk of 'green bridge' transmission (see 'crop husbandry' section of the current report) (HGCA 2003). However, the overall effect of providing a variety of habitats which can harbour natural enemies is positive and should form part of any IPM approach.

Farmers are advised to **avoid pesticide use** when aphid populations are low to conserve natural enemies (Croprotect website). Spiders in particular are highly vulnerable to pyrethroid sprays (AHDB 2014a). In autumn, web-building spiders are believed to be highly effective natural enemies because they are present in high numbers, prevent the spread of immigrating aphids, and their webs continue to catch aphids after being abandoned (AHDB 2014a).

No commercially viable way has been found to enhance the biological pest control of aphids by releasing 'mass-produced' natural enemies into the agroecosystem. This is to be expected since aphids can readily disperse through the farmed landscape (AHDB 2016b).

Wireworms

There is a lack of published research about the natural enemies of wireworms and the adult click beetles, and it is possible that they do not have many predators or parasitoids (AHDB 2016b). Nevertheless, current industry advice is that the main natural enemies of wireworms are fungi and parasitic wasps (AHDB 2014a). Ground beetles attack wireworms and the adult click beetles (not themselves a crop pest (HGCA 2003)) are eaten by birds (AHDB 2014a).

Grassy field margins are known to benefit both wireworms and their natural enemies. Further research is needed to establish the overall effects of different types of field margin management on crop damage by wireworm (AHDB 2016b).

Slugs

A range of organisms are known to attack slugs, including ground beetles, rove beetles, parasitoids, birds, amphibians and hedgehogs. Farmers are advised that providing habitats for these may help control slug populations (AHDB 2014a). **Suitable habitat could include well-managed hedgerows, field margins and beetle banks.** AHDB guidance on slug control (AHDB Information Sheet 04) states that "the establishment and management of beetle banks in field margins as habitats for carabid beetles has been shown to reduce slug numbers by predation, mainly from June to September" but a reference is not given. There is some evidence that beetle banks do benefit beetles and other beneficial organisms (Dicks 2012), although the effects are variable at different sites and times (Fera 2012). The effectiveness of carabid beetles as pest control agents can vary according to which species of beetle and of slug are present, and beetles can be diverted away from feeding on slugs by the presence of other, more palatable prey such as aphids (AHDB 2016b). As stated in the introduction to this section, providing a range of habitats to support a variety of natural enemies is likely to be the best way to promote robust natural pest control.

There is a potential conflict in that some measures intended to conserve natural enemies, such as reduced tillage and provision of in-crop habitat, also benefit the slugs themselves. This highlights the need to adopt the IPM approach completely rather than piecemeal. Natural enemies need a number of factors to thrive, including year-round habitat and resources and the absence of pesticides. Providing only some of these (for example, installing beetle banks but continuing to routinely spray insecticides) could fail to increase natural enemy populations while benefiting slugs. There is also evidence that neonicotinoid seed treatments can harm the natural enemies of slugs (Douglas 2014). Further field trials to better understand and quantify the overall effects of these measures on slug damage would benefit farmers but should not be a reason to delay advice being given to farmers now based on existing experience and knowledge on encouraging natural enemies.

Orange Wheat Blossom Midge

The most important natural enemies of OWBM are small parasitic wasps, particularly Macroglens penetrans. The wasp lays its eggs in the midge eggs and the larvae develop on the midge larva after it has overwintered. The reduction to crop damage is therefore not immediate (AHDB 2014a). However, the new generation of wasps infects the next generation of OWBM, reducing the pest population in the following year. If populations of M. penetrans are allowed to develop, there is a long-term cumulative reduction in pest pressure. Insecticides, however, kill the parasitoid and cancel the beneficial effect. In addition to avoiding insecticide use, parasitoids can be encouraged by providing suitable habitat in crop margins (AHDB 2016b).

OWBM are also preyed on by many generalist predators (AHDB 2014a). There is some evidence that these can help prevent population build-up in the soil (AHDB 2016b).

Biopesticides

The term 'biopesticide' refers to a wide variety of pest management agents based on pheromones, microorganisms, plant extracts or other novel alternative products (HSE website). Often their mode of action is more complex than conventional pesticides, making it less likely that pests will evolve resistance (AHDB 2016b). Biopesticides, like chemical pesticides, are an intervention based on introducing a new substance or organism to the farmed environment, and therefore potential risks to non-target organisms and the wider environment must be rigorously assessed on a case-by-case basis.

There is currently no significant use of biopesticides on cereal crops in the UK[1]. There is however growing interest in biopesticides, and a group of farmers has founded a company, Real IPM UK, with the aim of getting a number of biopesticides that were developed in Africa authorised for arable use in the UK (RealIPM UK).

Aphids/BYDV

In laboratory conditions, various naturally-occurring phenolic acid mixtures from plants were found to reduce rates of development and reproduction in grain aphid (Chrzanowski 2012). A glasshouse experiment concluded that neem oil and turmeric powder at 3% concentrations control grain aphid and cherry-oat aphid in wheat plants (Bushra 2014). It is important to note, however, that the neem extract Azadirachtin was recently found to be highly toxic to bumblebees (Barbosa 2015), highlighting the fact that biopesticides can also pose risks to non-target organisms. A number of essential oils are known to have insecticidal effects against rose-grain aphid (Sánchez 2012). The company Real IPM markets a fungus, Real Metarhizium 62, which kills aphids (species not specified) in fruit crops (RealIPM UK).

Wireworms

There are various current lines of research into developing biopesticides for use against wireworms. Strains of entomopathogenic (disease-causing) fungus and nematode have delivered positive (though inconsistent) results in lab and field trials, and research is also being conducted on bacteria that affect wireworms. Further field research is needed to better understand interactions between biological control agents, wireworms and their environment before any of these will be viable as pest management tools for farmers (Barsics 2013).

1 The supplementary information accompanying the Pesticides Forum Annual Report 2015 lists biopesticide usage in the UK where area treated is over 100 hectares: http://webcommunities.hse.gov.uk/connect.ti/pesticidesforum/view?objectId=49875. None of the substances listed is authorised for use on wheat. https://secure.pesticides.gov.uk/pestreg/ProdList.asp.

As mentioned elsewhere in the current report, many brassica species contain substances known to be toxic to wireworms. Trials have been carried out where fresh plant material or defatted seed meal from such species is applied to the soil, but results have been mixed. Again, further research is needed to understand what factors determine the success or otherwise of this method (AHDB 2016b).

Attempts have been made to develop semiochemical-based strategies for wireworms, but results have been disappointing and no breakthroughs look likely for the near future. Plant-derived volatile substances have been tested for their repellence to wireworms, and may in future form part of a push-pull strategy to decrease populations of wireworm within crops. However, there are no techniques nearing commercial viability (AHDB 2016b).

Slugs

The nematode Phasmarhabditis hermaphrodita is a lethal parasite of slugs that is commercially available as a biological molluscicide. In ideal conditions, the product reduces crop damage for about six weeks after application. Nematodes have the advantage that they can target soil-dwelling slugs, as opposed to pellets which only reach slugs active on the soil surface (AHDB Information Sheet 04). However, the high costs of purchasing and using this product mean it is mostly used in high-value vegetable crops, not arable agriculture. The product's cost-effectiveness could potentially be improved by applying it at lower rates, extending the nematodes' persistence using slow-release gels, or increasing the virulence of the strains used – further research is needed (AHDB 2016b).

Various naturally-derived compounds including garlic (Schüder 2003) and caffeine (Hollingsworth 2002) have been experimentally shown to be effective molluscicides and some (including garlic) are in use on horticultural crops and by gardeners. However, no alternative products have as yet been developed commercially for arable use.

Orange Wheat Blossom Midge

There have been some trials of plant extracts for OWBM control. The plant extract NeemAzal T/S reduced OWBM populations but was not as effective as the pesticides currently on the market (AHDB 2016b). It appears that, because there are effective pesticides and resistant varieties, the development of biopesticides against OWBM is not an attractive area for research.

Pesticides

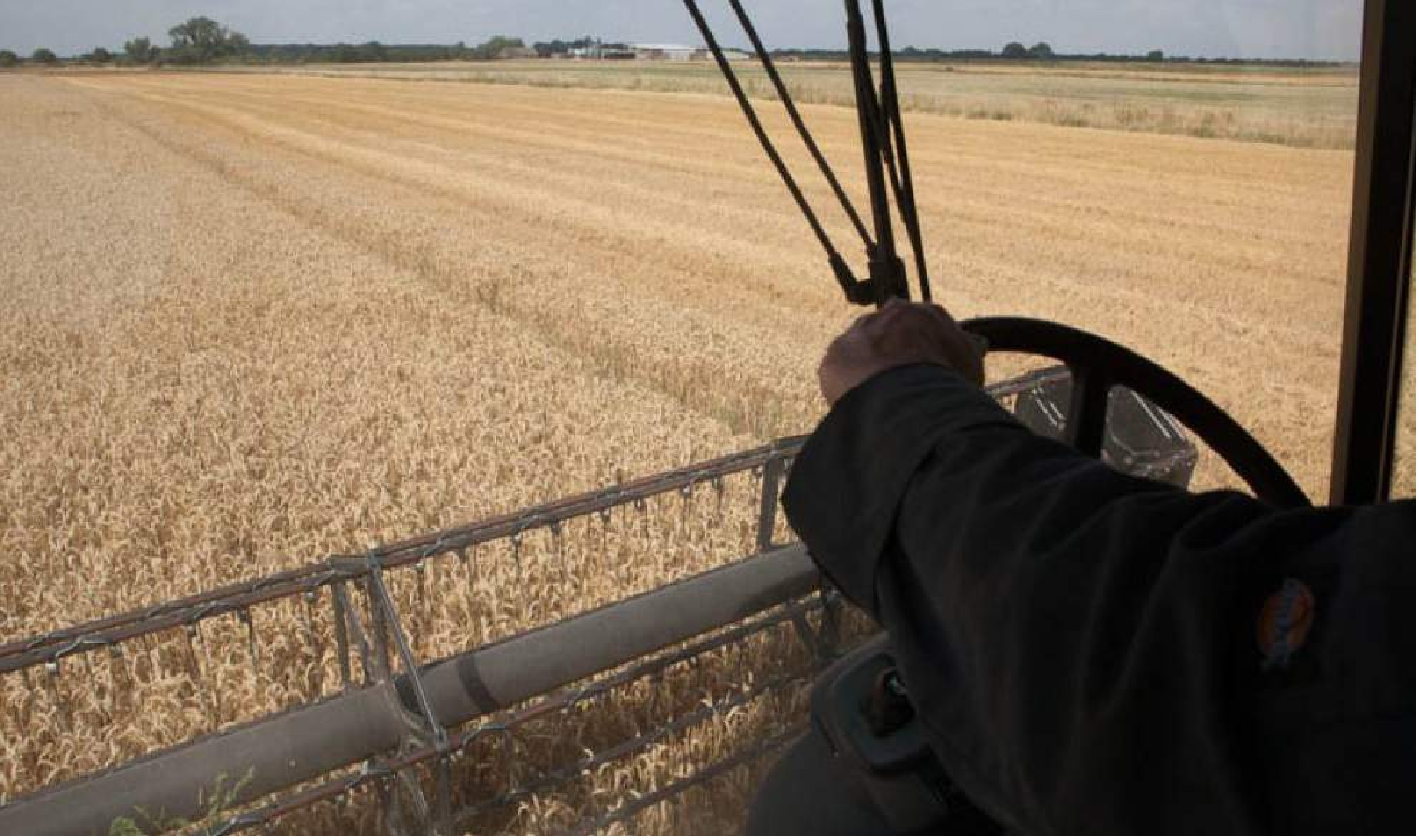
Introduction

An IPM approach does not preclude the use of pesticides, but stipulates that they should be considered a last resort when other approaches have failed. IPM also requires that:

- The pesticide with the least side effects on non-target organisms, human health and the environment should be chosen;
- No more pesticide should be used than is necessary for effective treatment;
- Anti-resistance strategies should be applied (for example avoiding over-reliance on one chemical);
- Pesticide applications must be recorded and pest organisms monitored, and this information used to check the effectiveness of pesticide use (EU Directive 2009/128/EC).

Although more than half of the UK wheat crop is grown without neonicotinoid seed treatments, some farmers and agronomists consider them to be the best option for pest control. Such growers argue that compared to sprays neonicotinoids are highly targeted (both in terms of which organisms are exposed to them and which organisms they are toxic to), and are used in very small amounts (Alan Dewar, Dewar Crop Protection Limited, August 2016, personal communication; Andrew Barr, East Lenham Farm, October 2016, personal communication). However, the growing evidence that neonicotinoids contaminate the wider farm environment (see evidence section in Background) and can be harmful to non-target organisms at extremely low doses (see for example Woodcock 2016) contradicts the assertion that they are targeted. It is also important to note that seed treatments are commonly used in conjunction with sprays rather than replacing them (see below).

Seed treatments are by their nature a prophylactic treatment, because the decision to use them is taken before any assessment can be made of the pest threat in any particular year. They cannot be used as a 'last resort' after non-chemical means of control have been tried and so can never be in line with IPM principles.



Ruth Levene Courtesy of A Field of Wheat

As evidence increases of the environmental and human health impacts of insecticides, more are being withdrawn from the market. While this can present a challenge to farmers it is a process that has been happening for some time and the logical response from research institutions and industry would be supporting farmers to increase their take up of IPM.

Aphids/BYDV

Aphids are the key reason for use of neonicotinoid seed treatments on UK wheat (Toby Bruce, Rothamsted Research, August 2016, personal communication). Pyrethroid sprays are the main chemical alternative, and in fact neonicotinoids and pyrethroids are commonly used in conjunction. Bayer advise that if large numbers of aphids infest the crop a follow-up treatment will be required in addition to the seed treatment (Bayer website). At any rate, neonicotinoid seed treatments only provide protection for 4-6 weeks after sowing in autumn: if aphids are invading after this period a pyrethroid spray treatment may be necessary. In the case of crops untreated with neonicotinoids, if aphids are present a pyrethroid spray is recommended when the first leaves appear to reduce the risk of BYDV infection (Croprotect website).

In 2014, 1.6 million hectares of wheat[2] were treated with an insecticide spray, of which the large majority was a pyrethroid. Of the respondents who specified a reason for using a spray, 94% cited aphids (Fera 2015). Much of this spraying takes places in the autumn with the aim of reducing BYDV infection. AHDB advises that **"the sporadic nature of aphid attacks in time and space means that prophylactic use of insecticides does not make economic sense. It also increases the risk of insecticide resistance and damages the environmental reputation of the industry"** (AHDB Aphid News). Nevertheless, usage is believed to be higher than necessary in many years: pyrethroids tend to be applied as insurance sprays because they are cheap, especially when compared with the high management costs of monitoring aphid populations (AHDB 2016b). The case studies featured in this report show that farmers can successfully remove insurance sprays without additional damage to crops if they adapt alternative means of control. The use of neonicotinoid seed treatments is necessarily prophylactic, since the decision to purchase neonicotinoid-treated seeds take place well before the risk from aphids can be forecast (AHDB 2016b).

Resistance to pyrethroids has been detected in grain aphids, but as yet not in bird cherry-oat aphids (AHDB 2014a). Scientists at Rothamsted Research are monitoring resistance in the grain aphid. They currently advise that resistance is at a low level in the UK and is unlikely to result in complete failure of control (AHDB, 2 March 2016). Farmers are advised to apply pyrethroid sprays at the full recommended field rate to avoid promoting resistance (Crops, 19 July 2014), and to avoid repeat spraying with pyrethroids if it appears resistance is present in the population (Croprotect website). An IPM approach, whereby pyrethroids are only used occasionally as a last resort, would help to slow the development of resistance.

No pesticides other than neonicotinoids and pyrethroids are currently authorised for application

2 Area treated refers to the **active substance treated area**. This is the area treated with each active substance, multiplied by the number of times the area was treated.

against aphids in autumn (Alan Dewar, Dewar Crop Protection Limited, August 2016, pers. comm.).

Table 2 provides a summary of insecticides (other than neonicotinoid seed treatments and pyrethroids) currently approved in the UK for use against grain aphids, or which could potentially be authorised for this use in the future. They include dimethoate (an organophosphate) and pirimicarb (a carbamate), each marketed under various product names (HSE pesticides register). Dimethoate products may not be applied between 15 August and 1 April (Headland Agrochemicals). The authorisations for pirimicarb products are set to expire on 31 July 2017 (HSE pesticides register) and they will no longer be authorised for use on cereals after this date (Alan Dewar, Dewar Crop Protection Limited, August 2016, personal communication). It should be noted that carbamates and organophosphates have the same mode of action as pyrethroids, so are of limited use in combating resistance in grain aphids (Insecticide Resistance Action Committee (date unknown)).

Products containing chlorpyrifos (an organophosphate) were banned for use on wheat from April 2016 (AHDB 'Chlorpyrifos withdrawal'), which was unsurprising given that evidence had been available for many years of adverse human health impacts related to exposure to this chemical. Several thiacloprid-based products are currently approved for use in wheat against OWBM (HSE pesticides register), but not against aphids (see for example relevant product labels (Bayer website)). It should be noted that, although thiacloprid was not included in the EU neonicotinoid restrictions, it is under review and there is evidence that its use may pose risks to bees (Fischer 2014, Iwasa 2004).

Flonicamid is a systemic insecticide which inhibits aphid feeding (Morita 2007). It is classed as a pyridinecarboxamide and has a different mode of action to neonicotinoids (Ishihara Sangyo Kaisha Ltd). It is licenced in the UK for use on wheat under the brand name Teppeki, first authorised in 2005 (HSE pesticides register), but does not currently appear to be used on wheat (Fera pesticide usage statistics). Teppeki can only be applied once 50% of the wheat ear is emerged (Belchim Crop Protection), which in winter wheat occurs in the spring/summer (AHDB 2015), so again use of this product cannot be used to protect against early infection of the crop in autumn.

A set of field trials carried out in 2012 aimed to test the efficacy of alternative products against populations of aphids known to be resistant to pyrethroids (AHDB 2014b). Pirimicarb gave moderate control at one site and good control at the other; thiacloprid gave good control at both sites. Acetamiprid (a neonicotinoid not currently approved for use on wheat) gave poor control while pymetrozine (a pyridine azomethine also not approved for use on wheat) gave good control at the one site where it was tested. Chlorpyrifos gave the best control at all sites. However, as explained above, none of these products are currently authorised for use on wheat in autumn. Chemical options for growers are currently therefore limited to neonicotinoid seed treatments, pyrethroids (unless resistance is present), and any off-label authorisations that might be granted for other products on the market (Alan Dewar, Dewar Crop Protection Limited, August 2016, personal communication). This highlights the urgent need to develop and promote non-chemical alternatives as part of an IPM approach.

Wireworm

Wireworms are soil-dwelling and as such are difficult to treat with pesticides. As noted earlier wireworms have only become a serious threat to wheat in recent decades possibly linked to the prevalence of winter cropping. Seed treatments are currently recommended to control wireworm in fields where they are known to be present in significant numbers; however growers are warned that even if a seed treatment is used damage can occur under high pest pressure (AHDB 2014a). As with aphids and slugs, the use of a seed treatment does not necessarily negate the need to use sprays.

The available active ingredients for seed treatments are neonicotinoids (usually clothianidin) and pyrethroids (tefluthrin and cypermethrin). These protect the crop in its vulnerable seedling stages. Pyrthroid seed treatments were applied to 34,299ha of cereal crops in the UK in 2014 (Fera pesticide usage statistics). In one three-year study by a Canadian government research department (Vernon 2009), neonicotinoid and pyrethroid seed treatments (alone and in combination) were found to provide effective protection for wheat crops although populations of wireworm were not significantly reduced. According to this study these seed treatments appear to reduce wireworm feeding on wheat seeds without killing the insects. In the same study, a fipronil seed treatment (not currently authorised in the UK) also provided good protection, and in this case no wireworms were detected in the trial plots the following spring. Fipronil, although not classed as a neonicotinoid, is a systemic pesticide and has been identified as posing an acute risk to honeybees. Its use is currently restricted in the EU (European Commission, 22 October 2015).

Neonicotinoid seed treatments are commonly applied for aphid control (see elsewhere in the current report) but have possibly been helping to reduce wireworm damage in these crops as well. There is concern in some sections of the industry that restrictions on neonicotinoids will place more pressure on the remaining active ingredients, risking the development of resistance in wireworm (there is currently no known resistance (AHDB 2014a)). This has led to calls for new pesticides to control wireworm, which are economically significant pests of potatoes and other crops as well as wheat (AHDB 2016b). Alternatively, this could be seen as an opportunity to develop an IPM approach to managing wireworm, keeping the existing pesticides available as a last-resort option.

Slugs

The primary means of chemical control for slugs are molluscides in the form of slug pellets, with metaldehyde or ferric phosphate as the active ingredients. In 2014, the total area of cereal crops in the UK treated with metaldehyde was 389,853 ha, and with ferric phosphate 28,056 ha. 32,160ha were treated with methiocarb, but 2014 was the last year this active ingredient could be used as it has been withdrawn (Fera pesticide usage statistics, Croprotect website, HSE pesticides register). In all, 22% of wheat crops in 2014 received a molluscicide (AHDB 2016b).

The market dominance of metaldehyde has been helped by its pricing and is not necessarily about its effectiveness. Use of ferric phosphate increased sharply in 2014, probably because of the withdrawal of methiocarb. Ferric phosphate is believed to be safer for non-target organisms than metaldehyde and equally effective against slugs. It is however more expensive, and there may be a perception that it is less effective because the slugs tend to die underground, rather than on the surface where they are more obvious to the farmer (AHDB 2016b).

Metaldehyde is frequently detected in the UK's waterways and is extremely difficult to remove. The problem is made more acute by the fact that slug activity and therefore the need for slug control increases in wet weather, when the risk of pesticides washing into waterways is high (AHDB 2016b). There is a strong possibility that regulations governing the use of metaldehyde use will be tightened under the EU Water Framework Directive requirements, possibly extending to a complete ban on the product (Voluntary Initiative (date unknown), DWI 2016). It is not currently clear how the UK's proposed exit from the EU might affect the application of the rules in the UK in future.

There is currently no known pesticide resistance in slug populations (AHDB 2014a). However, the effectiveness of slug pellets is limited: they only remain on the soil surface 4 –7 days and only kill actively feeding slugs. In suitable conditions slug populations can recover quickly and crop damage may resume within weeks of treatment (HGCA 2003). The efficacy of pellets is poor compared with other pesticides, largely due to ineffective targeting of the pellets. Improving the advice given to farmers on application timing and technique could potentially improve the effectiveness of slug control (AHDB 2016b). A quality control scheme has been called for to help farmers choose between the numerous slug pellet formulations on the market (Defra Project PS2805).

Neonicotinoid seed treatments are claimed to reduce damage caused by slugs and activity against slugs is included on the product label for clothianidin-based products such as Redigo (Bayer website), but evidence for their effectiveness appears to be limited. It should be noted that seed treatments do not negate the need for other forms of control. Seed treatments do not protect the emerging seedling from slugs, so farmers are advised to use a slug pellet at crop emergence even when they have used a neonicotinoid seed treatment (Bayer website). Trials with imidacloprid found that it could act as a repellent to slugs, but to achieve consistent effects it had to be used at well above the approved rate. A study by Bayer (as reviewed by AHDB, 2016) found that clothianidin had repellent activity against slugs in wheat, resulting in a mean increase of 29% in plant number in seven trials. It is not clear from this review whether final crop yield was measured (AHDB 2016b).

Concerns have been raised about possible impacts of neonicotinoids on beneficial invertebrates, including potential predators of slugs (Pisa 2015) and this is an area requiring further research. One study in the United States found that

a neonicotinoid seed treatment (thiamethoxam) increased slug damage in soya bean by killing the natural enemies of slugs (Douglas 2015).

Orange Wheat Blossom Midge (OWBM)
Chlorpyrifos sprays were the recommended means of chemical control for OWBM (HGCA 2003, Voluntary Initiative 2005) until their withdrawal in March 2016 (HSE Pesticides eBulletin, 12th February 2016). Since the ban was announced, AHDB has updated its guidance on pest control options, now emphasising the importance of resistant wheat varieties (AHDB 'Chlorpyrifos withdrawal'). Currently, three active substances are approved for OWBM control: lambda-cyhalothrin and beta-cyfluthrin (pyrethroids) and thiacloprid (neonicotinoid). These are all broad-spectrum chemicals which will harm any beneficial insects present in the crop (AHDB 2014b). Close monitoring of midge populations and precise timing of pesticide applications is vital to achieve effective control (AHDB Information Sheet 53), since pesticides cannot kill the larvae once they have burrowed into the wheat ears. This means that, if a farmer identifies a need to spray, the whole crop will probably need to be done within four days: a significant workload challenge for many holdings (AHDB 2016b). Thiacloprid sprays were applied to 3,000 ha of cereal crops in England in 2008 but have not been used in the UK in subsequent years up to 2014. Lambda-cyhalothrin was applied to 811,392ha of cereal crops in 2014 and beta-cyfluthrin to 18,017ha (Fera pesticide usage statistics).

Table 1: Current options available for control of key pests of winter wheat

This table summarises the body of the current report and sets out current options available to farmers – it does not constitute recommendations by Friends of the Earth. Sections in *italics* are identified research needs or techniques that have been proposed but which are not yet available to farmers.

Pest/disease	Choice of crop variety	Husbandry/cultural control	Monitoring/ thresholds	Natural enemies	Biopesticides	Pesticides
Aphids Occasionally cause yield reductions through feeding but main concern is virus transmission.	No current resistant varieties. *Active area of research.*	Delay sowing of winter crops until mid-October. Consider growing spring wheat. Assess specific risk factors to decide on minimum tillage vs removing grass weeds from field. *Potential role for bi-cropping with clover.*	Thresholds are given for feeding damage, assessed by visual inspection of plants. AHDB publishes weekly updates on regional aphid activity to help focus monitoring efforts.	Many species. Recommended approaches: minimum tillage; avoid spraying when aphid populations are low; provide habitat heterogeneity with margins and beetle banks.	No products commercially available for use on wheat. *Various natural extracts known to be active against aphids.*	Neonicotinoid seed treatments and pyrethroids. Partial resistance to pyrethroids is widespread.
BYDV High risk areas of UK are coastal areas of the S, SE and SW. Yield losses of up to 2.5 tonnes per hectare (losses range from 5% – 80%, average 30%).	No current resistant varieties. *Active area of research – potentially a key tool against BYDV.*	See 'aphids' – however, anything less than 100% aphid control may not protect against virus transmission.	No threshold: presence of any aphids in autumn is considered reason to act.	See 'aphids' – however, anything less than 100% aphid control may not protect against virus transmission.	See 'aphids' – however, anything less than 100% aphid control may not protect against virus transmission.	See 'aphids' – however, anything less than 100% aphid control may not protect against virus transmission.
Wireworms Worst case yield losses of up to 0.6 tonnes per hectare.	No current resistant varieties. *Resistance and tolerance is known to vary in different cultivars – recommended as a priority for future research.*	Consolidate seedbeds and control grass weeds. Consider inversion ploughing and including a spring crop/wireworm-tolerant crop in the rotation. *Avoiding sowing during peak wireworm activity could reduce damage but more research and modelling needed to make this a practical option. Some success in Italy with brassica cover crops – research needed in UK systems.*	No satisfactory methods beyond determining presence/ absence. *Improving sampling methods and determining thresholds is an active area of research.*	Main enemies believed to be fungi and parasitic wasps. Ground beetles and birds also known to attack wireworms and adult click beetles. *More research needed on natural enemies and effective strategies to enhance natural pest control.*	No products commercially available. *Promising lines of research include entomopathogenic fungi and nematodes, bacteria and extracts of brassica species. Further research needed.*	Pyrethroid and neonicotinoid seed treatments.

Slugs Little published data on yield losses. Early infestation can prevent crop establishment.	Unlikely to make a significant contribution to control.	Prepare a fine, consolidated seedbed and minimise weeds and organic matter on the soil surface. *Research needed to ascertain whether and under what circumstances this is the best approach; and to investigate higher seed rates as another option. Boosting plant silicon levels reduced slug feeding in lab conditions; field research needed.*	Monitoring protocol and thresholds are given but do not appear to be widely followed. *Wheat can compensate for slug damage in some situations – need for an improved understanding of which crops are vulnerable.*	Many species. Recommended approaches: provide habitat, particularly beetle banks. *There is some evidence that neonicotinoids can harm natural enemies of slugs: more research needed. The measures that benefit natural enemies also benefit slugs: there is a need for better understanding of the interactions.*	No products commercially available for use on wheat. *Various biopesticides used in amateur settings and for high-value crops but currently not cost-effective for arable farmers.*	Slug pellets, mainly metaldehyde and increasingly ferric phosphate. Efficacy is low and metaldehyde may be banned due to water contamination. Neonicotinoid seed treatments are claimed to repel slugs but evidence of overall efficacy seems to be limited.
OWBM Very patchy distribution in time and space. In rare peak conditions can causes yield losses of 75% or more (last major outbreak 2004).	14 resistant varieties on the recommended list; key tool in managing this pest. *Resistance depends on one gene; risk of OWBM evolving tolerance is recognised e.g. in Canada – research needed in UK systems.*	Cultural approaches not currently an important tool for winter wheat. Options include deep ploughing, block cropping and leaving straw residues, but all have drawbacks and trade-offs with management of other pests. Consider growing spring wheat. *Avoiding rye-grass in favour of other grass species on arable farms may reduce crop infestation – has not been specifically researched.*	Main monitoring methods are pheromone traps, yellow sticky traps and visual inspection. Thresholds are given for each method and a simple decision support tool has been developed.	In the absence of insecticides, small parasitic wasps provide effective control which accumulates over time. They can be further encouraged by providing appropriate habitat in margins. Generalist predators may also help prevent population build-up.	No products commercially available. *In trials, the plant extract NeemAzal T/S reduced OWBM populations but was not as effective as the pesticides currently on the market.*	Currently, three active substances are approved for OWBM control: lambda-cyhalothrin and beta-cyfluthrin (pyrethroids) and thiacloprid (neonicotinoid). No known resistance. Precise timing of pesticide sprays is vital to achieve effective control.

Table 2: Summary of pesticides which are or could be used to control aphids in wheat

(HSE pesticides register) (excluding neonicotinoid seed treatments and pyrethroid sprays)

Active ingredient (and class)	When can product be applied to winter wheat?	Use on cereals in the UK in 2014[3]	Summary of environmental characteristics and key human health concerns
Acetamiprid (neonicotinoid)	Not currently authorised for use on wheat	N/A	Very toxic to aquatic life with long-lasting effects. Slightly toxic to predatory mites and generally slightly toxic to other beneficials[4]. In humans, possible developmental neurotoxicity[5].
Dimethoate (organophosphate)	No later than 15 August	3,112 ha (25,200 ha in 2012)	Non-persistent in the environment. Moderate to high toxicity to aquatic organisms, earthworms, mammals and birds, with some evidence for sub-lethal effects. Highly toxic to bees on an acute contact basis so should not be applied when crops or weeds are flowering. Considered high risk to non-target insects in general[6]. Moderately toxic to humans; concerns over acute and chronic impacts through occupational exposure[7].
Flonicamid (pyridinecarboxamide)	Not before 50% ear emerged and no later than 28 days before harvest (early August[8])	No use recorded	Low risk to soil micro-organisms, honeybees and other beneficial arthropods, and low toxicity to earthworms. Harmful to aquatic organisms, with moderate toxicity to fish, algae and invertebrates. Not considered as harmful to mammals and birds[9].
Pirimicarb (carbamate)		24,727 ha	Very toxic to aquatic invertebrates and moderately toxic to fish and algae: may cause long term adverse effects in the aquatic environment. Moderately toxic to mammals and earthworms and highly toxic to birds. Not persistent in water or soil. Considered low to risk to bees and other non-target arthropods [10,11].
Agrotech-Pirimicarb 50 WG	No later than 31 March in the year of harvest and/or before the early dough stage (June/July[12])		
Other products	No later than 14 days before harvest (early August[13])		
Pymetrozine (pyridine azomethine)	Not currently authorised for use on wheat	N/A	Dangerous to bees but considered low risk to other non-target arthropods. Low toxicity to mammals and birds. Moderately toxic to aquatic life and low to moderate persistence in soil[14].
Thiacloprid (neonicotinoid)	Up to and including flowering (usually June[15]) (in wheat, this chemical is currently authorised only for use against Orange Wheat Blossom Midge)	No use recorded	Very toxic to some aquatic invertebrates, moderately toxic to fish and algae: may cause long term adverse effects in the aquatic environment. Low toxicity to earthworms and soil micro-organisms. Low persistence in soil. Low toxicity to mammals and bees and moderate toxicity to birds. The spray Biscaya may have adverse effects on non-target arthropods, especially foliage-dwelling predatory insects[16]. Although thiacloprid has lower acute toxicity to bees than the currently restricted neonicotinoids, evidence exists for adverse impacts, especially in conjunction with other stressors[17]. In humans, thiacloprid is harmful if swallowed (fatal at very high doses[18]), is suspected of causing cancer, and may damage fertility and the unborn child[19].

Footnotes

3 Fera pesticide usage statistics

4 www.certiseurope.co.uk/fileadmin/downloads_uk/products/insecticides/INSYST_CLP_20140619.pdf

5 www.efsa.europa.eu/en/press/news/131217

6 Dimethoate 40 Environmental Information Sheet www.voluntaryinitiative.org.uk/ImportedMedia/EIS/Dimethoate-40-[V1].pdf

7 Pesticide Action Network UK, Pesticides News No. 55, March 2002 www.pan-uk.org/pestnews/Actives/dimethoa.htm

8 https://cereals.ahdb.org.uk/media/883980/1-RLDL_2016-17_Winter_Wheat_RL-V6.pdf

9 Teppeki Environmental Information Sheet www.belchim.co.uk/pdf/EIS/Teppeki_EIS.pdf

10 Phantom Environmental Information Sheet www.voluntaryinitiative.org.uk/ImportedMedia/EIS/Phantom.pdf

11 Aphox Environmental Information Sheet www.syngenta.co.uk/product/crop-protection/insecticide/aphox

12 https://cereals.ahdb.org.uk/media/883980/1-RLDL_2016-17_Winter_Wheat_RL-V6.pdf

13 https://cereals.ahdb.org.uk/media/185687/g66-wheat-growth-guide.pdf

14 www.syngenta.co.uk/product/crop-protection/insecticide/plenum

15 https://cereals.ahdb.org.uk/media/185687/g66-wheat-growth-guide.pdf

16 Biscaya Environmental Information Sheet www.bayercropscience.co.uk/our-products/insecticides/biscaya/

17 Friends of the Earth Thiacloprid briefing and references therein www.foe.co.uk/sites/default/files/downloads/friends-earth-thiacloprid-pesticide-briefing-march-2015-76087.pdf

18 Vinod, K. V. et al. (2015) A fatal case of thiacloprid poisoning. The American journal of emergency medicine 33: 310-e5.

19 Biscaya Safety Data Sheet www.bayercropscience.co.uk/our-products/insecticides/biscaya/

Case studies

The information for these case studies was kindly provided by the featured farmers and agronomists. The seven case studies cover a variety of farm types: organic and conventional; arable, mixed and agroforestry; minimum-tillage and ploughed. Potential case studies were identified through personal contacts and internet searches. Because this report is focussed on finding solutions that will work for farmers if the current restriction on neonicotinoid seed treatments are extended to wheat the studies featured here showcase experiences of successfully growing wheat without neonicotinoids on a variety of holdings. They are not intended as a representative sample of UK wheat growers.

Case study 1: **Peter Lundgren, White Home Farm** – the economic case for avoiding neonicotinoid seed treatments

White Home Farm is an arable holding in Lincolnshire. Peter runs the farm conventionally (i.e. using pesticides), with a strong focus on Integrated Pest Management (IPM) principles and on encouraging beneficial insects. In 2014 Peter provided a report to Friends of the Earth giving an economic analysis of growing wheat and oilseed rape with and without neonicotinoids*. The current case study is based on this and on an interview with Peter carried out in August 2016.

Peter's key finding from the 2014 study was that switching to a neonicotinoid-free pesticide regime in winter wheat could save him money. At 2014 prices, a typical aphid control regime based on a neonicotinoid seed treatment plus two applications of pyrethroids would cost £24.40/ha, while an alternative regime based on three applications of Hallmark (active ingredient lambda-cyhalothrin, a pyrethroid) would cost in the region of £11/ha. Other options exist that may have less impact on non-target species but are more expensive, notably Mavrik (active ingredient tau-fluvalinate, a novel pyrethroid) and Teppeki (active ingredient flonicamid, a pyridincarboxamid).

Peter says that, other than aphids, the key pests to consider are Orange Wheat Blossom Midge, gout fly and bulb fly. Gout and bulb fly are not controlled by neonicotinoid seed treatments so would be of equal concern under both regimes. They can be managed according to the IPM principles of using cultural techniques to reduce risk, monitoring, and intervening only when thresholds are exceeded. The risk from OWBM can be negated by choosing a resistant wheat variety.

Since 2014 Peter has considerably reduced his pesticide use and now only considers using pesticides in wheat to control aphids in the autumn. He believes that this has been made possible by the increase in the numbers of beneficial insects that has resulted from the reduction in pesticide use and the choice of more targeted products when pesticides are used. Peter feels strongly that in order to promote healthy ecosystems and natural enemies, the cropped area must be managed sympathetically as well as providing habitat for wildlife around the edges of fields.

Peter believes that using a seed treatment runs counter to the principles of IPM. The decision to buy treated seeds has to be taken well before the growing season, when the farmer can have very little idea of what the pest pressure is going to be. In many years pest thresholds are not reached, meaning that money spent on a neonicotinoid seed dressing was wasted. Nevertheless, seed treatments are understandably appealing to many farmers and agronomists because they are seen as bringing peace of mind.

In Peter's experience, incentives to apply pesticides as 'insurance', rather than in response to an actual pest attack, are a key barrier to better adoption of IPM. He believes that there is an unfortunate culture of blame or even litigation against the agronomist if a crop fails, creating a strong incentive to recommend 'just in case' pesticide treatments such as seed treatments. Furthermore, many agronomists are directly employed by an agri-chemical distribution company. For these agronomists, a proportion of their income will come from selling the chemicals, but in many cases the bill they present to the farmer combines the cost of their time and expertise with the actual cost of inputs. The farmer therefore has no way of knowing how much they are paying for advice and how much they are paying for pesticides, and there is no financial incentive for the agronomist to give good advice that does not increase pesticides sales. On White Home Farm, Peter employs an independent agronomist, paying a flat rate for their advice on a per hectare basis and buying pesticides directly from suppliers rather than through the agronomist. Trust is an important part of the arrangement, and Peter and his agronomist have an agreement not to lay blame should a crop fail to yield as much as expected. This approach has clear advantages for agronomists, farmers and the wider sector, but it appears that it is currently followed only by a minority of farmers.

Peter believes that change is coming. The moves back to spring cropping should lead to a reduction in pesticide sales, meaning that agri-chemical and agronomy companies will have to change their business model to maintain profits. The tightening of pesticide regulations is often met with panic from the industry, but experience has shown that regulation is a key driver of innovation in pest control: farmers can expect more options to become available to them as old pesticides are taken off the market. What is needed from the agriculture industry is clear leadership and a positive vision for the future, and to work with our research institutions, plant breeders and agrochemical companies to develop economically viable and sustainable methodologies to control crop pests.

* http://www.peterlundgren.co.uk/2014/01/27/is-there-a-future-without-neonicotinoids/

Case study 2:
John Pawsey, Shimpling Park Farm – A balanced agroecosystem avoids insect problems

Shimpling Park Farm is a 1039-hectare holding in Suffolk. John started conversion to organic production in 1999 and the holding is now entirely organic. The farm became mixed in 2014 when a flock of New Zealand Romney sheep was introduced.

The choice of crops grown depends largely on the market, but a typical rotation would be:

- **Years 1 & 2:** fertility building ley – either a rye grass/white clover/herb mix for sheep grazing or a pollen and nectar mix including legumes for nitrogen-fixing.
- **Year 3:** a cereal, for example winter wheat.
- **Year 4:** spring oats
- **Year 5:** a legume, for example field beans
- **Year 6:** spring barley undersown with the 2-year ley.

Since converting to organic production, John has not experienced any significant problems with insect pests in his wheat crop. Orange Wheat Blossom Midge is present at varying levels in different years, but has never reached sufficient numbers to affect yields. Barley Yellow Dwarf Virus has occasionally been present in the barley crop (less since switching to spring barley) but has never been a problem in the winter wheat.

John does not view insect pests as a major concern in his organic system. He attributes this to healthy populations of predatory insects and other beneficial organisms. This was effectively demonstrated in 2015 when John's spring bean crop experienced a major attack of aphids. The ladybird population responded almost immediately, bringing aphid numbers under control within about a week.

Shimpling Park Farm is in the Higher Level Stewardship agri-environment scheme and incorporates habitats managed specifically for wildlife. However (like Peter in the previous case study), John feels strongly that sensitive management of the *whole* farming system is essential: providing space for wildlife 'round the edges' is important but not sufficient to build healthy ecosystems. Since converting to organic production, John's rotation is much more complex than a typical conventional farm, providing a greater diversity of habitats. Low levels of weeds in the organic crops provide in-field habitats for beneficial insects and the absence of pesticide use means populations can build up. Greater numbers of weeds and insects translates into more abundance higher up the food chain. Regular bird surveys over many years reveal that, compared to a conventional neighbouring farm, Shimpling Park Farm has three times the breeding bird population in summer and 17 times the number of birds in winter.

John's approach can be summed up as farming for profit while maintaining a natural balance in the farmed ecosystem. He observes the problems increasingly experienced in conventional chemical-based agriculture and welcomes signs that farmers are starting to think outside the box with pest management.

Case study 3:
Ian Dillon, Hope Farm
– using a variety of Integrated Pest Management tools

Hope Farm is a 180-hectare arable holding outside Cambridge in the east of England. Since 2000 it has been owned and managed by the RSPB as a commercial farm. Ian Dillon is the farm manager. He works closely with independent agronomist Dave Sheldon to make decisions about pest management within the context of the farm's Integrated Pest Management strategy.

For most of its time under RSPB management, Hope Farm has had a typical rotation of winter wheat, oilseed rape and spring beans. In recent years, other crops such as peas and barley have been included in the rotation and an increasing amount of spring cropping has been introduced, but winter wheat continues to be a major crop. Both the oilseed rape and the wheat have been grown without neonicotinoids in most years, and the RSPB took a decision in 2012 to completely stop using neonicotinoids unless as part of research projects.

Ian and Dave have chosen to grow mainly Group 3 varieties of wheat (usually used for biscuits and cakes, with less demanding standards than top-quality milling wheat). Disease profile is very important in their choice of specific variety, particularly resistance to Orange Wheat Blossom Midge. They also favour varieties that are good at competing with black-grass, an arable weed that is becoming a serious problem in this part of the country.

Since switching to Orange Wheat Blossom Midge resistant varieties, aphids are the main insect pest on Hope Farm's winter wheat. Crops are drilled in October, in line with advice about reducing aphid risk. Hope Farm incorporates a greater diversity and area of wildlife habitats than many conventional farms. To date, no specific monitoring has been carried out to determine whether these habitats are having a significant effect on populations of aphids or natural enemies. From general observation, weather remains the key factor determining aphid populations.

The non-neonicotinoid treated wheat crops usually receive one or two pyrethroid spray treatments in autumn, with neonicotinoid–treated crops (when they have been grown pre-2012 or as part of research projects since) generally needing zero or one sprays. No significant pyrethroid resistance has been recorded in this area as yet. Decisions to spray in spring and summer are based largely on weather and past experience: for example when there have been heavy frosts over winter, spring sprays are not usually needed. Where possible, insecticides are combined with another pesticide or fertiliser in the spray tank to reduce the number of treatments and thus the costs of spraying. For example, the wheat fields always need to be treated with herbicide in autumn to control black-grass, so sometimes a pyrethroid can be added at the same time.

Hope Farm recently hosted a research project that required growing wheat with and without neonicotinoids. The experimental set-up involved a pair of winter wheat fields, one treated with neonicotinoids and one untreated (swapped in year two), and both drilled on the same date. After this point, each field received the usual inputs as recommended by the agronomist (see table). Although clearly no wider conclusions should be drawn from such a small sample size, and this data set does not include final yields, several points are interesting to note. Firstly, in both years, non-treated seeds were slightly *more* expensive than neonicotinoid treated seeds. This is partly because the non-treated seeds were drilled at a higher seed rate (i.e. more seeds per hectare), but mostly because seed prices are very variable and farmers can pick up a 'bargain' by buying at the right time. Secondly, the use of a neonicotinoid seed treatment led to only one avoided insecticide spray over the two years. For the crop harvested in 2014, the non-neonicotinoid treated field required sprays for aphids in November and June, whereas the treated field only required the June spray. In 2015, no insecticides (other than the seed treatment) were used on either field. This was because wet weather prevented any operations in winter, and then a late spring cold snap killed off overwintering aphids and made a spring pesticide application unnecessary. Finally, on Hope Farm at least, the cost of insecticides is a very small proportion of the overall input costs – especially if they can be applied at the same time as other inputs. The experience on this farm suggests that the desire to reduce costs might not be an effective incentive to reduce insecticide use, since they are such a small part of the budget already.

Dave and Ian feel that access to truly impartial advice is critical to help farmers adopt better systems of Integrated Pest Management. Many agronomists are employed by pesticide distribution companies, and receive commissions on pesticide sales. The pesticides industry can also influence agronomic advice in other ways including through advertising pesticides and funding training courses. Profitability to the agri-chemical industry could be a factor in some of the pesticides advice given to farmers. In some cases this could lead to unnecessary pesticide applications or use of the most expensive (rather than the most appropriate) pesticide. Better communication, especially through social media, is helping farmers compare their experiences and benchmark their pesticide spending against that of their peers. An additional driver of pesticide use is the culture of blame – the agronomist is rarely thanked for minimising pesticide use when the yield is good, but is inevitably blamed when yield is poor. Like Peter Lundgren (see separate case study), Dave and Ian advocate a pay-per-hectare approach to agronomy advice.

	2014 harvest Total cost/ha (number of applications)				**2015 harvest** Total cost/ha (number of applications)			
	Neonic		*Non-neonic*		Neonic		*Non-neonic*	
Seeds	£90.71		£116.35		£76.92		*£77.26*	
Fertiliser	£202.64		*£200.47*		£216.10		*£216.10*	
Herbicides	£140.44	(8)	*£140.44*	*(8)*	£120.84	(8)	*£128.56*	*(7)*
Mollusicides	£12.92	(1)	*£12.92*	*(1)*	£11.30	(1)	*£7.97*	*(1)*
Fungicides	£130.57	(7)	*£130.57*	*(7)*	£105.49	(9)	*£107.68*	*(9)*
Insecticides*	£2.62	(1)	*£5.53*	*(2)*	£0.00	(0)	*£0.00*	*(0)*
Total inputs**	£579.90		*£606.28*		£530.65		*£537.57*	

* excluding neonicotinoid seed treatment: this is included within the seed cost
** cost of product only: excludes costs of operations

Case study 4:
Jay, Courtyard Farm
– top quality wheat production with no need for insecticides

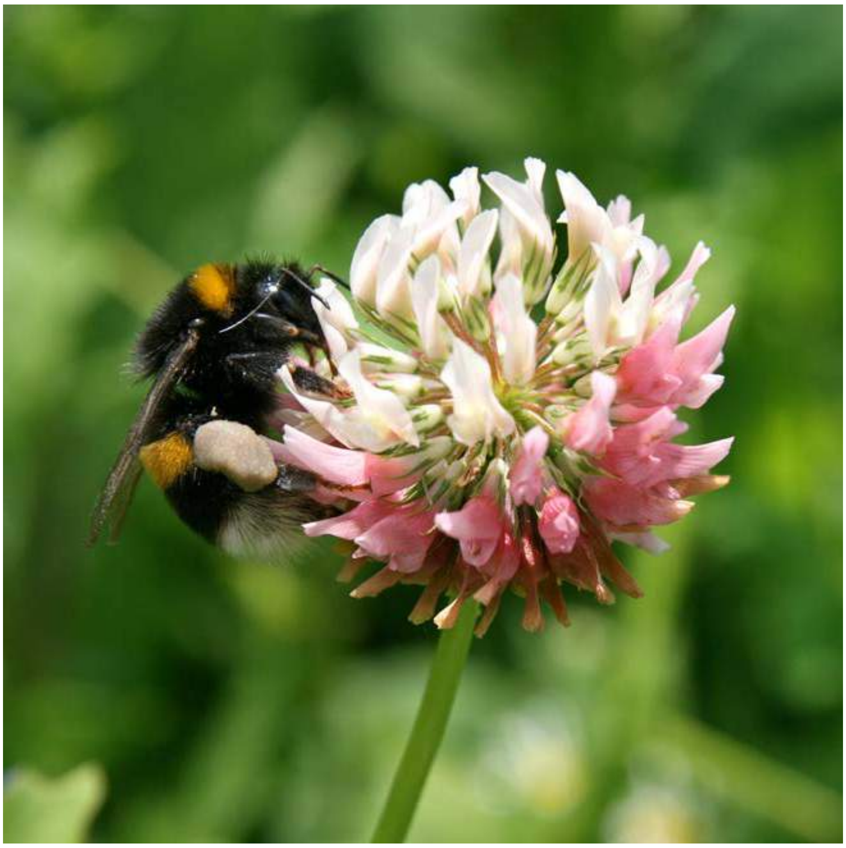
Courtyard Farm is a 360ha organic holding in Norfolk. It is managed on a six-year rotation, with spring wheat, barley, beans and peas, and red and white clover as the main crops grown. The wheat and most of the other crops are grown for use as seed by other organic farmers, which requires a very high quality crop.

The wheat variety grown is Mulika, a high yielding and high quality spring wheat which is resistant to Orange Wheat Blossom Midge. The wheat is undersown with clover, which enhances the nitrogen content of the soil. The clover remains in place for two more years after the wheat is harvested, and is cut for silage and grazed by cattle in summer.

Courtyard Farm finished converting to organic in 2000. No pesticides are used, except once on one field (not wheat) when special permission was granted to use a product to tackle a pest problem. Jay has farmed for five years and in that time has never seen any significant insect problems in the wheat crop. The wheat meets the seed quality grade every year with no use of pesticides.

Courtyard Farm is rich in wildlife because of sensitive crop management, a long crop rotation and extensive habitat creation supported through the Higher Level Stewardship agri-environment scheme. The focus is on creating a healthy and balanced agro-ecosystem to avoid any species becoming a pest: prevention rather than cure. Because insect pests are not a problem in the wheat, and because there is no 'quick fix' available if a pest problem did develop, detailed monitoring of insects in the crop is unnecessary.

Courtyard Farm is an example of a holding that practices many of the options explored in the current report: lengthened rotations with spring cropping, using a pest-resistant wheat variety, bi-cropping with clover and encouraging natural enemies. It is not possible to quantify the contribution each of these makes to pest control, but it is clear that this approach as a whole is successful.



Case study 5:
John Cherry, Darnalls Hall Farm – no-till, minimal pesticides and trusting in natural enemies

Darnalls Hall Farm is a 1000 ha conventional holding in Hitchin, Hertfordshire. The farm has been in continuous zero-tillage for six years and John is a passionate advocate for no-till farming.

The crop rotation is very flexible from year to year but typically includes some combination of winter wheat, oats or spring barley, a 2- or 4-year grass and clover or herbal ley (either cut for silage or grazed) and spring or winter beans. Oilseed rape has been included in the past but John believes that problems with cabbage stem flea beetle have made this an unreliable crop for his farm.

John grows both milling wheat and feed wheat. He aims to choose varieties that do well without high inputs of fertiliser or pesticide. Some of the wheat grown is OWBM resistant. John has tried spring wheat in some years but yields have been disappointing.

Most of the wheat at Darnalls Hall Farm is now grown from farm-saved seed. Neonicotinoid seed treatments are not currently used, although they have been in the past. John aims for zero use of insecticide sprays and minimal use of slug pellets. He believes that use of pesticides can create a vicious circle by killing off the natural enemies that would have helped control the pests: the more you spray, the more you need to spray. Spraying with a pesticide is at best a temporary solution as pests will rebound, and repeated use of a pesticide increases the risk that pests will develop resistance.

This approach is paying off. John did not use a neonicotinoid seed treatment or spray his wheat crop last autumn. Although aphids were present and there were some patches of BYDV, John observed that his neighbours who sprayed their crops up to three times suffered far worse losses to BYDV. He believes that the natural enemies (including spiders and beetles) that are flourishing in his no-till fields keep the aphids under control.

There is a similar story with slugs. John is aware that farmers sometimes experience a severe increase in slug damage after switching to no-till systems. However, after six years of no-till at Darnalls Hall Farm the system appears to have reached a balance, with slugs kept in check by their natural enemies. There are occasional spikes in the slug population, but so far these have been quickly controlled by natural enemies with rarely any need for slug pellets. John has also found that when wheat is drilled into green cover (such as oilseed rape volunteers from the previous harvest), the slugs will eat the volunteers in preference to the wheat seedlings. He further suspects that slugs prefer to feed on fusarium and other fungi on decaying plants, helping to reduce disease pressure on the wheat. In John's experience, slugs only really attack the wheat when there is no alternative.

John believes that too many farmers and agronomists have become used to relying on pesticides as a quick fix, or even to be used 'just in case', rather viewing them as a last resort. He shares the concerns expressed by other farmers featured in the current report about the lack of independent advice. John has switched to an independent agronomy firm due to his perception that agronomists who receives commission on pesticide sales are more likely to recommend unnecessary sprays.

Case study 6:
Stephen and Lynn Briggs, Whitehall Farm
– agroforestry helps create habitat diversity to keep pests in check

Whitehall Farm is a 103ha organic holding located in the fens, near Peterborough in the East of England. Stephen and Lynn took over the tenancy in 2007 and quickly identified soil loss through wind erosion as a major problem. To address this issue while increasing the farm's profitability, they designed and implemented an agroforestry system that combines apple trees and arable farming. The trees grow in parallel rows 27m apart, with a 3m perennial pollen and nectar strip under each row. The 24m alleys between the trees grow mainly cereal crops (wheat, oats and barley), with some vegetables and cover crops.

As Whitehall Farm is organic, there is no use of pesticides. Stephen's approach to pest management hinges on selecting crops that minimise the risk of pest outbreaks and on providing year-round habitat for the natural enemies of pests.

The main wheat varieties grown at Whitehall Farm are Mulika and Paragon – both milling-standard spring varieties. Mulika is OWBM resistant; Paragon is not but to date there have been no problems with OWBM. Cultivation is necessary before sowing to control weeds (non-organic no-till farms generally rely on glyphosate), although Stephen is involved in the early stages of research to develop reduced-tillage organic systems.

On Whitehall Farm the rows of trees with their pollen and nectar strips play a key role in encouraging natural enemies. The farm has hosted various MSc and PhD studies and these have shown that the 24m spacing allows natural enemies to penetrate all of the wheat crop with no 'dead zones' beyond their reach. The farm is in a Higher Level Stewardship agri-environment agreement, which has supported additional wildlife habitat provision including wild bird cover, over-wintered stubble and hedge planting.

The organic agroforestry approach has proved successful in managing pests. Aphids are present within the wheat crop but not at levels which cause economic damage. There are no problems with slugs, which Stephen largely attributes to the absence of oilseed rape in the rotation. Under this system, both biodiversity and farm profits have risen compared to when the farm was under conventional management.

Stephen believes that the key to the success of this system lies in its diversity: "Nature doesn't do monoculture – a farming system where the vegetation cover is varied (over both time and space) has more natural checks and balances built in, and is more resilient than the simplified systems that dominate much of the farmed landscape".

Case study 7:
David Walston, Thriplow Farms
– eliminating uneccesary pesticide treatments

Thriplow Farms is a 900-hectare holding in Cambridgeshire, East of England. David grows winter wheat in rotation with oilseed rape, peas and beans, winter and spring barley and oats. The farm is in its second year of zero tillage, and David is working to cut down insecticide sprays to a minimum. He has never used a neonicotinoid seed treatment on the wheat crop. The farm is in a higher level agri-environment agreement, and 100ha of the holding is devoted to non-cropped wildlife habitats.

The main insect pest problem in David's winter wheat is aphids. The wheat crop usually receives one pyrethroid spray in autumn to control aphids and reduce the risk of BYDV infection. In general in the past, BYDV has not been a major problem on Thriplow Farms. Last year David decided not to spray three of his wheat fields. Two of these went on to produce satisfactory yields, while the third was badly affected by BYDV, leading to losses of 3 – 4 tonnes per hectare (although some of this loss could also be due to the fungal disease yellow rust). David does not currently have any theory as to why one field suffered from BYDV while the other two did not, despite none of them receiving the autumn spray.

In the past, like many farmers, David has also applied a pyrethroid spray in spring as an insurance against feeding damage by aphids. However, as mentioned David is now attempting to minimise spraying. In 2016 he did not spray in spring, and this decision was justified as no significant aphid problem developed, despite the exceptionally mild winter.

David rarely experiences significant slug damage in his wheat crops. Slug populations appear to be highest following oilseed rape. However, David has found that when wheat is drilled into fields of oilseed rape volunteers, the slugs will eat the rape in preference to the wheat, so the crop remains undamaged. He has also noticed that the habitat strips seem to encourage higher numbers of slugs, but this does not translate into significant increased crop damage. David uses slug pellets sometimes as needed to keep populations down, for example in mild autumns. Although slugs have not been a major problem in the past, it is possible they will become so in the new zero-till system.

No formal monitoring has been carried out on Thriplow Farms to determine how pests and their natural enemies are responding to the zero tillage regime and the abundance of wildlife habitats on the farm. However, David believes that encouraging a healthy ecosystem has to be better for pest control as well as for biodiversity.

Conclusions

In 2017 the European Commission will make decisions, about whether to maintain and extend existing restrictions on neonicotinoid insecticides. With evidence growing of the persistence and mobility of neonicotinoids in the environment and harm to bees and other wildlife there is a strong case for current restrictions to be extended to all crops. At the same time the available choice of other insecticides is reducing. It is clear that increasing the uptake of non-pesticide management techniques, as part of IPM and organic farming systems, is the sustainable solution for farmers and for wildlife.

The main reason for farmers currently using neonicotinoid seed treatments in wheat is to reduce Barley Yellow Dwarf Virus infection by controlling aphids in autumn, with control of wireworms, and possible slugs, as a secondary aim. In addition, neonicotinoid spray formulations are available to control OWBM, but are not widely used. An increase in winter cropping has resulted in several of the current pest problems that neonicotinoids are used for. However, the fact that currently over half of the UK wheat crop is grown without neonicotinoid seed treatments indicates that neonicotinoids are not essential to wheat production.

Many farmers – whether or not they use neonicotinoid seed treatments – are using other insecticides, particularly pyrethroids, which carry their own risks to wildlife and the environment. The research and case studies in this report illustrate that wheat can be grown without seed treatments and with a significant reduction in, or even elimination of, the use of pyrethroids. There are non-chemical approaches that work effectively. Successfully implementing Integrated Pest Management and relegating pesticides to a last resort option will involve a significant change in approach for some farmers but would also bring multiple benefits including boosting soil health as well as helping bees and other beneficial insects.

This report has looked at the options currently available or in development for each of the key pests (summarised in Table 1). Together, the analysis of existing research in this report, and the practical findings of the case study farmers gives a good indication of where there is most evidence of success and where more research or action is required.

What can farmers do now?

The evidence suggests the following measures should be taken up by farmers now (approaches will of course vary from farm to farm):

- Create and maintain a network of habitats across the farm to provide resources for natural enemies, including beetle banks, margins and hedgerows.

- Unless there is an overriding reason not to, choose an Orange Wheat Blossom Midge-resistant wheat variety. Broad-spectrum insecticide sprays against OWBM in spring and summer are extremely harmful to beneficial organisms and wider biodiversity.

- Consider growing spring wheat and/or including other spring crops in the rotation. Spring-sown wheat rarely experiences problems from aphids or OWBM. Including spring crops in the rotation can interrupt the wireworm lifecycle and allow control of eggs and larvae.

- If possible, delay sowing of winter wheat until mid-October to reduce the risk of aphid infestation.

- For conventional (non-organic) farmers: consider adopting a minimum or zero tillage approach. Reduced tillage can have many benefits for soil health, beneficial organisms and fuel use and some farmers have found that it improves natural pest control over time. (Note that the approach may not be equally successful on all farm and soil types)

- If wireworms are known to be present or are predicted to be a threat in a particular field (for example due to cropping history), plan the rotation so that there is a gap where wheat and other susceptible crops are not grown in this field.

- Apply recommended monitoring techniques for aphids, slugs and OWBM. Subscribe to monitoring and alert services such as Aphid News; use recommended monitoring techniques on-farm for aphids, slugs and OWBM (if a susceptible wheat variety is being grown) and do not apply pesticides unless the published thresholds are exceeded.

The evidence in a nutshell

Natural Enemies and biopesticides
Successful IPM (and organic) strategies hinge around natural enemies. All the insect pests of wheat which neonicotinoids are used to control are known to have natural enemies. The available evidence suggests that an approach based around minimising or eliminating use of broad-spectrum insecticides and other pesticides, reducing damaging operations like ploughing, and providing habitat in the form of margins, hedges, beetle banks etc., will also be successful in encouraging natural enemies, and so increasing natural pest control.

The farmers featured in this report are encouraging natural enemies through a variety of techniques including reduced/more targeted/zero insecticide use, providing a diversity of on-farm habitats through lengthened crop rotations and the creation of non-cropped wildlife habitats, tolerating low levels of pests and weeds in the crop, and practising reduced or zero tillage. Having built up healthy populations of natural enemies, the farmer has to trust these organisms to do their job, resisting the urge to intervene unnecessarily.

More could be done to find out what level of pest control natural enemies can provide and how best to encourage them. Biopesticides are rarely used in arable systems, although research is ongoing to develop cost-effective products against some of these pests.

Crop Varieties and crop husbandry
Orange Wheat Blossom Midge is the only pest for which resistant crop varieties are currently available, although crop resistance is an active area of research for aphids/BYDV and may in future play a role for wireworm.

Choice of crop types and crop varieties is clearly important to the farmers featured in the case studies. Successful IPM and organic farmers design their rotations with pest management in mind. An obvious example is growing OWBM-resistant wheat, but other key decisions include incorporating spring cropping, and avoiding crops in the rotation that are high-risk for a particular area or when pest numbers are known to be high (for example some crops are much more susceptible to wireworm and best avoided when wireworm numbers are high).

Advice on husbandry and cultural control is available for all the pests, but is not always well-evidenced and in some cases conflicts with advice for controlling other pests or for conserving natural enemies. However there is good evidence that minimum/zero tillage is an effective tool to help manage aphids and BYDV. Farmers practising these techniques have had good success with reducing overall insecticide use. Minimum or zero tillage helps to encourage natural enemies and seems to be particularly effective if given time to achieve a balance on the farm – for example slugs may increase at first but should be brought under control without chemicals over time.

Monitoring and thresholds
Monitoring methods and thresholds have been developed for aphids, slugs and OWBM, and attempts are being made to do the same for wireworm. However, these are not always taken up by farmers (especially where the cost of a pesticide treatment is less than the cost of monitoring) and there tends to be a trade-off between the accuracy of a method and how time-consuming and complicated it is to apply. Furthermore, it is not clear to what extent these thresholds take into account effects on populations of natural enemies. For example, farmers are advised to spray a broad-spectrum insecticide against OWBM if numbers reach a certain level, despite the fact that this will also harm populations of the small parasitic wasps which are known to provide effective OWBM control over the long term.

- Farmers making the transition to lower pesticide use may want to consider switching to an independent agronomy contract that pays for advice on a per-hectare basis, with any pesticide purchase dealt with separately.

IPM works best as a package. Farmers will gain some benefits from adopting some of the individual techniques but a truly successful IPM approach involves using the full range of techniques in combination. For example, natural enemies require habitat and resources all year round and an absence of damaging practices such as ploughing and spraying. Providing for only some of their needs – for example creating flower-rich margins but maintaining a hostile environment within the crop itself – is less likely to result in improved pest control.

What further research and action is needed?

As described above, there are many actions that farmers can currently take, and many are already taking, to effectively manage pests without neonicotinoids and while reducing overall pesticide use.

The success of different approaches will vary from farm to farm and year to year. But as knowledge increases and is shared significant progress towards low pesticide use on all farms should be possible. Individual farmers (such as those featured in the current report) with in-depth knowledge, the drive to innovate and the willingness to share their experience with others are crucial to the overall progress of the farming industry. This experience should be shared and drawn on by the industry and research institutions.

There are also actions that organisations such as AHDB, government, research institutions and funding bodies need to take to further the state of knowledge and facilitate the uptake of IPM and organic approaches by more farmers. The need for more research and development into non-chemical alternatives was recently highlighted by the National Farmers Union in relation to the neonicotinoids restrictions on oilseed rape with NFU vice-president Guy Smith stating that “We desperately need more R&D into non-chemical solutions.” (Farmers Weekly, 16 November 2016).

Independent Advice

A common theme to emerge from the case studies was that the advice farmers receive from agronomists and elsewhere is not always independent or impartial. Advice is often biased towards greater reliance on pesticides. Sometimes this is because the advisor has a vested interest in increasing pesticide sales. Sometimes it is simply because of a strongly risk-averse culture: agronomists and farmers often prefer to apply an insecticide ‘just in case’, even if it turns out to be unnecessary, rather than wait and see if a problem develops. This effect is strengthened by the low monetary cost of many insecticides and the fear of losing all or part of a crop.

For many farmers who are currently following a typical strategy based on pesticides, a switch to a genuine IPM strategy could include significant changes in approach and attitude (such as tolerating increased pest presence in the crop), and the confidence to stick with a new approach long enough to realise its benefits: experience shows that, even once a benign management regime has been adopted, it can take several years for beneficial organisms to build up to levels where they provide effective pest control. Farmers will need support to have the confidence to make these changes.

Farmers will benefit from accessing existing information about alternatives to pesticides including training sessions and conferences; online discussions and industry advice such as the information sheets produced by AHDB. Peer-to-peer communication between farmers is important in particular to provide the confidence to try innovative techniques. Such communication can be fostered through a variety of means including farmer-led conferences (such as Groundswell, the minimum-tillage conference hosted by John Cherry), online discussion platforms such as The Farming Forum and Agrichat, and specialist programmes such as the Nuffield Farming Scholarships.

But given that agronomists are such a key source of information to farmers there is a clear need for more independent on-farm advice to be readily available to farmers and separated from pesticide purchases.

Support to farmers

The evidence in this report has shown the importance of providing a variety of habitat on farms to encourage natural enemies. Environmental Stewardship schemes have been an important source of funding for some of this habitat provision. As the UK leaves the EU it will be important to ensure that whatever system of funding that replaces CAP supports farmers to create habitat on farms that encourages natural predators. This should be recognised as a useful contribution to pest control as well as providing much needed havens for wildlife.

Consideration should also be given to how public funding and policy could be used to support farmers to make the transition to IPM. Changing a farming system involves an element of financial risk. There seems to be little or no immediate economic incentive for farmers or agronomists to reduce pesticide use even though it would deliver benefits in the longer term. Some farmers suggest that a support scheme that helped farmers reduce the financial risks of switching to a low or zero pesticide system, while providing scientific evidence to farmers of the long-term benefits of such systems and the best way to realise these benefits, could be an effective way to overcome the barriers to change (e.g. Andrew Barr, East Lenham Farm, October 2016, personal communication).

Research

In the past the availability of cheap pesticides has perhaps made research into alternatives seem less urgent to the farming industry and research institutions, even though there have long been good reasons to carry out such research to reduce farming's environmental impact. Now, with chemicals being withdrawn as evidence of their negative impacts increases there is growing recognition of the need to increase research into non-chemical approaches (Farmers Weekly, 6 September 2016 and 16 November 2016, AHDB research review 2016). With the need for farmers to find alternatives combined with the need to reverse biodiversity decline on farmland it would make sense for Government agricultural research budgets to support such work. In particular, further research in the following areas would help farmers find effective alternatives to pesticides:

- Develop non-GM wheat varieties with improved tolerance and resistance to key pests and diseases, especially BYDV.

- Ensure that research and advice on spring crops (for example development of new varieties, pest monitoring alerts, AHDB fact sheets) keeps pace with that on winter crops. In recent years the focus has shifted largely on to winter crops, but given that increasing numbers of farmers are turning to spring crops there is a clear demand for agronomic support focused on them.

- Conduct farm trials of techniques that have shown promise in laboratory or field trials. These include bi-cropping winter wheat with clover to reduce aphid infestation; use of brassica cover-crops against wireworm; sowing at higher seed rates to counteract slug damage; and swapping out ryegrass in favour of other grass species in margins etc. to reduce OWBM incidence.

- Continue to research and quantify the role of natural enemies and develop and promote effective methods to encourage them in real farm situations.

- Refine advice on slug control. Current advice does not appear to be well-evidenced and risks making problems worse in the long-term by harming the natural enemies of slugs. Slug pellets are not being used efficiently, and are causing water quality problems. The research needs include a better understanding of the relationship between slug presence and actual yield loss under various agronomic conditions; and the potential of natural enemies to provide satisfactory control in the absence of pesticides.

- Continue to update and refine monitoring methods and thresholds for key pests according to latest scientific knowledge and farmer experience. Work with farmers to understand and overcome the barriers to applying monitoring and thresholds. Continue to develop national monitoring and forecasting protocols for key pests (along the lines of Aphid News) and make them available to all farmers.

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Information about Friends of the Earth's The Bee Cause campaign can be found at www.foe.co.uk/bees