Guidelines for minimising the risk of glyphosate resistance in the UK

June 2015

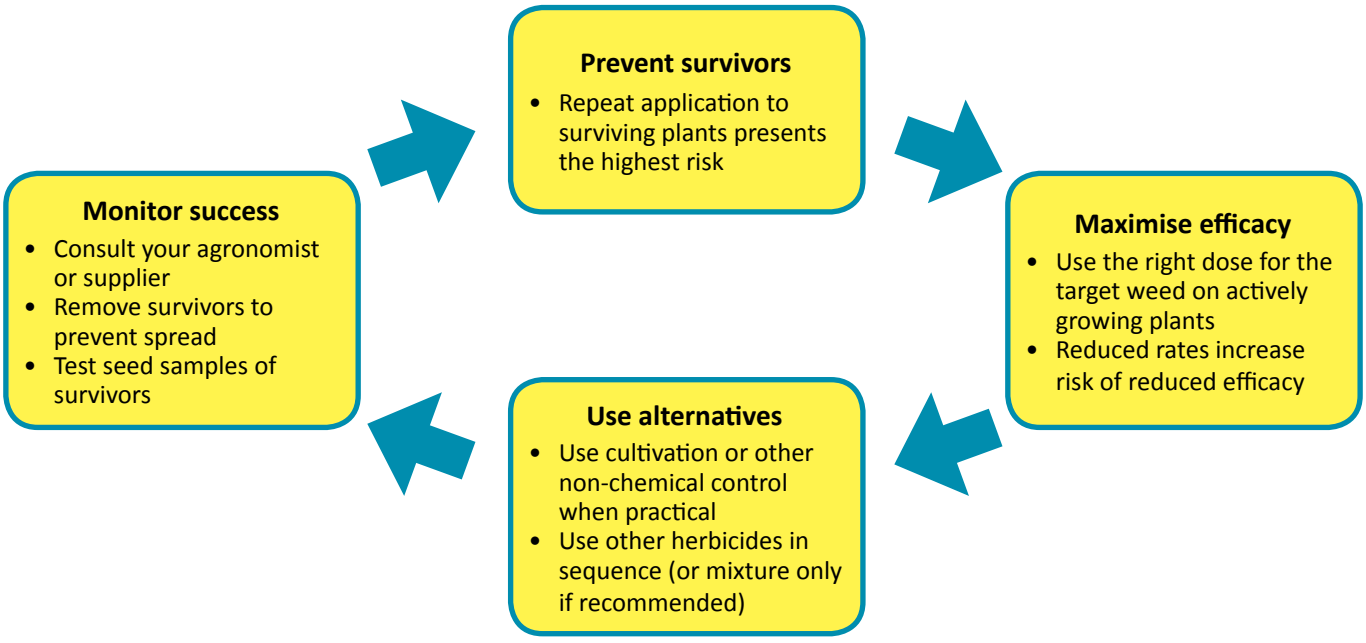
The herbicide glyphosate has been commercially available for 40 years. It is one of the most frequently used herbicides in the UK in all crop production systems, including annual and perennial crops, and non-cropped areas. There are currently **no known cases of glyphosate resistance in the UK**, however, globally, resistance to glyphosate has evolved as a result of repeated use and over-reliance.

Current changes in usage patterns in the UK are potentially increasing the risk of glyphosate resistance development. An over-reliance on a limited group of herbicide modes of action has accelerated the development of herbicide-resistant grass weeds, particularly black-grass (*Alopecurus myosuroides*). This has been mainly due to a lack of new herbicides, regulatory policy changes, a limited crop rotation and the under-exploitation of cultural control practices.

The main threats of resistance to glyphosate in the UK are in:

1. **Annual arable crops**, especially where it is used to control grass weeds that exhibit resistance to many selective herbicides;
2. **Perennial crops and amenity use**, where it is used on annual and perennial weeds where few alternative modes of action are available.

Reducing the risk of glyphosate resistance



Specific risks of glyphosate resistance can be summarised as:

Agronomic factor	Higher risk	Lower risk
Cropping system	Continuous monoculture or perennial crops	Varied rotation- winter and spring cropping
Cultivation	None or insufficient to kill weeds	Thorough disturbance to kill weeds
Weed infestation level	High	Low
Control method	Glyphosate only	Mixed use of glyphosate with effective use of other modes of action and cultural control
Number of glyphosate applications pre-drilling	More than two applications and no cultivation	Fewer than two applications and sufficient cultivation
Target weed size for glyphosate dose	Weeds too large for dose rate; reduced or less-effective dose rates used	Weeds at correct growth stage; full and effective dose rates used

Maximising the efficacy of glyphosate

To maximise efficacy spray at the **right dose rate**, at the **right growth stage** and in the **right conditions**. Further detail can be found below but in brief ideal conditions are:

Dose rate: Get dose rate right for the weed and growth stage. Annual grasses typically require 540 g a.i./ha for seedlings up to 6 tillers and 1,080g a.i./ha when flowering.

Growth stage: Ideally, spray when plants are at least 5cm but before the start of rapid stem extension. Apply prior to 'shading' from other plants.

Conditions: Apply to actively growing plants, in warm conditions (15-25ºC), with at least 6 hours before any rainfall.

Choice of nozzles, water volume and the addition of water conditioner can also be influential.

Managing the risk of glyphosate resistance development

Annual weeds in annual crops

Key species at risk: Black-grass and Italian rye-grass.

Glyphosate applied prior to drilling a crop is an effective weed control option, but it needs to be used sensibly.

- Maximise efficacy of glyphosate to reduce the number of survivors
- Use the manufacturers recommended dose rate for the weed sizes present
- Avoid repeat applications of glyphosate to the same (surviving) weeds
- Supplement glyphosate use with sufficient cultivation to kill survivors and effective subsequent herbicides (pre- and post-emergence)
- Monitor the success of control strategies carefully and frequently
- Remove survivors to reduce seed spread
- Report suspected survivors to your crop protection adviser and/or the product manufacturer

Based on current understanding, two applications of glyphosate, with sufficient cultivation to kill survivors and effective subsequent herbicide use, is likely to be a manageable risk. Multiple applications in the absence of sufficient cultivation should be avoided.
Application of glyphosate within crops, such as between crop rows through shrouded sprayers, presents an increased risk of resistance developing in survivors that will need careful management.

Adjuvant use is often associated with use of reduced rates of glyphosate products. Unless specifically recommended on glyphosate product labels we suggest extreme caution should be taken as any reduction in efficacy could increase the risk of resistance development.

A single pre-harvest application of glyphosate per crop should not increase the risk of resistance development unless there are survivors present from prior glyphosate applications.

Further details can be found below.

Perennial crops and amenity areas

See 'Herbicide Resistance in Amenity Weed Control Situations' for more information)

- Avoid over-reliance on a single herbicide (e.g. glyphosate). Use mixtures of herbicides whenever possible
- Consider non-chemical control measures (e.g. hand weeding, cutting, flaming, steam treatments) as a supplement or alternative to herbicide treatment
- Monitor and assess herbicide efficacy after spraying to detect any loss of control
- If resistance is suspected, act quickly to prevent it spreading. Use a strategy involving alternative herbicides and non-chemical methods and continue to monitor
- Consider collecting and testing seed samples to confirm resistance
- Good record keeping and assessment after spraying is essential in the early detection of herbicide resistance

See Defra-funded project PS2802 for more information on integrated control on hard surfaces.

Introduction

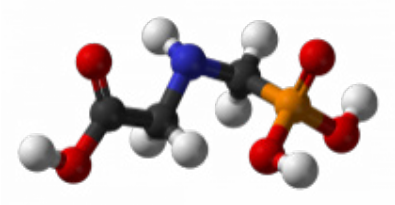
The herbicide glyphosate has been commercially available for 40 years and is one of the most frequently used herbicides in the UK in all crop production systems, including annual and perennial crops, and non-cropped areas.

In arable cropping systems in particular there has been a rapid increase in herbicide resistant grass-weeds in the last 20 years mainly due to a lack of new herbicides, a limited crop rotation and a lack of cultural control practices being included in weed management strategies. Therefore an over reliance on a limited group of herbicide modes of action has accelerated the grass-weed resistance issue.

There are currently **no known cases of glyphosate resistance in the UK**. Worldwide there are many cases of glyphosate resistance reported, especially where glyphosate-tolerant crops were introduced. A clear lesson from this experience was that reliance on the use of glyphosate alone (without mitigation measures, such as cultivation) is a key driver for resistance development. Although there are no glyphosate-tolerant crops approved in the UK, patterns of use and reliance on glyphosate have led to a heightened risk.

This leaflet, produced by WRAG, highlights the potential risks and provides guidance for users to minimise the risk of glyphosate resistance development to sustain the effective use of this vital herbicide. The main focus is on annual weeds in annual crops – the largest area of use and also one with a defined user group and communication channels, however perennial crops and amenity use are included.

Background, importance and UK use



Glyphosate is an EPSP synthase inhibitor (HRAC G) and is a non-selective foliar acting herbicide with no soil residual activity, therefore it is only used to control weeds post-emergence. It is fairly slow acting compared to other similar herbicides with symptoms visible after 7 to 10 days. Glyphosate is regularly used in arable cereal crops as a stale seed bed tool pre-drilling and as a desiccant pre-harvest.

Glyphosate is one of the most frequently used herbicides across arable, horticultural, ornamental crops and amenity situations and therefore has extremely high national importance. The development of weed resistance to glyphosate would therefore have a major impact on the economics of the agriculture, horticulture and amenity industries resulting in a wide scale problem. The cost, socio-economic and environmental impacts of a loss of glyphosate in the UK, which could also equate to future resistance to glyphosate, were discussed by Cook *et al*., (2010) & Wynn *et al*., (2014). There would be a loss of crop production (it was estimated that a 20% yield loss would occur without the use of glyphosate pre-drilling (Clarke *et al*., 2009) and potential loss of quality due to an increase in resistant weeds hindering normal practices in all systems. Glyphosate is a relatively cost-effective herbicide and there are many products containing this active ingredient available on the market, providing a wide range of choice to users.

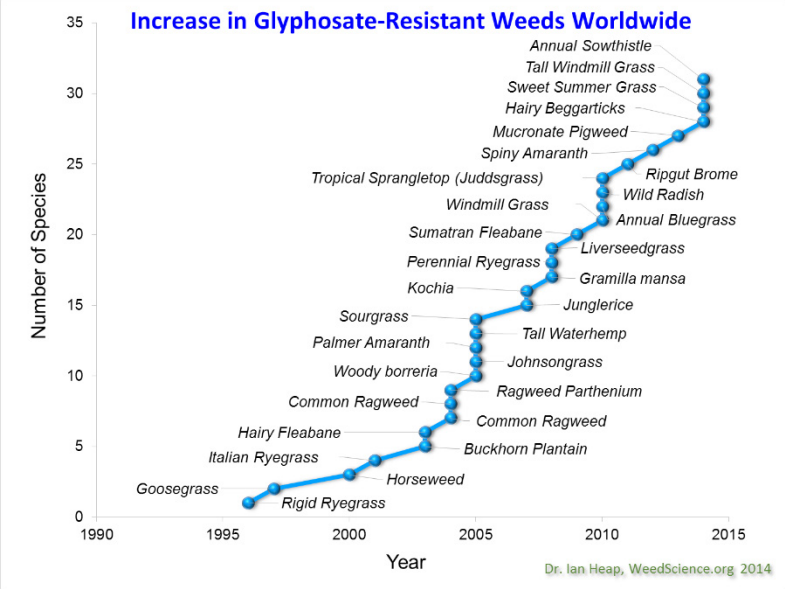
Herbicide resistance development

In arable cropping systems in the UK there has been a rapid increase in herbicide resistant grass-weeds in the last 20 years, especially black-grass, as reported by Moss *et al*., (2011) and Hull *et al*., (2014). This is mainly due to a lack of new herbicides coming onto the market, a reduction in the number of different herbicide modes of actions being available as a result of regulatory policy changes (such as Directive 91/414 (replaced by Regulation 1107/2009), Water Framework Directive etc.), a limited crop rotation and a lack of cultural control options being included in weed management strategies. The resulting over reliance on a limited group of herbicide modes of action has accelerated the grass-weed resistance issue. Resistance in broad-leaved weeds, in particular poppy (*Papaver rhoeas*) and common chickweed (*Stellaria media*) is increasing in the UK, although the number of cases is still small, (Hull *et al*., 2014) and is mainly linked to an over reliance on ALS-inhibitor herbicides.

Glyphosate resistance development

There are currently no known cases of glyphosate resistance in the UK. However, the first case of a glyphosate resistant weed in the world was reported for rigid rye-grass (*Lolium rigidum*) in 1996 in Australia (Powles *et al*., 1998, Preston, 2010). Simulation modelling in rigid ryegrass Neve *et al*. (2002) predicted that the greatest risk factors were sole reliance on glyphosate for pre-drilling control in systems with reduced tillage. In this situation, resistance could evolve in 10-15 years.

Glyphosate resistance has occurred in a number of different species in Europe, including *Conyza* spp. and a recent review of the development of glyphosate resistance in this species (Sansom *et al*., 2013) highlighted that the key factors in resistance evolution were sub-lethal glyphosate dose rates, sub-optimal weed growth stage at application and overreliance on one active - glyphosate. The first case of glyphosate resistance in an arable crop in Europe was reported in Italy (Collavo + Sattin, 2014) to ryegrass (*Lolium* spp.), which also showed multiple (cross) resistance to ACCase and ALS-inhibitor herbicides. Previous to that, glyphosate resistant weeds in Europe were located in perennial crops (orchards) where usage patterns differ to arable crops as often no additional modes of action or cultivations are used.



Worldwide there are currently 31 weed species (11 grasses), across 22 different weed families (a total of 232 individual biotypes) with reported glyphosate resistance (Heap, 2015). A case of multiple resistance across glyphosate, glufosinate, paraquat and ACCase-inhibiting herbicides in a population of *Eleusine indica* has recently been reported in Australia (Jalaludin *et al*., 2015). Glyphosate-tolerant crops were introduced in North and South America and Canada in the mid-1990s and resulting in a huge increase in area sprayed with glyphosate. This has led to an increase in glyphosate resistant weeds in the years that followed. A clear lesson was that reliance on the use of glyphosate alone (without mitigation measures, such as cultivation) was a key driver for resistance development.

Glyphosate resistance risk in the UK

The stale seed bed technique pre-drilling is an extremely important part of a weed management plan in arable crops as it allows newly emerged grass-weeds to be removed ahead of crop drilling. This reduces the pressure on the in-crop herbicide programme and potentially reduces the overall resistance risk on the weeds present. Target weeds should be at a very small growth stage at this time so control should be high and the resistance risk from single applications is normally fairly low. However there are now many reports of multiple glyphosate applications pre-drilling between every crop every year in the rotation. This strategy may not be sustainable in the longer-term due to resistance development and the wider pressures on glyphosate usage, such as to ensure protection of water quality.

Given the increasing amount of glyphosate used, the reliance on it for effective control and other future changes, the risk of glyphosate resistance is now a reality in the UK. Glyphosate forms an essential component of grass-weed management strategies and ensuring it is effective for many more years is critical to arable production systems. Recognising the greater risk, there are now an increasing number of enquiries regarding poor control and possible glyphosate resistant weeds in the UK. The majority refer to black-grass, but queries have been raised in the last two years on brome (*Bromus* and *Anisantha* spp.) species, sowthistles (*Sonchus* spp.) and annual meadow-grass (*Poa annua*).

Although there are no glyphosate-tolerant crops approved in the UK, patterns of use and

reliance on glyphosate have led to a heightened risk. Increasing herbicide resistance, especially in grass-weeds, to selective herbicides, is resulting in even greater use of glyphosate pre-drilling. Additionally there is interest in the use of glyphosate within crops. For example, in the UK there are already authorisations for glyphosate to be applied in a wide variety of vegetable and fruit crops and advance interest in gaining authorisation for application between wide rows in an oilseed rape crop. These have the potential for the target grass-weeds to be larger in size and application of a robust dose rate is critical to control weeds of that size, otherwise a tolerance to glyphosate may evolve rapidly with frequent exposure.

Maximising the efficacy of glyphosate

To maximise efficacy spray at the right rate, at the right growth stage and in the right conditions. Listed below is key information to help get all three correct.

Application

Dose rate:

Make sure the correct dose rate is chosen for the growth stage and use situation (e.g. for annual grasses 540 g a.i./ha for seedlings up to 6 tillers and 1,080g a.i./ha when flowering). Sub-optimal dose rates will give less reliable results, especially if other conditions are also less than perfect. The dose rate used should be the highest necessary to give effective control for weed species or most advanced growth stage present.

Water volume:

80 - 250 litres/ha. Lower volumes give best results providing correct nozzles are used (see spray quality). Low dose rates and higher water volumes lead to a low concentration of glyphosate and surfactant in each drop, which can lead to poorer results especially in conjunction with hard water or other sub-optimal conditions.

Spray quality:

Medium-coarse BCPC (200-400 microns). Use droplets on finer side of medium for optimum wetting of spike and seedling stage black-grass. Conventional flat fan nozzles (such as F110-03 or F110-04) are most suitable for seedlings. Low drift nozzles can be used on well-tillered plants.

Hard water

Hard water containing high levels of calcium, magnesium and other polyvalent metal cations such as iron and aluminum can lock-up glyphosate by a process known as chelation. This effectively reduces the applied dose rate of glyphosate and is most noticeable at low application rates and high water volumes. Addition of a proprietary water conditioner, choosing a low water volume and maintaining the correct dose rate will mitigate the effect.

Current label advice

At present, all glyphosate professional product labels should at least include a standard warning phrase as follows:

> *'Strains of some annual weeds (e.g. black-grass, wild-oats, and Italian rye-grass) have developed resistance to herbicides which may lead to poor control. A strategy for preventing and managing such resistance should be adopted. This should include integrating herbicides with a programme of cultural control measures. Guidelines have been produced by the Weed Resistance Action Group and copies are available from the HGCA, CPA, your distributor, crop adviser or product manufacturer.'*

Products should also include wording to the effect that:

> *'There is a low risk for the development of weed resistance to XXX. Growers are encouraged to implement a weed resistance strategy based on a) Good Agricultural Practices and b) Good Plant Protection Practices by:*
>
> - *Following label recommendations*
> - *The adoption of complimentary weed control practices*
> - *Minimising the risk of spreading weed infestations*
> - *The implementation of good spraying practice to maintain effective weed control*
> - *Application only under appropriate weather conditions*
> - *Monitoring performance and reporting any unexpected results to XXXXXXX.'*

Given the known risks it is considered appropriate to strengthen the current label warnings. There is also a need for more information on the interaction with cultivation and the total number of applications of glyphosate that can be applied per crop or year. The recommended dose rate needs to be more clearly stated for weed species and size as labels are updated and/or reviewed. This leaflet could be a reference for further information.

Growth stage/timing

- Ensure weeds are green and growing
- Black-grass seedlings should have a minimum of 5 cm growth
- Aim to spray dense populations of black-grass seedlings before shading prevents adequate coverage

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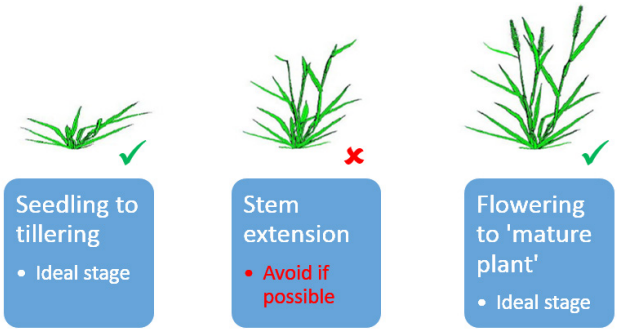
- Poor downward translocation will occur during the stem extension phase of growth in April/May. The natural flow of sugars from photosynthesis in the leaf is upwards to the rapidly extending stem for use in the developing flower head
- Treatment in early spring can lead to a dieback of the stem but subsequent re-growth from the base
- Spraying once the head is formed will give excellent translocation down to the roots and a much higher level of kill



Weather

- Moderate temperatures favour efficacy (15-25ºC). Avoid periods of prolonged frost
- Avoid spraying in evenings where there is a high risk of run-off from night rainfall from the prolonged drying time
- Spraying onto damp leaves is acceptable, but do not spray if rain is forecast within a few hours. Heavy frontal rain before uptake can lead to very poor results (40-60% of the control achieved without rain)

Managing the risk of glyphosate resistance evolving in annual weeds in annual crops

It is currently difficult to be very precise in any management guidelines, although we believe that it is necessary to highlight key risk factors and concerns. WRAG recognises that the risk needs to be investigated further to enable greater precision in any advice. This includes a better understanding of the risk of glyphosate resistance evolving if current practice continues and quantification of how particular management changes would reduce the risk. However, there is compelling evidence from experience in other countries that repeat use of glyphosate alone presents a high risk for resistance development. What is more difficult to define is the number of applications that would present an acceptable risk or how the integration of glyphosate use with cultivation and pre- and post-emergence herbicides would reduce risk to manageable and hence acceptable levels.

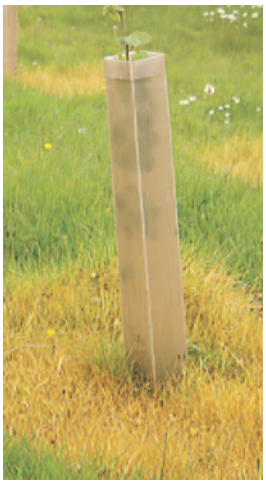
The following does however aim to highlight key points:

- Black-grass and Italian rye-grass present key weeds at risk.
- Glyphosate applied prior to drilling a crop, such as in a stale seedbed, is an effective weed control option, but it needs to be used sensibly.
- It is difficult to define how many applications, or at what rate and timing, present an unacceptable risk, however you are advised to:
  - Avoid multiple applications of glyphosate to the same weed plants (e.g. survivors of previous applications)
  - Always maximise efficacy and use the manufacturers recommended dose rate for the weed sizes present. Reduced rates that allow more survivors may encourage resistance development
  - Reduce risks by ensuring that glyphosate use is supplemented by sufficient cultivation to kill survivors and effective herbicides of different modes of action either in sequence in following crops (pre- and post-emergence) or in mixture (if appropriate and available)
- Based on current understanding, two applications of glyphosate, provided there is cultivation and effective subsequent herbicide use, is likely to be a manageable risk. Multiple applications in the absence of cultivation should be avoided.

- Application of glyphosate within crops, such as between crop rows through shrouded sprayers, can present an increased risk that will need careful management. Due to the later timing, it is likely that weeds will be larger when treated and there is also a greater risk of survivors from pre-drilling use receiving follow up treatment with the same mode of action. This presents a much higher potential risk as there may be less 'mitigation' such as from cultivation and/or post-drilling herbicide use. In such situations:
  - Continued and intensive monitoring of effectiveness of treatments should always be carried out
  - Use of other modes of action effective on the target weeds should be included where possible
  - Based on current understanding, two applications of glyphosate (at any timing), supplemented with effective cultivation and effective subsequent herbicide use is likely to be a manageable risk. Where no such 'mitigation' is included restrict use to one application pre-drilling and one within the crop
- Mixtures can form an effective component of resistance management strategies. However, as many can reduce the efficacy of glyphosate you should only ever use mixtures recommended by manufacturers. To be an effective component of a resistance management strategy both components of the mixture must be effective on the same target weeds at the relevant growth stage and timing. Remember, that the key target grass-weeds (black-grass & Italian rye-grass) are already resistant to many of the potential herbicides that can be used. In addition there are demands to minimise their total area of use and hence risk of being found in water. In practical terms, strategies should therefore aim to mitigate the resistance risk from glyphosate by ensuring use is accompanied by cultivation and/or herbicides in sequence.
- Adjuvants or water conditioners which are included as recommendations on glyphosate product labels will have been assessed for efficacy and associated resistance risks. However, those which do not appear on product labels have not received the same evaluation. Adjuvant use is often associated with use of reduced rates of product. In such situations we suggest extreme caution should be taken as any reduction in efficacy could increase the risk of development of resistance.
- A single pre-harvest application of glyphosate per crop should not increase the risk of resistance to annual weeds in annual crops, unless there are survivors present from prior glyphosate application.
- Monitor the success of control strategies carefully and frequently. Remove survivors to prevent seed spread. Report suspected survivors to your crop protection adviser and/or the manufacturer of the product used.

Practical measures to manage herbicide resistance risk in perennial crops and amenity areas

See 'Herbicide Resistance in Amenity Weed Control Situations' for more information



- Avoid over-reliance on a single herbicide (e.g. glyphosate). Use mixtures of herbicides whenever possible
- Consider non-chemical control measures (e.g. hand weeding, cutting, flaming, steam treatments) as a supplement or alternative to herbicide treatment
- Monitor and assess herbicide efficacy after spraying to detect any loss of control
- If resistance is suspected, act quickly to prevent it spreading. Use a strategy involving alternative herbicides and non-chemical methods and continue to monitor
- Consider collecting and testing seed samples to confirm resistance
- Good record keeping and assessment after spraying is essential in the early detection of herbicide resistance

See Defra-funded project PS2802 for more information on integrated control on hard surfaces.

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About WRAG

The Weed Resistance Action Group (WRAG) is an informal and independent group of those involved in research and communication in relation to managing herbicide resistance in the UK. It receives no regular funding, although it receives in-kind support from members who provide facilities for meetings. Organisations, such as HGCA have also contributed funding for publications. WRAG was formed in 1989. There is a steering group of about 10 people comprising: representatives of the Crop Protection Association (CPA) and Agricultural Industries Confederation (AIC) member companies; and organisations involved in herbicide resistance research (e.g. ADAS UK Ltd, Rothamsted Research, Health and Safety Executive (HSE)/Chemicals Regulation Directorate (CRD), universities, colleges and Agricultural and Horticultural Development Board (AHDB). There are normally one or two steering group meetings per year, with communication to a wider membership of meeting minutes and topical items through an extensive e-mailing list and through occasional open meetings. We maintain contact with other groups worldwide, such as Herbicide Resistance Action Committee (HRAC).

www.pesticides.gov.uk/guidance/industries/pesticides/advisory-groups/Resistance-Action-Groups/wrag or www.tinyurl.com/weedrag

Note: The technical content of the summary pages (1 and 2) of this leaflet are identical to AHDB Information Sheet 03, which is available from the AHDB Cereals & Oilseeds website.
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