Factsheet 01/13

Cross sector

Practical measures to prevent and manage insecticide, fungicide and herbicide resistance for horticultural crops

David Talbot, John Atwood, Jude Bennison, Mike Grimmer, Mike Lole and Tim O'Neill, ADAS

This factsheet outlines how the repeated use of insecticides, fungicides and herbicides if not properly managed, can result in the development of resistant pest, pathogen and weed populations. It lists the known cases of resistance that may potentially cause problems in the control of a range of pests, diseases and weeds that commonly occur on horticultural crops in the UK and advises how to prevent resistant strains developing.

Action points

- Inspect and put into quarantine bought-in plant material and obtain a record of the pesticides applied to the plants by your supplier.
- Minimise reliance on chemical pesticides by implementing integrated pest, disease and weed management systems, utilising biological control agents, biopesticides, physically acting pesticides and appropriate cultural techniques where possible.
- Monitor crops thoroughly if using biological pest control agents so that pesticide use can be restricted to 'hot spots' of pest and disease incidence. Figure 1 shows careful crop monitoring.
- Always use pesticides at the label or EAMU recommended rate and spray volume.
- Note and adhere to the information provided on the product label or EAMU covering resistance management strategies.
- Use pesticides from as many different mode of action groups as practical when managing pest, pathogen and weed populations, to minimise resistance selection pressure.
- If using conventional insecticides use sequential applications of individual insecticides from different mode of action groups rather than mixtures of insecticides with different modes of action – mixtures can encourage the development of resistance in pest populations. For fungicides, product mixtures are considered more effective for resistance management than sequential applications of individual actives.
- Do not continue to use pesticide products with a particular mode of action against specific pests, pathogens or weeds where those target organisms are known, or suspected to have, resistance to products with that mode of action.

1. Crop monitoring is an important practice for determining pest levels, as part of an Integrated Pest Management (IPM) strategy

Background

Pests that have multiple generations per season, such as aphids, Thrips and whitefly, are more likely to develop resistance to insecticides than those with a single generation, particularly where selection pressures are high. Many plant diseases including powdery and downy mildews and annual weeds that are problematic in horticultural crops also have multiple generations per year. Selection pressure is greatest when pesticides from one mode of action group are repeatedly applied to achieve control, which may occur when products are used at reduced rates and / or application practice is poor, for instance when foliar sprays do not give good coverage of the plant or target organism. Using insecticide resistance as an example, susceptible individuals will be killed by appropriate applications of insecticides. However, each application selects insects that are less susceptible to the product(s), so over time these will come to dominate breeding populations resulting in a reduction or complete loss of the effectiveness of the insecticide, and of all products with the same mode of action in the target pest. Fungicide and herbicide resistance develops in a similar way, however mutations generally occur more frequently in fungi than in higher organisms and mutant strains may be less susceptible to fungicides. Relying on a small number of fungicide and herbicide groups will change the structure of the pathogen and weed populations; selecting individuals with reduced sensitivity and ultimately leading to resistance.

Chemical groups and mode of action

It is not always straightforward to identify the chemical group of an insecticide, fungicide or herbicide from the product container label. For some newer products, resistance management information is included on the label for guidance. If the chemical group of the product cannot be seen on the label then information on insecticides is available in a downloadable poster on the Insecticide Resistance Action Committee (IRAC) website (www.irac-online.org). Fungicides are classified by mode of action by FRAC (Fungicide Resistance Action Committee). The FRAC Code List© and the FRAC Mode of Action Poster© are downloadable from the FRAC website (www.frac.info/). Herbicides are classified into groups by the Herbicide Resistance Action Committee (HRAC). The HRAC classification of herbicides according to site of action is downloadable from the HRAC website (www.hracglobal.com).

IRAC, FRAC and HRAC are generally regarded as the authoritative classification of insecticides, fungicides and herbicides respectively. Similar information is available in the UK Pesticide Guide which is published annually (see www.bookshop.cabi.org) or on the Liaison website (https://secure.fera.defra.gov.uk/liaison).

It may be useful to note the IRAC, FRAC and HRAC mode of action groups along with the product name, active ingredient and MAPP number on appropriate pesticide records, such as the pesticide store stock records, for reference.

Further historical reports of resistance in the UK including cases of confirmed insecticide resistance both in the UK and overseas are listed in the Arthropod pesticide resistance database by the IRAC. Examples of fungicide resistance in arable crops, and reports of resistance overseas are listed by the Fungicide Resistance Action Group UK (FRAG-UK). Worldwide reports of herbicide resistance in weeds, are listed by the HRAC (http://www.weedscience.org/summary/home.aspx). Reports of resistance to insecticide, herbicide or new fungicide active ingredients in arable crops, resulting in either complete loss of control or gradually declining performance, may provide useful information on insecticides, herbicides or fungicides that are likely to be high risk for resistance development when used on horticultural crops. It is worth noting that horticultural crops generally have fewer active ingredients with authorisations (label recommendations or EAMUs) for use when compared to arable crops e.g. cereals. Resistance prevention strategies are essential as nearly half of the reported cases of fungicide resistance in Europe in recent years have occurred in horticultural crops.

Insecticide resistance

Mechanisms of resistance

According to the IRAC classification, insecticide active ingredients are divided into 28 separate mode of action groups and a catch-all group covering compounds of unknown mode of action. Each group of chemicals works in a different way but they can be broadly categorised as those which affect:

- Nerve and muscle action
- Growth and development
- Metabolism

An example of how a number of apparently different insecticide products share a common mode of action group is presented in Table 1.

Table 1. Example insecticide products in the same IRAC mode of action group (pyrethroids and pyrethrins)

IRAC mode of action group	Product name*	Active ingredient*	MAPP number
3A	Cyperkill 10	Cypermethrin	13157
3A	Decis	Deltamethrin	16124
3A	Clayton Cajole	Esfenvalerate	14995
3A	Warrior	Lambda-cyhalothrin	13857
3A	Spruzit	Pyrethrins	13438

* **The table contains example active ingredients and products; the list is not exhaustive.**

The mode of action group is the most important practical factor to consider when deciding what products to use. For example, when resistance to a specific pyrethroid insecticide (e.g. cypermethrin, IRAC group 3A) occurs, resistance to all other pyrethroids and the related pyrethrins in IRAC group 3A is highly likely. Occasionally, resistance to one group of insecticides can also confer cross-resistance to a different group of insecticides.

Globally, following the introduction of every new group of insecticides, cases of resistance have been reported within two to 20 years in a number of key pest species; the exact time taken being dependent upon the class of insecticide in question, the type of pest and the selection pressure, i.e. the frequency of application, including earlier applications made overseas on any imported plant material.

The mechanism of resistance is the physiological or bio-chemical change that occurs in the pest that enables it to resist the active ingredient applied. Broadly, these usually fall into two categories: a) *enhanced detoxification*, where the insect has developed an enzyme system to break down the insecticide; or b) *altered site of action*, where a genetic mutation has changed the receptor site for the insecticide compound in the insect, in such a way that the insecticide no longer has an effect.

Examples of insecticide resistance

Table 2 lists the main mechanisms of resistance within key pest populations, however, not all resistance mechanisms are necessarily known.

Table 2. Examples of insecticide resistance

Pest species	Resistance mechanism (if recorded)	IRAC mode of action code and chemical sub group	Example active ingredients affected and comments*	Example product**
Aphids - melon-cotton aphid (*Aphis gossypii*)	AChEs, Esterase	1A Carbamates	pirimicarb (all populations in the UK are resistant)	Aphox
	AChEs, Esterase, Oxidase	1B Organophosphates	chlorpyrifos	Dursban WG
	Kdr/super-kdr (knock-down resistance)	3A Pyrethroids	cypermethrin deltamethrin esfenvalerate	Toppel Decis Clayton Cajole
		4A Neonicotinoids***	acetamiprid imidacloprid (resistance to neonicotinoids not yet confirmed in the UK)	Gazelle SG Intercept 70 WG
Aphids - peach potato aphid (*Myzus persicae*)	Enhanced expression of esterase	1A Carbamates	pirimicarb	Aphox
		1B Organophosphates	chlorpyrifos	Dursban WG
	MACE (modified acetylcholinesterase)	1A Carbamates	pirimicarb	Aphox
	Kdr (knock-down resistance)	3A Pyrethroids	cypermethrin deltamethrin	Toppel Decis
		4A Neonicotinoids***	imidacloprid (resistance to neonicotinoids not yet confirmed in the UK, but reduced sensitivity reported)	Intercept 70 WG
Glasshouse whitefly (*Trialeurodes vaporariorum*)		1B Organophosphates	chlorpyrifos	Dursban WG
		3A Pyrethroids	cypermethrin deltamethrin	Toppel Decis
		4A Neonicotinoids	imidacloprid (resistance not yet widespread in UK)	Intercept 70 WG
		9B Pymetrozine	pymetrozine (low levels of reduced susceptibility, cross-resistance with neonicotinoids may become a problem in the future).	Chess WG
Thrips - onion thrips (*Thrips tabaci*)		3A Pyrethroids	deltamethrin	Decis
Thrips - western flower thrips (WFT) (*Frankliniella occidentalis*)		1B Organophosphates	chlorpyrifos	Dursban WG
	Kdr (knock-down resistance suspected)	3A Pyrethroids	cypermethrin deltamethrin	Toppel Decis
		5 Spinosyns	spinosad	Conserve Tracer
		6 Avermectins	abamectin	Dynamec

Pest species	Resistance mechanism (if recorded)	IRAC mode of action code and chemical sub group	Example active ingredients affected and comments*	Example product**
Tomato leaf miner (*Tuta absoluta*), a notifiable quarantine pest in the UK		3A Pyrethroids	deltamethrin (not compatible with IPM thus inappropriate on tomato)	Decis
		6 Avermectins	abamectin	Dynamec
Two-spotted spider mite (*Tetranychus urticae*)	Cholinesterase	1B Organophosphates	chlorpyrifos	Dursban WG
		3A Pyrethroids	deltamethrin	Decis
		6 Avermectins	abamectin (resistance not yet confirmed in the UK)	Dynamec
		10A Clofentezine	clofentezine (resistance not yet confirmed in the UK)	Apollo 50 SC
		21A METI acaricides	fenpyroximate tebufenpyrad	Sequel Masai
		23 Tetronic and tetramic acid derivatives	spirodiclofen spiromesifen (resistance to these actives not yet confirmed in UK)	Envidor Oberon

*** Only active ingredients currently authorised or with Extensions of Authorisation for Minor Use, (EAMU, formerly SOLA) for use in the UK at the time of writing are included. For an up to date full list of active ingredients affected visit www.irac-online.org and download the Arthropod Pesticide Resistance Database (access via teams and resistance database tabs). Where one active ingredient is listed as being affected, in most cases it can be assumed that all actives within that insecticide group will be ineffective where resistant populations exist.**

**** Where more than one active ingredient is affected, an example product is listed for each active in order.**

***** Intense selection pressure may result in more potent resistance to imidacloprid and other neonicotinoids.**

N.B. This table does not list all UK pests (or potential quarantine pests in the UK) with known resistances. Not all UK populations of each pest species will necessarily have the same level of resistance; this will depend on target species, history of pesticide usage and immigration of resistant populations. Further information on current resistance issues in the UK can be found on the UK Insecticide Resistance Action Group (IRAG-UK) website (see www.pesticides.gov.uk/rags_home.asp).

Pest control and avoidance of insecticide resistance

A number of crop management practices will help to prolong the useful life of key insecticides, these include the following:

Bought-in plant material

Where plant material is bought-in there is the potential risk of bringing in resistant pest species. In some situations it is therefore important to place into quarantine such plants to permit detailed crop inspections to be undertaken before new plants are placed alongside other crops. Pesticide application records should also be obtained for bought-in stock both from UK and overseas suppliers. Such information is vital for the planning of Integrated Pest Management (IPM) programmes to ensure no persistent pesticides have been applied that could adversely affect the establishment of biological control agents. The information also helps to plan any further pesticide programmes in order to avoid overuse of insecticide group(s) which may have been involved in the production of the plant material.

Crop hygiene

This should be maintained all year round; production areas should be weed-free, as many weeds can harbour pests. Areas used to raise or hold deliveries of new plants should be cleaned and swept between batches to help prevent pests and other problems carrying over between crops. Unmarketable and infested plants should be placed into covered bins before appropriate disposal, and infested leaves or plants should be removed by hand and placed in sealed plastic bags for disposal. Freshly potted plants should not be placed near to infested crops.

Crop monitoring and pest identification

Regular crop monitoring is essential in order to detect pests before their numbers reach damaging levels, and also to assess the efficacy of any control programme. Suitable methods of crop monitoring include: crop inspections, use of sticky traps and or pheromone traps and inspections of indicator plants within crops. Correct identification of pests, pest damage and biological control agents is essential before deciding to use further control measures, especially in the case of aphids, whitefly and Thrips where the species present determines which control measures are needed. There are a number of publications to aid in the identification of key pests including relevant HDC crop walkers' guides and a range of HDC factsheets. Figures 2-5 show some key pests of protected edible and ornamental crops.

Pesticide spray application

Where an application of an insecticide results in unsatisfactory control, it is important to determine whether the product was applied correctly before assuming that insecticide resistance is an issue. Poor spray coverage can reduce the efficacy of some contact-acting products and coverage can be checked using water-sensitive paper attached to suitable parts of plants within a crop.

Where translaminar or systemic insecticides are used, spray coverage is less crucial, since the insecticide is moved within the leaf (translaminar), or plant (systemic). Such products are particularly useful in dense crops where it is difficult to achieve good coverage. However, the efficacy of systemic products can be reduced when the plant is not actively growing. The insecticide product label will usually indicate if a product has translaminar or systemic activity.

2. **Peach-potato aphid (*Myzus persicae*)**

3. **Glasshouse whitefly (*Trialeurodes vaporariorum*)**

4. **Two-spotted spider mite (*Tetranychus urticae*)**

5. **Western flower thrips (*Frankliniella occidentalis*)**

Pest life stage

Some pests can be easier to control with chemical pesticides at certain stages in their life cycle, therefore optimum timing of pesticide application can be important. Specific pesticides with ovicidal properties are needed to kill insect or mite eggs. Eggs of some pests (e.g. Thrips) can be laid inside plant tissue and therefore cannot be reached by contact-acting pesticides. Some species of leafminer, moth and Thrips pupate in the soil or substrate, so are not controlled by foliar-applied insecticides.

Some insect pests are also physically protected in some way, for example some aphid species, mealy bugs and scale insects are covered in wax. This barrier can shield the insects from contact-acting insecticide sprays. Such adaptations should not be confused with resistance as these pests are often controlled using the addition of an appropriate wetting agent to the contact insecticide or by the use of a suitable systemic insecticide.

Fungicide resistance

Mechanisms of resistance

According to the FRAC classification, fungicides active ingredients are divided into 11 mode of action groups and a further two groups where the mode of action is either unknown or unclassified. Mode of action groups are split into a further 68 FRAC codes.

An example of how a number of apparently different fungicide products share a FRAC code is presented in Table 3.

Table 3: Example fungicide products in the same FRAC group

FRAC code	Product name*	Active ingredient	MAPP number
11	Amistar	azoxystrobin	10443
11	Stroby WG	kresoxim – methyl	08653
11	Vivid	pyraclostrobin	10898

How resistance occurs

Where fungicide resistance occurs within a FRAC code (e.g. Amistar, FRAC code 11), resistance to other fungicides with a FRAC code of 11 is highly likely. Therefore a fungicide's FRAC code is one of the most important factors to consider when deciding which fungicide to use, particularly when planning fungicide programmes. This is important where target pathogens such as Botrytis / powdery mildews have multiple generations per season and thus have the potential for mutant strains to build-up; resulting in fungicide resistance.

Background

Fungicide resistance has been a problem in horticultural crops since the introduction of systemic fungicides in the 1970s. Once a resistant pathogen strain emerges, its frequency increases within the pathogen population due to the selection pressure imposed by fungicide use. Resistant pathogen strains may be identified through monitoring studies or resistance may first be recognised when disease control problems occur in practice. The identification of a resistant strain does not necessarily indicate impending control problems, since the strain may carry a fitness penalty that slows the increase in frequency. For example, the resistant pathogen strain may be less able to survive extremes of temperature. Resistance may result in a rapid, complete loss in disease control (with certain cases of resistance to the benzimidazole, strobilurin and phenylamide mode of action groups) or a more gradual shift in fungicide efficacy may occur (with certain cases of resistance to triazoles and dicarboximides). Cross-resistance, whereby a pathogen strain is resistant to some or all fungicides within a mode of action group, is a common occurrence.

Fungicides with single-site modes of action against the pathogen, such as strobilurins (e.g. azoxystrobin) and triazoles (e.g. tebuconazole), are known to be at higher risk of fungicide resistance than fungicides with multi-site modes of action (e.g. chlorothalonil). In many cases of resistance, a single genetic mutation of the fungicide target in a pathogen strain is sufficient to cause control problems with a single-site fungicide. In other cases, a single mutation may cause a small shift, and secondary mutations may further contribute to a loss in fungicide efficacy. A further known mechanism of resistance is over-expression of the fungicide target protein within a pathogen strain. Strains of *Botrytis cinerea* (grey mould) with multiple drug resistance (MDR) have been detected on grapevines in France and Germany. It is reported that these strains have broad-spectrum resistance due to increased ability to transport chemicals out of fungal cells. The implications for control of *Botrytis cinerea* (which affects a wide range of horticultural crops) in the UK are currently unclear.

Examples of fungicide resistance

Reports of fungicide resistance on horticultural crops in the UK are shown in Table 4. In addition, resistance has been reported in *Botrytis cinerea* on a wide range of crops to fungicide groups; benzimidazoles – carbendazim e.g. Ringer, dicarboximides – iprodione e.g. Rovral WG and anilinopyrimidines – pyrimethanil e.g Scala.

Examples of fungicide resistance relevant to UK horticulture include the fungicide metalaxyl-M used for downy mildew control on a wide range of edible and ornamental crops. For example, many isolates of impatiens downy mildew tested in 2011 were found to be resistant to metalaxyl-M. On lettuce, difficulties in controlling downy mildew due to the emergence of pathogen strains that can break down resistance of newly bred varieties, is further confounded by development of strains that are resistant to metalaxyl-M. With the strobilurin (QoI) fungicides, examples of resistance include isolates of chrysanthemum white rust and cucumber gummy stem blight with reduced sensitivity to azoxystrobin.

Table 4. Examples of fungicide resistance

Crop	Pathogen	Disease	FRAC mode of action code and chemical sub group*	Example active ingredients affected**	Example product
Apple	*Venturia inaequalis*	Scab	3 Triazoles	myclobutanil	Systhane 20 EW
			1 Benzimidazoles	Not currently authorised on this crop	N/A
			U12 Guandines	dodine	Radspor FL
	Gloeosporium spp.	Fruit rot	1 Benzimidazoles	Not currently authorised on this crop	N/A
	Penicillium expansum	Fruit rot	1 Benzimidazoles	Not currently authorised on this crop	N/A
	*Phytophthora syringae****	Fruit rot	4 Phenylamide	metalaxyl-M	Fubol Gold WG
Blackberry	*Septocyta rubrum*	Purple blotch	M1 Inorganic	copper	Cuprokylt
Brassicas	*Peronospora parasitica****	Downy mildew	4 Phenylamide	metalaxyl-M	SL 567A
	Mycosphaerella brassicicola	Ring spot	1 Benzimidazoles	Not currently authorised on this crop	N/A
Celery	*Septoria apiicola*	Leaf spot	1 Benzimidazoles	Not currently authorised on this crop	N/A
Chrysanthemum	*Puccinia horiana*	White rust	3 Triazole	myclobutanil	Systhane 20 EW
			11 Oximino acetates (strobilurins)	kresoxim methyl	Stroby WG
			5 Morpholine	Not currently authorised on this crop	N/A
Clematis	*Phoma clematidina*	Wilt	1 Benzimidazoles	Not currently authorised on this crop	N/A
Cucumber	*Penicillium oxalicum*	Stem rot	1 Benzimidazoles	Not currently authorised on this crop	N/A
	Didymella bryoniae	Black stem rot	1 Benzimidazoles		
			2 Dicarboximides	iprodione	Rovral WG
	Sphaerotheca fuliginea	Powdery mildew	8 Hydroxy – (2mino-) pyrimidines	bupirimate	Nimrod
			1 Benzimidazoles	Not currently authorised on this crop	N/A
			3 Imidazoles	imazalil	N/A
			3 Pyrimidines	fenarimol	N/A
Dianthus (Pinks)	*Fusarium culmorum*	Stub rot	1 Benzimidazoles	Not currently authorised on this crop	N/A

Crop	Pathogen	Disease	FRAC mode of action code and chemical sub group*	Example active ingredients affected**	Example product
Impatiens	*Plasmopara obducens****	Downy mildew	4 Phenylamide	metalaxyl-M	Fubol Gold WG
Leek	*Phytophthora porri****	White tip	4 Phenylamide	Not currently authorised on this crop	N/A
Lettuce (field)	*Bremia lactucae****	Downy mildew	4 Phenylamide	metalaxyl-M	Fubol Gold WG
Lettuce (protected)	*Bremia lactucae****	Downy mildew	4 Phenylamide	metalaxyl-M	Fubol Gold WG
	Phoma exigua var. exigua	Leaf rot	2 Dicarboximide	iprodione	Rovral WG
	Rhizoctonia solani	Basal rot	2 Dicarboximide	iprodione	Rovral WG
			14 Aromatic hydrocarbons	tolclofos-methyl	Basilex
Lily	*Botrytis elliptica*	Leaf rot	1 Benzimidazoles	Not currently authorised on this crop	N/A
Lobelia	*Alternaria alternata*	Leaf and stem rot	2 Dicarboximide	iprodione	Rovral WG
Narcissus	*Fusarium oxysporum*	Basal rot	1 Benzimidazoles	thiabendazole	Storite Clear Liquid
	Penicillium spp.	Bulb rot	1 Benzimidazoles		
Tomato	*Didymella lycopersici*	Stem rot	1 Benzimidazoles	Not currently authorised on this crop	N/A
	Erysiphe sp.	Powdery mildew	3 Pyrimidines	fenarimol	N/A
Watercress	*Pythium* spp.***	Root rot	4 Phenylamide	metalaxyl-M	SL 567 A

Source: FRAG-UK (list available online at http://frag.csl.gov.uk)

*** Intense selection pressure may result in more potent resistance to various fungicides within individual FRAC codes.**

**** Only active ingredients currently authorised or with Extensions of Authorisation for Minor Use, (EAMU, formerly SOLA) for use in the UK at the time of writing are included. For an up to date full list of active ingredients affected visit www.frac.info and look under the 'What's new' section on the homepage. Working groups meeting minutes and updated use recommendations collate and give an up to date picture on the resistance status effectiveness of various types of fungicide, following the recommendations help to achieve the best possible result.**

***** Different species of pathogens can develop resistance to a chemical sub group. This must be borne in mind when planning control strategies.**

In recent years, a number of succinate dehydrogenase inhibitor (SDHI) fungicides have emerged onto the crop protection market. 'First generation' SDHI fungicides (e.g. carboxin) were discovered more than 40 years ago and typically had a narrow spectrum of activity. Newer SDHI fungicides (e.g. boscalid, co-formulated with pyraclostrobin in the horticultural fungicide Signum) tend to have a broader spectrum of activity. SDHIs are however single-site fungicides and therefore considered to be at risk from resistance development. SDHI resistance has already been reported overseas in a number of diseases of horticultural crops (Table 5), with a number of causal target-site mutations identified. Examples of crops and diseases where resistance has been found are shown in Figures 6-9.

Table 5. Overseas reports of SDHI resistance in horticultural crop diseases

Crop	Pathogen	Disease
Asparagus	*Stemphylium vesicarium*	Purple spot
Cucurbits	*Didymella bryoniae*	Black stem rot
	Podosphaera xanthii	Powdery mildew
Lily	*Botrytis elliptica*	Leaf rot
Pistachio	*Alternaria alternata*	Leaf rot
Various	*Botrytis cinerea*	Grey mould

Source: Fungicide Resistance Action Committee (www.frac.info)

6. **Powdery mildew is a pathogen with the ability to develop resistance rapidly, thus needs managing proactively**

7. **Many isolates of Impatiens downy mildew tested in 2011 were resistant to metalxyl-M**

8. **Purple spot on asparagus has had reports of resistance to succinate dehydrogenase inhibitor (SDHI) fungicides**

9. **Planning spray programmes with different modes of action will reduce the chance of developing resistance**

Disease control and avoidance of fungicide resistance

Integrated Crop Management (ICM) plays a role in reducing the need to apply as many fungicides to a crop, particularly in protected cropping. ICM techniques that help to limit the impact of fungal diseases include ensuring sufficient spacing between crops, increasing air movement through the use of fans helps to dry foliage after overhead irrigation and to disperse humidity. Irrigating crops early in the day helps to minimise periods of leaf wetness, thus limiting disease pressure. Humidity management through heating and venting effectively eliminates diseases in some crops (such as blight in protected tomatoes). Whilst it is more difficult to control the crop production environment in field grown crops, cultural methods such as pruning out wood infected with scab or over wintering powdery mildew in apples during winter helps to reduce disease pressure the following season. Applying overhead irrigation to field crops early in the day to prevent the crop sitting wet overnight also helps to reduce disease pressure.

Regular crop monitoring, pathogen identification and detection, disease forecasting and decision support systems can be used to ensure that fungicides are only applied when the pathogen is present and when conditions are conducive for disease development. There are a number of publications to aid in the identification and management of key diseases including the HDC crop walkers' guides and a wide range of HDC factsheets.

A range of crop management strategies can be used by growers to reduce the risk of fungicide resistance development. Repeated applications of single-site fungicides within the same mode of action group represent a high risk of resistance development. To minimise the risk, growers should use fungicides from other modes of action in mixtures or sequence, and make use of multi-site modes of action (e.g. chlorothalonil, mancozeb) where possible. Active ingredients that are high risk for resistance development are often co-formulated with multi-site actives in order to reduce resistance risk. Manufacturers may provide guidelines for use of these products, for example suggesting maximum numbers of applications in a single season; it is essential that such recommendations are followed.

Overall effective doses of fungicides should be maintained, although unnecessary prophylactic fungicide use should be avoided. Where fungicide seed treatments are used, the contribution to the resistance risk should also be considered. The implementation of ICM systems represents an alternative method of disease control that allows for reduced fungicide use. Examples of ICM include the use of disease-resistant varieties and biopesticide use to reduce disease levels, where available. Disease pressure should be minimised through cultural practices such as use of clean seed or planting material, crop rotation, crop hygiene including disposal of primary inoculum sources such as plant debris, soil disinfestation and general hygiene techniques such as tool disinfection.

Where an application of a fungicide results in unsatisfactory control, it is important to determine whether the product was applied correctly, prior to assuming that fungicide resistance is an issue. Thorough spray coverage can be difficult to achieve for some horticultural crops where plants are large with dense foliage (e.g. asparagus). Specialist spray equipment may be required to ensure effective fungicide application and satisfactory levels of control.

Herbicide resistance

Mechanisms of resistance

According to the WRAG (Weed Resistance Action Group) classification, herbicides active ingredients are divided into 14 groups (A – N) by mode of action. Using herbicides from as many different herbicide groups (with different modes of action) as possible will help to prevent the onset of herbicide resistance.

An example of how a number of apparently different herbicide products belong to the same group and thus have the same mode of action is shown in Table 6.

Table 6: Example herbicide products in the same group (A)

WRAG	Product name*	Active ingredient*	MAPP number
A	Fusilade Max	Fluazifop-P-butyl	11519
A	Falcon	Propaquizafop	14555
A	Laser	Cycloxydim	12930
A	Aramo	Tepraloxydim	10280

***The table contains example active ingredients and products; the list is not exhaustive**

Crop safety and product authorisations limit which herbicide groups can be used on individual crops. Over-reliance on one class of herbicide with a specific mode of action can lead to the development of resistance in weeds that were previously susceptible. Table 7 shows the types of herbicide resistance in weeds that occur in horticulture.

The problem of herbicide resistant weeds is of major importance globally and of increasing significance in UK arable crops. By contrast relatively few new cases have been encountered in UK horticulture since the widespread occurrence of triazine resistance in groundsel from the 1980s onwards. Following the withdrawal of simazine in 2007 this resistance is of less importance now, although a legacy of cross-resistance to triazinone herbicides could still pose difficulties (see below).

Table 7. Examples of herbicide resistance

Weed species*	Resistance mechanism	How resistance occurs	HRAC group code and chemical family**	Example active ingredients***	Example product
Grass weeds	Enhanced metabolism resistance (EMR)	Results in herbicide detoxification and is the commonest resistance mechanism in grass weeds in the UK. It affects most herbicides to varying degrees but only in severe cases results in complete loss of control. Tends to increase slowly.	All herbicide groups and chemical families may be affected.	Can occur in any chemical group. There is no known resistance to propyzamide to date.	Many products including Stomp Aqua
Grass weeds	ACCase target site resistance (ACCase TSR)	Blocks the site of action specific to 'fop' (e.g. Fusilade) and 'dim' (e.g. Laser) herbicides in grass weeds. It only affects these groups of herbicides, but can result in very poor control. Can increase rapidly.	A Aryloxyphenoxy-propionates ('fops') and A Cyclohexanediones ('dims')	fluazifop-P-butyl and cycloxydim	Fusilade Max and Laser
Grass and broadleaf weeds	ALS target site resistance (ALS TSR)	Blocks the site of action of sulfonylurea and related herbicides in grass and broad-leaved weeds. It only affects this group of herbicides but can result in poor control. Currently less common than ACCase TSR, but is increasing.	B Sulfonylureas	flazasulfuron	Chikara
Senecio vulgaris (Groundsel)	Photosystem II inhibitor C1 target site resistance (PS II C1 TSR)	Blocks the site of action of triazine and sometimes the related triazinone herbicides. It only affects this group of herbicides but can result in complete failure of control. Weeds with this resistance may be less fit to compete in general populations but can increase rapidly.	C1 Triazinones	metamitron and metribuzin	Goltix and Sencorex

For further information see www.pesticides.gov.uk/rags_home.asp

*** Intense selection pressure may result in more potent resistance to various herbicides.**

**** Where resistance occurs within a HRAC group code all active ingredients within that code may be affected.**

***** Only active ingredients currently authorised or with Extensions of Authorisation for Minor Use, (EAMU, formerly SOLA) for use in the UK at the time of writing are included. For an up to date full list of active ingredients affected visit www.hracglobal.com and download the mode of action (MoA) classification. Where one active ingredient is listed as being affected, in most cases it can be assumed that all actives within that insecticide group will be ineffective where resistant populations exist.**

Examples of herbicide resistance

Figures 10-13 show examples of resistance issues and potential management options. The main problems currently encountered in UK horticulture are:

Black-grass in soft fruit and vegetable crops

Although not such a problem in horticultural as in arable production, black-grass is increasingly found in a range of vegetable and fruit crops. Many black-grass populations are now resistant to the selective grass herbicides approved in horticultural crops (typically fluazifop-P-butyl (e.g. Fusilade Max) or cycloxydim (Laser)) thus limiting the scope for spot treatment control of grasses in these crops. Fortunately many of the pre-emergence residual herbicides used in horticulture (e.g. propyzamide (e.g. Kerb Flo), napropamide (e.g. Devrinol), s-metolachlor (e.g. Dual Gold)) are still effective for the control of resistant black-grass. However it is necessary to anticipate the problem and ensure that adequate residual herbicide cover is maintained. In addition to black-grass, resistant populations of wild oats and perennial rye grass also can occur.

Canadian fleabane in fruit and nursery crops

Canadian fleabane is a widespread problem in amenity and industrial landscapes where weed control is maintained largely by repeated applications of glyphosate (e.g. Roundup Biactive) to which most populations are largely resistant. It mainly thrives in areas where the ground is left undisturbed and can build up in fruit plantations and non-cropped areas around nurseries. It readily germinates during the summer when spring applied residual herbicides may have reduced effectiveness. At present Canadian fleabane is an occasional problem in fruit and nursery crops but has the potential to increase. Many of the residual herbicides used in fruit and nursery stock have only partial efficacy; isoxaben (e.g. Flexidor 125), napropamide (e.g. Devrinol), oxadiazon (e.g. Ronstar Liquid) and herbicides with stronger efficacy such as metazachlor (e.g. Butisan S) are now limited in use for environmental reasons. At present flazasulfuron (e.g. Chikara Weed Control, used in non-cropped area) gives control but resistance to flazasulfuron has been reported in continental Europe so this may only be a short-term solution. Where directed contact herbicide applications are possible glufosinate-ammonium (e.g. Harvest) can work better than glyphosate.

Groundsel in fruit, nursery and asparagus crops

Triazine resistant groundsel was a widespread problem in all fruit crops from the 1980s until the withdrawal of most triazine herbicides in 2007. The true extent of triazine resistance in the UK is currently unknown as, with the exception of terbuthylazine (only available in co-formulations e.g. Bullet XL) these herbicides are not widely used. However because of the lack of residual herbicides effective against groundsel, some closely related triazinone herbicides are increasingly being used in horticultural crops (particularly perennial crops) where the ground is generally uncultivated e.g. fruit, field nursery stock and asparagus crops. A case of groundsel resistant to metamitron (e.g. Goltix Flowable) has already been recorded in asparagus in the UK and it is known that there is potentially cross-resistance between triazine and triazinone herbicides. Therefore there is a potential risk in relying solely on herbicides such as metamitron and metribuzin (e.g. Sencorex WG) (both of which are triazinone herbicides) for groundsel control.

Shifts in weed populations

There have been numerous cases where repeated use of a single or limited range of herbicides in cropping on the same site or within a tight rotation has led to the development of a particular weed flora. Where this occurs susceptible weeds are controlled by the herbicides that are used, however weed species that are not susceptible to the herbicides used can dominate the weed population as they are effectively selected out. The following are typical examples:

Pearlwort in container nursery stock production

Oxadiazon (Ronstar 2G) is the only active ingredient available as a granule formulation for use in container-grown nursery stock. Its crop safety and good weed control spectrum have led to its universal adoption. However, oxadiazon does not control species such as pearlwort, and common and mouse ear chickweed. The use of oxadiazon as the sole or predominant herbicide invariably leads to a build up of pearlwort in the pots and standing beds. These can be difficult weeds to control but the use of alternative herbicides such as isoxaben over the crop and flazasulfuron or terbuthylazine around the bed edges will help.

N.B Oxadiazon: Growers can use this product until 30 June 2015.

10. Many black-grass populations are now resistant to selective grass herbicides

11. Canadian fleabane (*Conyza canadensis*) readily colonises non cropped areas and should not be allowed to set seed

12. Perennial nettles provide a useful source of beneficial insects early in the year such as Anthocorid bugs and ladybirds, which contribute to pest control. Nettle aphids will not feed on crops

13. Forward planning is essential when sterilising soil to reduce disease and weed pressure which can help to reduce pesticide use

Shepherd's purse in lettuce production

There are a limited number of herbicides approved for use in lettuce and propyzamide (e.g. Kerb Flo) is widely used. Where rotations are close and propyzamide is used exclusively, spring germinating weeds such as shepherd's purse tend to build up because it is not controlled by propyzamide. Alternative herbicides such as pendimethalin (e.g. Stomp Aqua) and chlorpropham (e.g. Intruder) only offer partial control. Other cultural methods such as a stale seed bed prior to planting may be effective.

Weed control and avoidance of herbicide resistance

Where possible use cultural controls to reduce reliance on herbicides; make full use of cultural control measures (such as stale seed bed, cultivations) to control resistant weeds and reduce reliance on herbicides. Where it is cost effective to do so consider cultivating, hand-weeding, or the application of directed contact herbicide sprays to prevent resistant weeds setting seed. Cultivations are only appropriate when the soil is dry, however extra cultivations may contribute to increased soil erosion on sands/silts with a poor structure. Weed cover can be managed on sloping sites (by regular topping or mowing) to prevent weeds setting seed whilst the weed cover protects the soil preventing soil erosion. Flaming weeds is another option to consider in non cropped areas, there are also inter row flamers available for use in row crops which may be an alternative when the soil is too wet for inter row cultivations. Crop rotation in annual crops facilitates the use of a different range of herbicides in some production systems, so plays a part in helping to prevent the onset of herbicide resistance, although non target site cross resistance to different herbicides remains a threat for certain weeds (e.g. black-grass).

Where possible do not rely solely on one herbicide or class of herbicides, but use mixtures of products or change the programme from year to year. It is important to monitor herbicide performance in different fields to provide an early warning of potential problems ahead. If unexpected, poor control is experienced consider testing weed seeds from problem fields for herbicide resistance. It is important not to allow resistant weed populations to set seed which will make the problem worst.

Further information on herbicide resistance can be found on the website of the Weed Resistance Action Group (WRAG), see www.pesticides.gov.uk/guidance/industries/pesticides/advisory-groups/Resistance-Action-Groups/wrag

Resistance testing

Where cases of resistance are suspected growers are advised to visit the websites of the relevant resistance action group for up to date information on testing services.

Links to all the resistance actions groups can be found on the HSE website www.pesticides.gov.uk/rags_home.asp.

Further information

Information and advice on pesticide programmes designed to be at low risk of selecting resistant strains of pests or pathogens on specific pest and disease problems is given in many HDC factsheets (www.hdc.org.uk).

Information on the classification of pesticides by mode of action group, which it is essential to know when designing a control strategy, is regularly updated on the following websites:

IRAC
www.irac-online.org

IRAG
www.pesticides.gov.uk/guidance/industries/pesticides/advisory-groups/Resistance-Action-Groups/irag

FRAC
www.frac.info

FRAG-UK
http://frag.fera.gov.uk

WRAG
www.pesticides.gov.uk/guidance/industries/pesticides/advisory-groups/Resistance-Action-Groups/wrag

Useful information on pesticides and their mode of action can also be found at:

The Liaison website
https://secure.fera.defra.gov.uk/liaison.

The UK Pesticide Guide
www.plantprotection.co.uk.

HGCA
www.hgca.com

Potato Council
www.potato.org.uk

Acknowledgements

HDC is grateful to Dr Stephen Foster (Rothamsted Research) and Kevin Gorman (formerly of Rothamsted Research) for sharing their knowledge and experience with the authors.

Image copyright

All images (apart from image 5) are courtesy and copyright of ADAS UK Ltd.

Image 5 is courtesy and copyright of Nigel Cattlin FLPA.

While the Agriculture and Horticulture Development Board, operating through its HDC division, seeks to ensure that the information contained within this document is accurate at the time of printing, no warranty is given in respect thereof and, to the maximum extent permitted by law, the Agriculture and Horticulture Development Board accepts no liability for loss, damage or injury howsoever caused (including that caused by negligence) or suffered directly or indirectly in relation to information and opinions contained in or omitted from this document.

© Agriculture and Horticulture Development Board 2013. No part of this publication may be reproduced in any material form (including by photocopy or storage in any medium by electronic means) or any copy or adaptation stored, published or distributed (by physical, electronic or other means) without the prior permission in writing of the Agriculture and Horticulture Development Board, other than by reproduction in an unmodified form for the sole purpose of use as an information resource when the Agriculture and Horticulture Development Board or the HDC is clearly acknowledged as the source, or in accordance with the provisions of the Copyright, Designs and Patents Act 1988. All rights reserved.

£8.75
where sold

HDC is a division of the Agriculture and Horticulture Development Board (AHDB).

AHDB Agriculture & Horticulture DEVELOPMENT BOARD

Horticultural Development Company

Stoneleigh Park
Kenilworth
Warwickshire
CV8 2TL

T: 024 7669 2051
E: hdc@hdc.org.uk
Twitter: @HDCtweets

www.hdc.org.uk