Managing weeds in arable rotations – a guide

Incorporating WRAG guidelines

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Introduction

Weed management

Weed control is vital for high yields of good-quality crops and to prevent the spread of pests and diseases, e.g. ergot. Yet with fewer active ingredients, a need to protect water and manage herbicide resistance, the weed challenge must be managed across the rotation.

Weed control is more than just using herbicides. Many factors determine weed incidence and effective weed management in arable crops requires integration of all these factors:

- Crop choice and rotation
- Managing the weed seedbank
- Cultivations
- Drilling date
- Crop competition
- Herbicide choice, application and timing
- Recent weed-control strategies
- Weather
- Agronomist/farmer perceptions

The aim of this publication is to provide a practical guide for farmers and agronomists that brings together research to allow improved weed management through a rotation dominated by autumn-sown crops.

Weed control has always been challenging but has become even more difficult because:

- Herbicide availability has declined
- There are no new modes of herbicide action currently available
- Herbicides are being found in water
- Herbicide resistance is increasing

Improving weed management means:

- Getting the most out of cultural control and maximising herbicide performance
- Keeping weed populations low for good weed and resistance management
- Planning weed control across the full rotation

The EU Sustainable Use of Pesticides Directive (2009/128/EC) requires farmers to adopt integrated pest management, with priority given, wherever possible, to non-chemical methods of plant protection. For weed control, the challenge is to integrate crop choice/rotation, drilling date, cultivation method, herbicide use, resistance management and environmental protection.

These issues are also interrelated; for instance, a range of different crop species widens both chemical and cultural opportunities to control grass and broad-leaved weeds.

Properly managed weed control through a rotation can reduce costs while limiting the build-up of resistance, maintaining yields, protecting water quality and enhancing biodiversity.

This guide treats resistance management as an essential part of rotational weed management.

Therefore, the Weed Resistance Action Group (WRAG) Guidelines, together with practical information on cultural control and herbicide use, are integrated within this publication.

See pages 13–17 for WRAG Guidelines.

Weed biology

Crop competition

The damage weeds cause depends on:

- Weed species
- Weed density
- Competitive ability of the crops
- Growth stage when weeds compete

While some weeds are highly competitive, others pose little threat and may be valuable to wildlife. Weeds can delay ripening and harvesting, e.g. cleavers in oilseed rape, or impair produce quality, e.g. volunteer potatoes in peas (Table 1).

Table 1. Competitive ability of common arable weeds in wheat

Competitive ability (number of plants/m² that would typically result in a 5% yield loss in wheat)	**Weed** (Species in italics have a high feed for seed-feeding birds and herbivorous insects)
Very competitive (0–5)	Barren brome, cleavers, Italian rye-grass, wild-oat
Competitive (12–17)	Black-grass, black bindweed, *charlock*, common poppy, *creeping thistle, scentless mayweed*
Moderately competitive (up to 25)	*Chickweed, fat hen,* forget-me-not, *redshank*
Less competitive (50 and above)	Common fumitory, scarlet pimpernel, shepherd's-purse, dove's-foot crane's-bill, red dead-nettle, annual meadow-grass, knot-grass, groundsel, common filed-speedwell, field pansy

Source: Marshall E.J.P., Brown V.K., Boatman N.D. et al. (2003). *The role of weeds in supporting biological diversity within crop fields.* Weed Research 43, 77–89

Weed germination

Weeds emerge at different times and the interaction between weed and crop growth is important. Most problems occur when weeds and crops emerge at the same time. Being able to predict when a weed germinates can help determine the most appropriate control methods.

Non-chemical weed control

Non-chemical techniques are increasingly important to reduce weed numbers and the need for herbicides, hence limiting the risk of resistance developing. However, augmenting the number of species increases biodiversity (Table 2).

Table 2. Non-chemical options for weed control

	Potential to decrease number of species	Potential to increase number of species	Example: Black-grass control in wheat*
Spring crop	+++	+++	88%
Fallow	+++	++	70–80% per year (of seedbank)
Rotational plough	+++	+	69%
Delayed drilling	++	+	31%
Higher seed rates	+		26%
Competitive variety	+		22%
Mechanical weed control	(+)		(+)
Minimising weed dispersal	(++)		(++)

+++ high, ++ moderate, + low, ( ) limited experience
*from Lutman, Moss, Cook and Welham (2013)

Weed size and crop growth stage

Small weeds are generally easier to control (Figure 1), but very small weeds may be less easy to kill with herbicide due to small areas of spray contact.

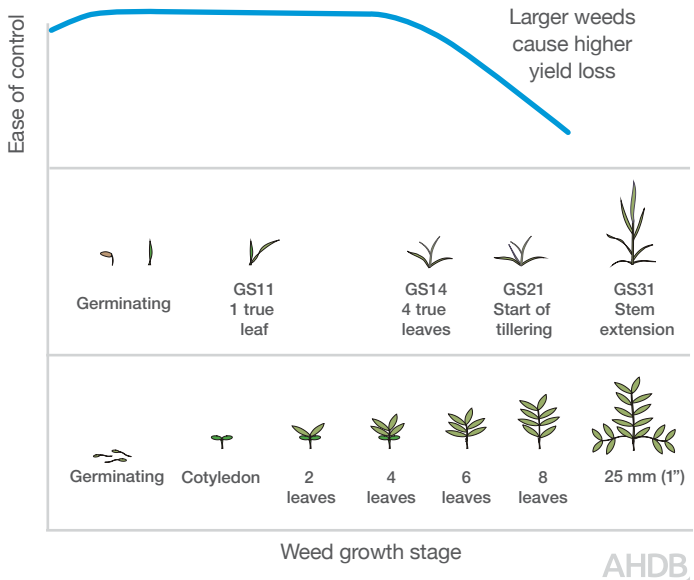


Figure 1. Ease of control declines as weeds grow

Table 3. Germination periods of common weeds

Timing	Common weeds	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Spring	Black bindweed, black mustard, charlock, common orache, fat hen, fool's parsley, hedge mustard, hemp-nettle, knot-grass, pale persicaria, redshank, spring wild-oat, volunteer oats												
Early summer	Black nightshade, scarlet pimpernel, sun spurge												
Mainly autumn, with significant spring flush	Cleavers, common poppy, field pansy, forget-me-not, scentless mayweed, small nettle, thistles, volunteer barley, volunteer oilseed rape, volunteer peas, volunteer wheat, wild radish												
Mainly autumn	Barren brome, black-grass, Italian rye-grass, loose silky bent, meadow brome, volunteer beans, winter wild-oat												
All year	Annual meadow-grass, common chickweed, common field-speedwell, crane's-bill, common fumitory, groundsel, mayweeds, red dead-nettle, shepherd's-purse, thistles												

Germination: under 5% 5%–20% over 20%

For more information on the biology of weeds, see: ***The Encyclopaedia of Arable Weeds*** on **ahdb.org.uk/arable-weeds**

Managing the seedbank

Soil contains many weed seeds – the 'seedbank'. This increases and decreases as both weeds and crops set and shed seeds. Weed seeds are scattered within fields by the combine spreading straw at harvest and by cultivations.

Weeds emerge each year, generally only from the top 5 cm of the soil. Cultivations stir up the seedbank, burying freshly shed seed and bringing seed from lower down the profile to the surface. Depending on species, some buried seed will become dormant and survive for many years, some will germinate, some decay and some will be eaten by wildlife, e.g. birds and insects.

Imported weed seeds

Most of the seedbank comes from local weeds, but some seeds may be imported on machinery or in crop seed. Manure and slurry applications may spread weeds from hay or bedding. Composting, drying manure or storing it for over eight weeks reduce the risk. Sewage sludge may contain weeds depending on how it is processed. Compost that conforms to the BSI PAS 100:2011 standard should be free of weed seeds; however, the equivalent standard for products of anaerobic digestion, BSI PAS 110:2010 (digestate, separated liquor and separated fibre), does not contain a requirement to test for weed seeds. Research is ongoing to determine if weed seeds can survive the anaerobic digestion process.

Depth of weed seeds

Weed seeds are distributed throughout the soil profile but usually only emerge from the top 5 cm; those buried deeper, apart from a few larger seeded species, e.g. barren brome and cleavers, seldom emerge. This is a key point when planning weed-control strategies.

Weed seeds are not viable forever and have a natural death rate that varies dramatically between species (Table 4). For example, barren brome seeds cannot survive in the soil for more than a year, but common poppy can persist for more than 50 years. The rate of natural seedbank decline will determine the short-term effectiveness of seedbank management.

Table 4. Weed seed longevity

Longevity	Grasses	Broad-leaved weeds
Under 1 year	Soft brome, rye brome, barren brome, volunteer cereals and oats	Volunteer sunflower and linseed
1–5 years	Perennial rye-grass, black-grass, winter wild-oat	Chickweed, crane's-bill, creeping thistle and mayweed
Over 5 years	Wild-oat, loose silky bent, Italian rye-grass, orache and many others	Black bindweed, charlock, common poppy, speedwells and volunteer rape

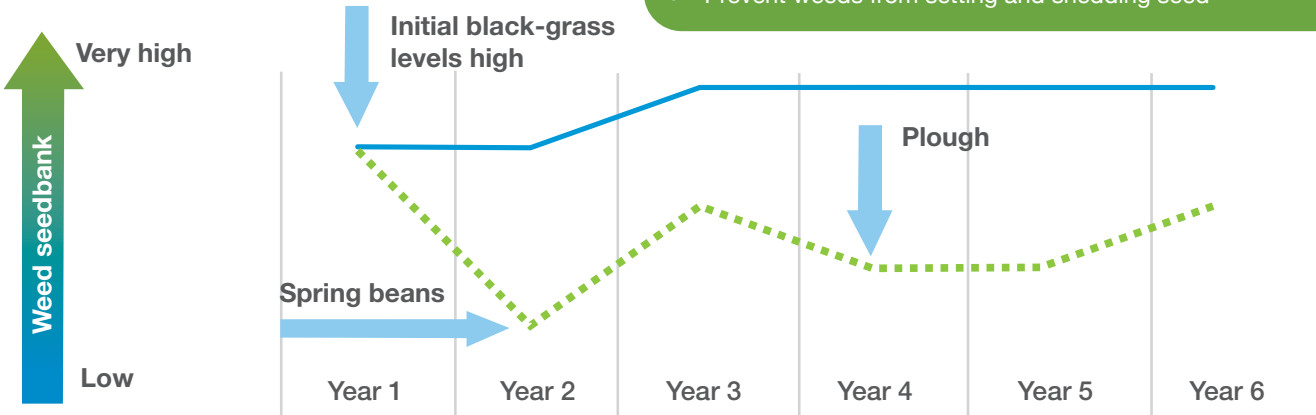
It is not necessary to count weed seeds in a soil profile; germinating weeds in an untreated area give a good indication of weed infestation.

Changing rotation to reduce the weed seedbank

The Weed Manager programme (Project Report 388) can predict weed seedbank levels through a rotation and has been used to derive Figure 2 and evaluate suggested improvements in the case studies (pages 18–22).

To reduce the weed seedbank

- Encourage weeds to germinate by changing crop type, cultivation timing and drilling dates
- Prevent weeds from setting and shedding seed



		Year 1	Year 2	Year 3	Year 4	Year 5	Year 6
Basic rotation	Cultivation	Non-invert	Plough	Non-invert	Non-invert	Non-invert	Non-invert
	Crops	WW	WBns	WW	WW	WOSR	WW
Amended rotation	Cultivation	Non-invert	Plough	Non-invert	Plough	Non-invert	Non-invert
	Crops	WW	SBns	WW	WW	WOSR	WW

SBns = spring beans
WBns = winter beans
WOSR = winter oilseed rape
WW = winter wheat

In year 2, changing to a spring crop significantly reduces the seedbank and this is reduced further by ploughing before the second wheat in year 4.

Figure 2. How changing crop type, cultivation and date in a heavy land rotation affects black-grass

Cultivation

Stubble cultivation

Shallow cultivation, immediately after harvest, can stimulate weed seed germination, especially barren brome and volunteer cereals. For best effect, soil must be moist. However, cultivations prevent mammals and birds eating weed seeds. Stubble cultivation reduces annual meadow-grass.

Primary cultivations

Apart from stubble cultivation, the 'primary' cultivation is the first one to prepare soil for the next crop.

Cultivations may be classified into four groups (Table 5) and are a balance between bringing older seed from depth and burying newly shed seed.

Plough

Ploughing is unique as it inverts soil, burying 95% of freshly shed seed to 15–20 cm but brings up 35% of old seed. Subsequent cultivations are shallower, so buried seed is not disturbed. Most weeds germinate from seeds shed in previous seasons.

The effectiveness and optimum frequency of ploughing will depend on the longevity of the weed seed in the soil (Table 4, page 6) and will be most effective for species with short-lived seed, such as barren brome and black-grass.

Deep till and shallow till

Non-inversion tillage mixes the upper layer to a set depth. Germinating weeds are a mix of newly shed seeds and those from previous seasons. About half the seed is buried below germination depth and 10% of old seed returns to the surface.

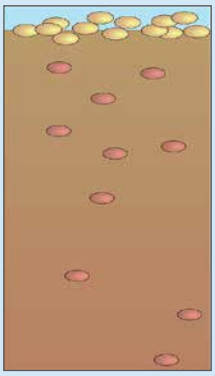
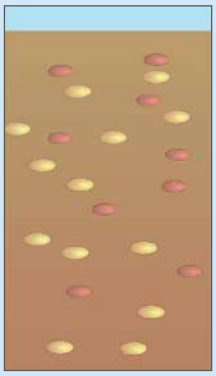
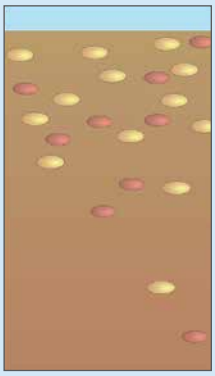
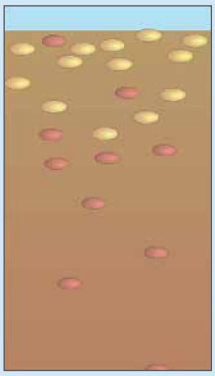
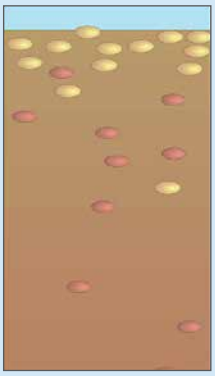
No-till

With no-till, including autocasting, the soil is only cultivated by the drill. Weed seeds are predominantly in the top 3 cm, but some smaller seeds move down soil cracks.

Other

Subcasting, using a subsoiler or modified cultivator, results in freshly shed seed falling down cracks but with little soil mixing. Using discs leads to more mixing – equivalent to deep or shallow till.

Table 5. Cultivation options and effect on weed seedbank

Cultivation	After harvest	Plough	Deep till	Shallow till	No-till
Soil movement	Not applicable	Inversion	Deep	Little	No mixing
Cultivation depth	Not applicable	Over 5 cm, inverted	Over 5 cm	Under 5 cm	None
Example	Not applicable	Plough	Discs over 5 cm	Discs under 5 cm	No-till drill
		Many old seeds brought to surface, most new seeds buried	Fewer old seeds brought to surface, some new seeds buried	Very few old seeds brought to surface. Few seeds added to the seedbank	A few seeds may change layers
Soil depth 5 cm 30 cm					
Weed control		Generally reduces weed populations	Has little effect on weed populations	Keeps weed seeds in top 5 cm of soil where they can germinate	Keeps weed seeds in top 5 cm of soil where they can germinate

Crop choice

Crop choice

Choice of crop affects many aspects, including the time of drilling, the type and timing of cultivations and the range of herbicides available. Some crops compete better than others with weeds (Table 6).

Rotations

The ideal rotation should include a balance of different crops. The aim is to provide an economically successful sequence that breaks pest and disease cycles, improves weed control, prevents erosion with crop cover and improves nutrient cycling and soil condition.

Table 6. Comparison of spring- and autumn-drilled crops

Crop			Number of herbicide actives available*	Competition with weeds	Benefits	Disadvantages
Autumn-sown – well suited to heavy soils. Usually higher-yielding. Provides overwinter crop cover	Cereals	Wheat	++++	+++		
		Barley	++++	++++		
		Oats	+++	++++		
		Rye	+++	++++		
	Broad-leaved crops	Beans	++	++		
		Oilseed rape	++	++++	Herbicides with no known resistance available	Cannot delay drilling. Most broad-leaved weed control must be pre-emergence. Volunteers can be a problem
Spring-sown – spreads workload. Changes weed species and numbers. Good for biodiversity. Less suited to heavy soils	Cereals	Barley	++++	++++		
		Wheat	++++	+++		Minimise cultivations on light soils if drought is a problem
		Triticale	+++	+++		
		Oats	+++	++++		Difficult to control grass weeds
		Rye	+++	++++		
	Broad-leaved crops or other crops	Beans	++	++		Late sowing can lead to a late harvest
		Peas	++	+		Delayed sowing reduces yield
		Oilseed rape	++	++++		Few herbicide problems. Susceptible to drought at drilling. Volunteers can be a problem
		Sugar beet	+++	+++	Multiple low-dose systems for weed control. Can be mechanically weeded	High capital investment. Poorly competitive initially. Very late harvest
		Potatoes	++	++++	Can use non-specific herbicides. Good competitor with weeds	High capital investment. Can leave volunteers

*Ranging from ++++ (high) to + (low)

Drilling date

The interval between harvesting one crop and drilling the next is important, as a non-selective herbicide can be used on emerged weeds. Delaying drilling increases the time available for weed control, but it can reduce subsequent crop competitiveness, although increased seed rate can help compensate. The effectiveness of delayed drilling will depend on the germination period of the weeds (Table 3, page 5) and will be most effective for weeds with low dormancy and a clear autumn flush.

Before drilling, aim to kill all emerged weed seedlings using a combination of non-selective herbicide and cultivations. Cultivations, however, especially in moist soils, will not kill seedlings and surviving plants will be larger and more difficult to control.

Where possible, wait for a weed flush before drilling. Drill fields with low weed populations first, leaving those with high grass-weed burdens until last.

Weather conditions

Dry weather between harvest and drilling minimises weed emergence, but crops will not emerge either. Dry soils and dry weather reduce the effectiveness of pre-emergence herbicides.

Maximising crop competition

A crop's ability to compete is a product of variety, seed rate and drilling date. Lower rates leave more space for weeds to establish, but early drilling means crops have longer for tillering and so are more competitive than those drilled later.

Crop establishment declines in cereals drilled after mid-October. Seed rates should be increased to maintain yield. Late-emerging weeds are less competitive and produce fewer seeds.

The window for drilling winter barley is narrower than for winter wheat. A low vernalisation requirement means barley is less suited to very early drilling, while yield declines rapidly when drilled after mid-November.

Variety choice affects crop competition. Some cereal varieties reduce the competitive effect of weeds by over 30%.

The effect of delayed drilling on specific weeds

A. Black-grass

Understanding dormancy and the effect of weather and soil conditions is important. Weather during ripening determines black-grass dormancy. Low dormancy occurs in warm, dry conditions and seeds will grow rapidly if moisture is not limiting.

In some years, black-grass germinates as the crop ripens. Conversely, cold, wet weather leads to high dormancy and delayed black-grass emergence from seed shed in the current season.

B. Bromes

Shallow-cultivate barren and great brome seeds to bury them as soon as possible after harvest, unless chopped straw provides good seed cover.

Meadow, soft and rye brome seeds are usually under-ripe, and burial immediately after harvest enforces dormancy. Leave seeds to ripen for one month before cultivating.

Brome emerges quickly in moist soil and dormancy has little effect on emergence. Wait until brome has emerged and spray off with glyphosate pre-drilling.

C. Wild-oat

Delayed drilling allows a longer period for predation and seed germination.

D. Annual meadow-grass

Delayed drilling has little effect.

E. Italian rye-grass

Seed dormancy is short-lived and most seed emerges by November. Delayed drilling reduces populations.

Optimising herbicide timing

Herbicides form a large part, typically 20–30%, of the variable costs associated with producing a crop. Product labels and technical support can provide growers with information to optimise herbicide effectiveness, but general principles apply to all crops (Table 7).

Table 7. Optimising herbicide timing in autumn-sown crops – factors to consider

Herbicide timing	Aim	Mode of action	Advantages	Disadvantages
Pre-drilling	Encourage weed growth. Control weeds from harvest to drilling	Contact	Can use non-selective herbicides, which reduce resistance risk	Early drilling shortens time for weeds to emerge and be controlled
At drilling	Apply before crop or weeds emerge, within 24–48 hours of drilling. Control weeds until end of winter	Residual	Prevents weed establishment. Essential building block of grass-weed control; only effective timing for some species/herbicides. Limited resistance to pre-em herbicides	Poor weed control where seedbed quality is poor or seedbeds are dry. Crop seed depth, or soil cover, can be an issue with some herbicides
Autumn/winter	Control later-germinating weeds or escapees from pre-emergence treatments. Target weeds when small	Residual Contact	Weeds visible to identify, which aids product choice	Control more difficult if weeds are large. Soils can be too wet. Stressed crops. Large crop canopies. Resistance problems common. Beware cold temperatures, which can reduce efficacy of some herbicides
Spring	Control spring-germinating weeds. Tidy up winter escapees	Contact Some residual	Weed spectrum visible	Large weed size. Sometimes too late for certain species. Target crop growth stage is missed
Pre-harvest	Control late-germinating and perennial weeds	Contact	Ideal timing for perennial weeds	Few species at correct growth stage. Some weed seed set. Some crop market restrictions

Cereal herbicides

Effective grass-weed control is essential in rotations with autumn-sown crops. Mixtures (several products applied together) or sequencing/stacking (several products applied in close succession) are more effective at controlling grass-weed populations than individual products. Pre-emergence options are less affected by resistance and should form a key part of a cereal herbicide programme.

Black-grass

Recent research shows flufenacet is a key active in programmes, but a further two to four actives are necessary to achieve good control. Commercially acceptable control is more likely where untreated populations are under 100 heads/m^2.

Annual meadow-grass

Herbicides are necessary to control this weed as it germinates throughout the season and cultural methods have very little effect. Both pre-emergence and post-emergence strategies can be very effective.

Barren or sterile brome

Cultural methods, e.g. ploughing and delayed drilling, can give good control. Otherwise a sequence of pre- and post-emergence herbicides is necessary.

Oilseed rape herbicides

Spring herbicide options are limited in oilseed rape and weed-control decisions need to be made prior to drilling.

Establishment methods and weeds present affect control options:

- Where shepherd's-purse and/or cleavers are predicted, a robust pre-emergence treatment – based on metazachlor – is required. Rapeseed must be well covered by soil to a depth of 15 mm
- For black-grass and other grass weeds, herbicides such as propyzamide are more effective after no or very shallow cultivation. Where deeper cultivations are used, adding a graminicide ('fop' or 'dim') will improve the level of control

Protecting water quality

The importance of keeping pesticides out of watercourses is increasing. EU and UK water-quality legislation may affect or restrict use of several herbicides, particularly those used extensively, as well as those used at high rates and applied at times of year when drains may be running or there is potential for run-off to watercourses. The result of new legislation could be restrictions on rate and/or timing, with product withdrawal as a last resort.

A small number of approved pesticides are detected regularly in surface water (Table 8). Herbicides can enter water in a wide range of ways:

- **Stores** hold concentrated chemicals; a fire or leak can have a huge impact downstream
- **Drips or spills** of concentrated chemical at sprayer filling can wash off concrete or hardcore into drains and watercourses
- **Over-spraying watercourses** is careless and jeopardises aquatic life and water quality
- **Drift** concerns neighbours and can harm aquatic life and water quality
- **Drain flow** is the main way herbicides leave the field in the winter months. Herbicides attached to soil particles or in drainage water enter watercourses when drains are flowing
- **Surface run-off** carrying soil and pesticides can occur on most soils and slopes after heavy rain and can be channelled by tramlines
- **Cleaning sprayers** produces large quantities of dilute pesticide that can easily reach drains if poorly managed
- **Disposing of pesticide containers** by burial is illegal and can cause long-term damage to water quality

Table 8. Best practice to avoid risk of water pollution from some herbicides commonly detected in water

	Metazachlor	Propyzamide or carbetamide	Clopyralid	Mecoprop-P
Main crop(s)	Oilseed rape	Oilseed rape Beans	Cereals Oilseed rape	Cereals Grassland
Best practice	Apply from pre-em to early post-em of weeds to moist soil Apply in late summer/early autumn Maximum dose of 750 g ai/ha, with no more than 1,000 g ai/ha over a three-year period	Apply to cold, moist soils (not saturated) Avoid use if drains are flowing or likely to flow in the near future	Apply when weeds are actively growing Avoid use if drains are flowing or likely to flow in the near future	Apply when a full crop canopy is present and no more than 50% bare ground Straight mecoprop cannot be applied to cereals between 1 October and 1 March

Source: H2OK? Water Protection Advice for farmers and advisers – 2009/10

Key points *(For herbicides in Table 8)*

- Establish grass buffer strips at least 6 m wide beside watercourses, or use a 5 m no-spray zone
- Do not spray when heavy rain or snow is forecast within 48 hours of application; nor when soil is very wet or drains are running or are likely to run
- Only spray in suitable, settled weather, preferably when soil is moist
- Do not spray when soil is dry and cracked
- Do not apply the above herbicides if the fields have been mole-drained or subsoiled below plough depth/layer
- Minimise dose rate if possible
- Take care when filling or emptying the sprayer
- Wash sprayer in the field and park under cover
- Pressure- or triple-wash and drain pesticide containers before storing them under cover to await disposal by a waste disposal contractor

H2OK? Keep it Clean

For detailed guidance on protecting water quality and responsible pesticide use, visit

www.voluntaryinitiative.org.uk

The Voluntary Initiative
Promoting responsible pesticide use

Effective herbicide application

Herbicide performance

Application technique can significantly affect herbicide performance, particularly for small weeds early in the season. Consideration should be given to:

- Timing of the application
- High levels of deposit of active substance
- Right droplet size
- Controlling spray drift

Optimum timing is important. Where weather conditions limit available spray days, high work rates are necessary but must be balanced against the risk of spray drift.

Spray deposits

Small weeds are particularly challenging targets, especially grass weeds because of their vertical structure.

The highest deposits on target weeds result from reducing both application volume and droplet size. Using lower volumes (around 100–150 L/ha) is generally more effective than volumes of 200 L/ha and higher.

Some horizontal movement of droplets is necessary to ensure adequate deposition on small grass weeds. Angling nozzles is one way to create horizontal velocities, which increases active-ingredient deposition on small vertical targets.

Droplet size

For many herbicides, finer-quality sprays are more reliable than coarser sprays. Often, air-induction nozzles giving the smallest droplet sizes perform as well as medium-fine conventional sprays (Table 9).

Controlling drift

Fine sprays are likely to lead to the highest drift. Applications where little crop canopy exists to absorb spray will also increase risk of drift. The lower the boom, the less the drift. Maintaining the correct boom height throughout the spray operation is essential. Wind speed has an important but smaller effect on drift.

Weed size

Large rather than small weeds are more suitable for treatment with air-induction nozzles, particularly those giving the smallest droplet sizes, which can still significantly reduce drift compared with conventional nozzles.

Formulation

Water-soluble liquid formulations with a high level of surfactants – such as glyphosate – may also increase spray drift, so additional precautions for controlling drift may be necessary.

Increasing work rate

Reducing water volume from 200–100 L/ha, achieved by changing nozzle size, gives an estimated 40% increase in work rate for a 24 m boom on a 3,000-litre, self-propelled sprayer. Increases in work rate can also be achieved by increasing forward speed and boom width. However, faster forward speeds and wider booms may require increased boom height. This increases the risk of drift, as does spraying reduced volumes through smaller-sized, conventional nozzles.

It is essential to comply with product labels and the Code of Practice for using plant protection products.

Table 9. Matching nozzles to weed challenge

	Nozzle style				
	Air induction		Conventional		
Spray droplet size	Small	Large	Fine	Medium	Coarse
Pre- and early post-emergence	▲	▲ ✶		▲	▲
Grass weeds – 3 leaves or fewer			▲▲	▲ ✶	
Grass weeds – more than 3 leaves	▲ ✶		▲	▲▲	
Broad-leaved weeds – up to 2 cm across			▲▲	▲▲ ✶	
Broad leaved weeds – 2–5 cm across	▲ ✶		▲	▲▲	
Broad leaved weeds – more than 5 cm	▲▲ ✶			▲▲	
Non-selective (e.g. glyphosate)	▲▲	▲ ✶		▲▲	▲

▲ = Acceptable ▲▲ = Preferred ✶ = Best for drift control

Minimise resistance risks

Optimising weed-control strategies for herbicide resistance management

Many of the most active herbicides (e.g. ALS and ACCase inhibitors) pose a very high resistance risk because they are affected by target site resistance and, in most cases, enhanced metabolism resistance too.

It is essential to utilise strategies to limit resistance to these herbicides, especially now that fewer lower-risk herbicides are available. Herbicide resistance is an irreversible process – it does not disappear or decline if herbicides cease to be used.

This means more use of non-chemical methods to reduce dependence on herbicides, maximising the benefit from pre-emergence herbicides and ensuring effective use and timing of remaining post-emergence products (Table 10).

Non-chemical control methods to reduce reliance on herbicides

Refer to pages 6 to 9 for more details. Non-chemical methods cannot replace herbicides on most farms, but reduced reliance on herbicides will be necessary both from a practical (increasing resistance, lack of new herbicides) and political (complying with new EU legislation) aspect.

Pre-emergence herbicides

- These reduce the overall weed population and the need for higher-risk post-emergence products
- Flufenacet, pendimethalin, prosulfocarb and triallate are all affected by enhanced metabolism resistance, but generally only to a limited extent
- Products or programmes based on combinations of these active ingredients usually give useful levels of control. Resistance to these herbicides does not appear to build up rapidly
- Pre-emergence herbicides are valuable in any integrated resistance management strategy, especially for grass weeds
- Post-emergence herbicides place less reliance on high-resistance-risk post-emergence herbicides
- The ACCase ('fops', 'dims', 'dens') and ALS inhibitors (e.g. sulfonylureas) are prone to resistance, and their regular use is associated with a high risk of herbicide resistance and, consequently, poor weed control
- To avoid or delay resistance development, do not rely on either class as the main weed control in successive crops
- Use these herbicides in mixture and/or sequence with lower-risk modes of action to help reduce weed populations. However, this will not prevent further selection for resistance
- Remember, there are restrictions on the sequential use of both ACCase and ALS inhibitors – introduced to reduce herbicide resistance risk
- Using mixtures and sequences is a sensible approach, but it is best considered as a strategy to delay, rather than prevent, resistance
- Where possible, use lower-resistance-risk post-emergence herbicides in the rotation, e.g. propyzamide and carbetamide, in oilseed rape

Table 10. Herbicide resistance risk factors

Agronomic factor	Lowest risk	Highest risk
Cropping system	Good rotation of spring and autumn crops	Continuous winter cereals
Cultivation system	Annual ploughing	Continuous non-ploughing
Control method	Cultural only	Herbicides only
Herbicide use throughout the rotation	Different modes of action	Single mode of action
Weed infestation level	Low	High
Resistance incidence	None in vicinity	Identified locally in similar cropping systems

Remember

- Check carefully any restrictions on mixing or sequencing herbicides
- Avoid treating in waterlogged or frosty conditions or if crop is suffering nutrient stress
- Most residual herbicides work poorly in soils of high organic matter content (over 5%)
- Residual herbicides require moisture and an even seedbed for good control
- Heavy rain after application can move herbicides down the soil profile away from the weed germination zone
- In no-till established crops where crop seed is not covered with soil, wait until the crop has established before applying herbicides

The Weed Resistance Action Group (WRAG) website includes guidelines and an up-to-date list of herbicide modes of action.

ahdb.org.uk/wrag

Managing herbicide resistance

Herbicide resistance is the inherited ability of a weed to survive a rate of herbicide that would normally kill it.

Resistance mechanisms

Herbicide resistance, first identified in black-grass in 1982, also affects wild-oat, Italian rye-grass and, more recently, common chickweed, common poppy and scentless mayweed.

Herbicide resistance occurs through selection of plants that survive herbicide treatment. With repeated selection, resistant plants multiply until they dominate the population.

Three main types of resistance are present in UK grass-weed populations (Table 11). In broad-leaved weeds, mainly ALS target site resistance has been confirmed.

Table 11. Resistance mechanisms

Non-target site resistance
Results in herbicide detoxification and is the commonest resistance mechanism in grass weeds in the UK. Affects most herbicides to varying degrees but only in severe cases results in complete loss of control. Tends to increase slowly
ACCase target site resistance (ACCase TSR)
Blocks the site of action specific to 'fop' (e.g. Topik, Falcon), 'dim' (e.g. Laser) and 'den' (e.g. Axial) herbicides in grass weeds. Only affects these groups of herbicides but can result in very poor control. Can increase rapidly
ALS target site resistance (ALS TSR)
Blocks the site of action of sulfonylurea (e.g. Atlantis) and related herbicides (e.g. Broadway Star, Attribut) in grass and broad-leaved weeds. Only affects this group of herbicides but can result in poor control. Currently less common than ACCase TSR but is increasing

Note: All three resistance types can occur independently, in different plants within a single field, or even within the same plant.

These WRAG guidelines bring together research and field experience to help UK farmers and advisers:

- Prevent resistant weed populations developing
- Manage existing resistant populations
- Prevent the spread of herbicide-resistant weeds

Key factors for more sustainable resistance management

Research has highlighted the key factors that can contribute to better integrated weed management strategies:

- **Increase use of non-chemical control methods to reduce reliance on herbicides.** Non-chemical methods cannot replace herbicides on most farms, but reduced reliance on herbicides will be necessary
- **Make greater use of pre-emergence herbicides.** These reduce the overall weed population and the need for higher-risk post-emergence products. Resistance to the pre-emergence herbicides used for grass-weed control tends to be only partial and builds up relatively slowly, so they appear to be a lower resistance risk than most post-emergence options
- **Place less reliance on high-resistance-risk post-emergence herbicides.** The regular use of ACCase- ('fops', 'dims', 'dens') and ALS-inhibiting herbicides (e.g. sulfonylureas) is associated with a high risk of herbicide resistance. Do not rely on either class as the main means of weed control in successive crops. Where possible, use lower-resistance-risk post-emergence herbicides in the rotation, e.g. propyzamide and carbetamide in oilseed rape and beans
- **Use mixtures and sequences to reduce the threat.** Using higher-resistance-risk herbicides in mixture or sequence with lower-risk modes of action will help reduce weed populations. However, this will not prevent further selection for resistance. Remember there are restrictions on the sequential use of both ACCase- and ALS-inhibiting herbicides – introduced to reduce risk of herbicide resistance
- **Monitor herbicide performance in individual fields.** Resistance can vary considerably between and, to a lesser extent, within different fields. Management strategies need to take account of this inter-field variation. Close monitoring of variations in herbicide performance, both within and between fields, can act as an early warning of potentially greater problems ahead
- **Carry out regular testing for resistance.** While the factors responsible for the evolution of herbicide resistance are well established, predicting the risk at an individual-field scale is imprecise. Consequently, actual testing of seeds or plants from fields provides a more robust indicator of the degree of herbicide resistance. This needs to be done regularly, at least once every two to three years, if changes in resistance are to be detected reliably

Monitor herbicide resistance

Detecting herbicide resistance

Early detection is very important. Symptoms of herbicide resistance are:

- A gradual decline in control, over several years
- Healthy plants beside dead plants of the same species
- Poor weed control, leading to discrete weed patches
- Poor control of one susceptible species when other susceptible species are well controlled

Testing for herbicide resistance

Have a test carried out on seed or plant samples if you suspect resistance could be developing. Good sampling methodology is important if results are to be credible (Table 12).

Preferably, collect samples while control levels are still good overall. Do not wait until herbicides fail totally, as by then resistance management options will be much more limited.

Discuss sample collection and testing options with your adviser or crop protection supplier.

Table 12. Sample areas for resistance

Unit of assessment	Consistency	Implication for sampling
Patches	Good	One sample is likely to be representative of that patch
Within fields	Good/variable	Collect seed from a number of patches across the field
Between fields	Variable	Consider carefully how to approach sampling and be prepared to take samples from several fields on each farm
Farms	Variable	Do not rely on the results at one farm to predict those of another

Monitor the success of resistance management strategies

- Keep accurate field records of cropping, cultivation and herbicide use, as well as control achieved
- Monitor herbicide performance critically within individual fields to detect any progressive loss in herbicide efficacy, which can act as an early warning of potentially greater problems ahead
- Test specific fields every three years – either those with a known degree of resistance or where there is a high risk of resistance developing

Causes of herbicide resistance

The threat of herbicide resistance continues to grow due to:

- Increasing use of higher-resistance-risk herbicides (ACCase and ALS inhibitors, e.g. Atlantis)
- Loss of lower-resistance-risk herbicides (e.g. trifluralin and isoproturon)
- Lack of herbicides with new modes of action
- Trend towards more non-inversion tillage, which favours grass weeds
- Dominance of autumn-sown cereals and oilseed rape in arable rotations

Rapid and effective tests of herbicide resistance are available.

Sensitive

Resistant

Herbicide resistance in individual weeds

Black-grass
(Alopecurus myosuroides)

The major resistance problem in England

Resistance first found	1982
Cases confirmed	over 2,500
Number of counties	35

It is now accepted that some degree of resistance occurs in virtually all fields in England sprayed regularly with herbicides to control black-grass.

Findings from research studies

- Resistance to mesosulfuron + iodosulfuron, introduced into the UK in 2003 as 'Atlantis', has been confirmed on over 400 farms in 26 counties. ALS target site resistance was confirmed in many resistant populations, although enhanced metabolism also poses a big threat
- Use of high-resistance-risk ALS- and ACCase-inhibiting herbicides in mixtures and sequences with lower-risk modes of action increases the overall level of weed control but does not prevent resistance increasing
- Resistance can reduce the efficacy of all currently available pre-emergence herbicides but usually only to a limited degree. Flufenacet appears the least-affected herbicide. Resistance also appears to increase more slowly compared with the post-emergence ACCase- and ALS-inhibiting herbicides
- Non-chemical control methods can give useful, if modest, levels of control of black-grass. Greater use of non-chemical control methods will reduce the dependency on herbicides and so reduce the risk of resistance

Resistance status

- Non-target site resistance – very widespread
- Target site resistance to 'fops', 'dims' and 'dens' – widespread
- Target site resistance to ALS inhibitors – increasing

Italian rye-grass
(Lolium multiflorum)

An increasing threat throughout the UK

Resistance first found	1990
Cases confirmed	over 475
Number of counties	33

Resistance is widespread but is currently less problematic than with black-grass. Resistance poses an increasing threat due to over-reliance on high-resistance-risk herbicides (ACCase and ALS inhibitors).

Findings from research studies

- Resistance to cycloxydim (e.g. Laser) and pinoxaden (e.g. Axial) was found in under 20% of farms
- Resistance was mainly due to enhanced metabolism, although ACCase target site resistance was also detected. Resistance to ALS-inhibiting herbicides is likely to increase
- Rye-grass produces more seeds per plant than black-grass and is at least as competitive, so high levels of control are needed
- Most plant emergence (94%) occurs in the autumn, from October to December. Autumn-emerging plants produce about 23 times as much seed as spring-emerging ones
- Weed control should be focused on autumn rather than spring treatments

Resistance status

- Non-target site resistance – common
- Target site resistance to 'fops', 'dims' and 'dens' – occurs, but less commonly than in black-grass
- Target site resistance to ALS inhibitors – confirmed in 2012

Common wild-oat and winter wild-oat

(Avena fatua and *Avena sterilis* ssp. *ludoviciana)*

A limited but widespread problem

Resistance first found	1994
Cases confirmed	over 250
Number of counties	28

Currently, resistance tends to be more localised than with black-grass and rye-grass. Resistance continues to pose a threat due to over-reliance on high-resistance-risk herbicides (ACCase and ALS inhibitors).

Findings from research studies

- Herbicide-resistant wild-oats appear to be a relatively limited problem in the UK and have not increased as predicted. This is surprising, as resistant wild-oats are an increasing problem in some other countries (e.g. Canada, Iran) where there is high dependence on ACCase- and ALS-inhibiting herbicides
- Wild-oats are self-pollinated and so resistance cannot be spread by pollen. This may be why resistant wild-oats tend to occur in discrete patches. Preventing resistant patches spreading should be a top priority
- In contrast to black-grass and rye-grass, ACCase target site resistance tends to be more specific to 'fops', with 'dims' and 'dens' often remaining effective

Resistance status

- Non-target site resistance – confirmed
- Target site resistance tends to be specific to the 'fop' herbicides
- Target site resistance to ALS inhibitors – not yet confirmed in the UK

Broad-leaved weeds – chickweed, groundsel, common poppy and scentless mayweed

(Stellaria media, Senecio vulgaris, Papaver rhoeas and Tripleurospermum inodorum)

Although resistance has only been detected in these three species in UK arable systems, worldwide experience shows that resistance could evolve in many other broad-leaved weeds too, so vigilance is required.

Findings from research studies

- Resistance is confined to ALS-inhibiting herbicides (e.g. sulfonylureas, such as metsulfuron-methyl) in all three species, with alternative modes of action giving complete control
- Alternative herbicides that give good control of ALS-resistant populations include fluroxpyr (e.g. Starane 2) on chickweed, pendimethalin (e.g. Stomp Aqua) on poppy and clopyralid and bromoxynil on mayweed
- Resistance to mecoprop in chickweed has been confirmed in the past, but the extent of the problem is uncertain
- Triazine resistance has been confirmed in four UK populations of groundsel in asparagus fields in Worcestershire and Warwickshire. Although triazine herbicides were banned in the EU in 2007, triazinone herbicides (such as metribuzin and metamitron) have the same mode of action as the triazines. Triazinone herbicides are still widely used for weed control in potatoes, sugar beet and other crops. These populations have partial resistance to the triazinone herbicides

Resistance status

- Non-target site resistance – not found in broad-leaved weeds in the UK
- Target site resistance to ALS inhibitors – confirmed in all three species

Note: ACCase resistance is irrelevant as these herbicides are not active on broad-leaved weeds

Weed management in practice 1

Chris Bailey
Knapwell
Cambridgeshire

“A cover crop before spring beans prevents nitrogen loss and gives a wide window for black-grass control”

180 ha
Hanslope clay

Problem weeds:
Highly resistant black-grass
Patches of wild-oat
Typical range of broad-leaved weeds including crane’s-bill

Rotation:
1. Winter wheat
2. Winter oilseed rape
3. Winter wheat
4. Spring beans
   Sometimes includes a second wheat

Cultivation and timing

Crop	Soil movement	Cultivation timing	Drilling
Winter wheat after spring beans	Disc and tine	Soon after harvest	End September
Winter oilseed rape	None	–	Seed broadcast into wheat before harvest
Winter wheat after OSR	Disc or tine	Soon after harvest	End September
Spring beans	Disc	October	March

Current practice

No-till establishment of oilseed rape
Keeps weeds rooting at soil surface for a very high level of control from propyzamide.

Spray out black-grass patches
Where black-grass populations are high and autumn herbicides have had little effect, spraying out black-grass with a non-selective herbicide minimises seed return.

Suggested improvements

Delay winter wheat drilling
Chris mainly sows early and uses non-inversion techniques in his rotation. At present, black-grass control is adequate, but the weed seedbank is building gradually. To reduce this, late sowing of the first wheat after oilseed rape allows for increased use of a non-selective herbicide, while ploughing before spring beans reduces the weed seedbank further.

Later sowings can maintain this lower seedbank.

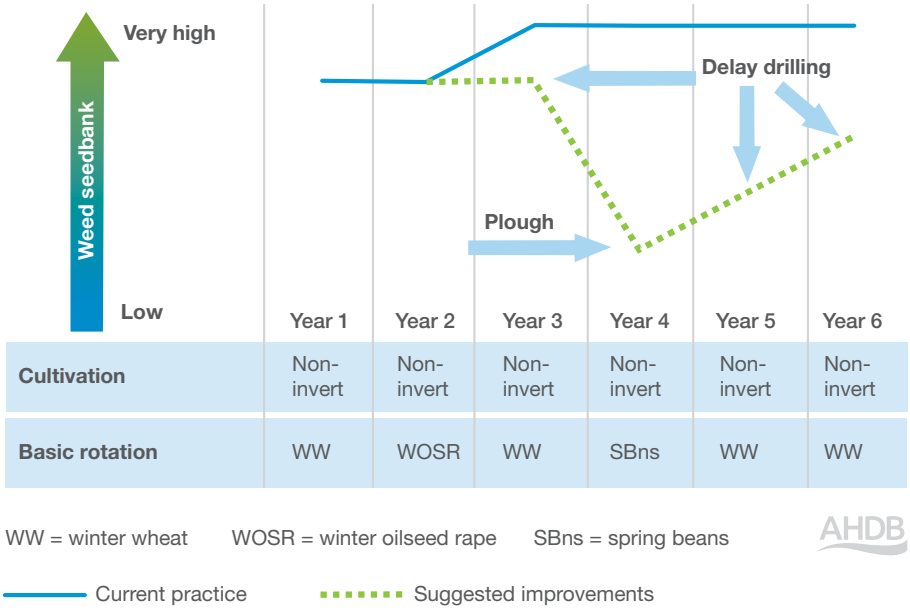


Figure 3. Impact of cultivation and rotation on the weed seedbank

Weed management in practice 2

Andrew Cragg
Romney Marsh
Kent

"Spring cropping is not attractive in the short term but offers many long-term benefits"

560 ha
Silty clay loam

Problem weeds:

Black-grass
(ALS resistance confirmed)

Crane's-bill and cleavers increased in recent years

Sow-thistle and charlock in oilseed rape

Hedge mustard in peas

Rotation:

1. Winter wheat
2. Winter wheat
3. Winter oilseed rape
4. Winter wheat
5. Winter wheat
6. Vining peas

Cultivation and timing

Crop	Soil movement	Cultivation timing	Drilling
First winter wheat	Disc	At drilling	Late September
Second winter wheat	Mainly disc or some plough	Soon after harvest	October
Oilseed rape	Loosening and power harrow	As early as possible	Early August
Vining peas	Plough and press	Early autumn	April/May

Current practice

Inclusion of a spring crop

Ploughing and a wide window for weed control with non-selective herbicides give high levels of black-grass control and a herbicide-free spring crop.

Controlled traffic system

Improved soil structure and oilseed rape establishment.

Suggested improvements

Ploughing and later drilling to reduce the black-grass seedbank

Ploughing down black-grass before spring peas results in fewer seeds in the germination layer. Ploughing before wheat in year three would lead to an initial decrease in black-grass. (Delaying sowing from October until early November would increase the effect much more.) Ploughing in year three also reduces the volunteer oilseed rape seedbank. A pea crop and October sowing of the final wheat crop maintains the lower black-grass seedbank.

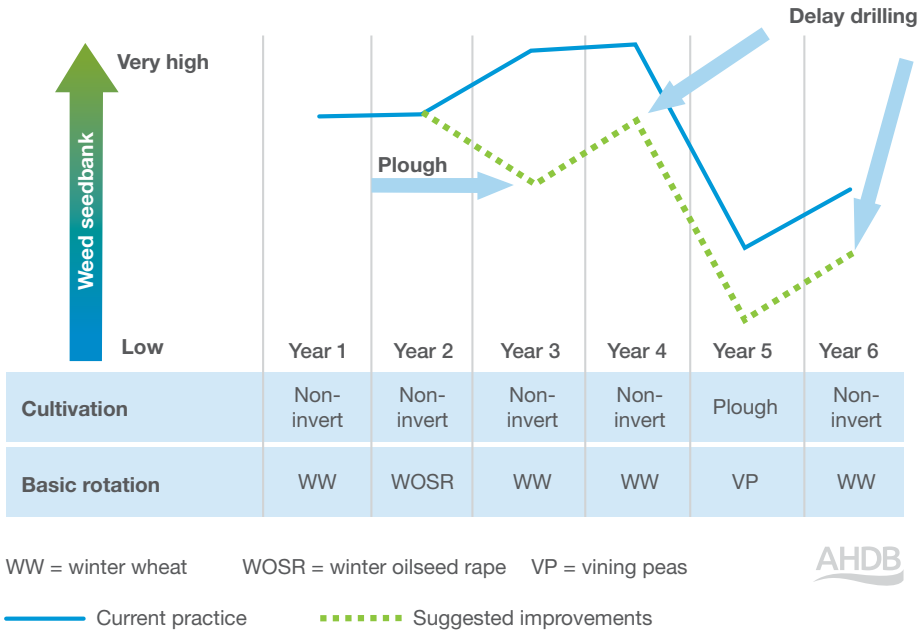


Figure 4. Impact of cultivation and rotation on the weed seedbank

Weed management in practice 3

Richard Davey
Chalgrove
Oxon

"Rather than having a poorly established break crop, it's better to have no crop at all"

1,150 ha
Light sandy loam to heavy clay

Problem weeds:
High levels of highly resistant black-grass

Rotation:
1. Winter wheat
2. Break
3. Winter wheat
4. Break

Soil type and topography dictate break crops, which include winter beans, winter and spring oilseed rape

Cultivation and timing

Crop	Soil movement	Cultivation timing	Drilling
First winter wheat	Disc and tines	Soon after harvest	End September
Winter beans	Disc and tines	Soon after harvest	End October
Winter oilseed rape	Disc and tines	Soon after harvest	Third week August

Current practice

Prompt herbicide application
Residuals applied within 24 hours of drilling.

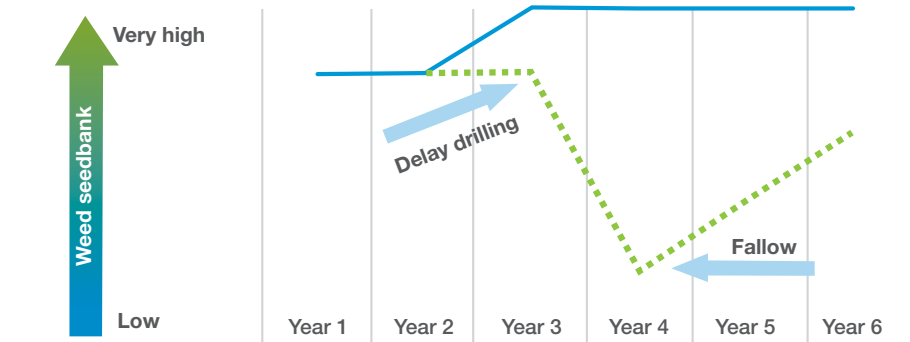
Stale seedbed
Shallow cultivation after harvest encourages black-grass to chit. If moisture is adequate, then deeper cultivations used for a better chit.

Delayed wheat drilling
Delaying drilling until early October enables weed control via stale seedbed.

Suggested improvements

Use fallows to reduce soil seedbank
Richard does not want to plough and is not keen on spring cropping due to establishment problems. While controlling weed numbers in his crop, his current practice has not reduced the black-grass seedbank.

A possible change may be the use of later sowing and fallows. A November sowing in year three begins to reduce the seedbank. A fallow in year four causes a further, large reduction.



	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6
Cultivation	Non-invert	Non-invert	Non-invert	Non-invert	Non-invert	Non-invert
Basic rotation	WW	WOSR	WW	WBns	WW	WOSR

WW = winter wheat WOSR = winter oilseed rape WBns = winter beans

Current practice Suggested improvements

Figure 5. Impact of cultivation and rotation on the weed seedbank

Weed management in practice 4

Philip Mortimer
Maidenhead
Berkshire

"Changing from winter to spring oats has helped to achieve better black-grass control"

397 ha
Heavy clay and silty loam

Problem weeds:
Suspected resistant black-grass, annually rogued wild-oat, crane's-bill

Rotation:
1. Winter wheat
2. Winter oilseed rape
   Spring beans or spring oats grown to break up the rotation

Cultivation and timing

Crop	Soil movement	Cultivation timing	Drilling
Winter wheat	Disc and flat lift	Soon after harvest	October
Winter oilseed rape	None	–	Broadcast behind combine header
Spring beans/ oats	Plough	Early autumn	March

Current practice

Broadcasting rape behind combine header
Keeps weed seeds on soil surface to maximise control from propyzamide.

Spring cropping
Maximises periods for non-selective herbicides to control germinating black-grass.

Ploughing
Buries short-lived seeds to decrease seedbank levels.

Suggested improvements

Reduce resistant black-grass seed numbers in the upper soil layer
Philip's target rotation is to alternate winter wheat and rape. He usually uses minimum tillage but will plough if black-grass levels seem to be getting too high. An alternative is spring cropping after ploughing, which provides a longer period for winter weed control. This reduces seed in the germination layer for future years.

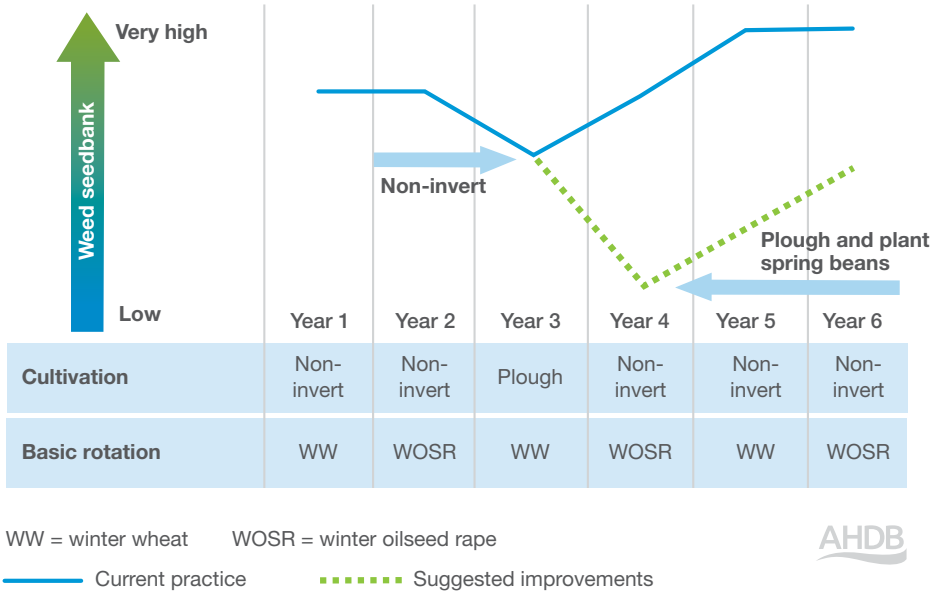


Figure 6. Impact of cultivation and rotation on the weed seedbank

Weed management in practice 5

Graeme Neill
Nr Arbroath
Angus

"Resistant chickweed is controlled before drilling and by using mixtures of herbicides"

262 ha
Sandy loam

Problem weeds:
ALS-resistant chickweed, common field-speedwell, annual meadow-grass, cleavers

Rotation:
1. Potatoes
2. Winter wheat/spring barley
3. Winter wheat
4. Spring barley
5. Winter oilseed rape
6. Winter wheat

Cultivation and timing

Crop	Soil movement	Cultivation timing	Drilling
Potatoes	Plough and stone separator	November/ December	April
Winter wheat	Deep till	Late September/ October	End September or later
Winter barley	Plough	Early September	Early September
Spring barley	Plough	December	March
Winter oilseed rape	Plough	August	August/September

Current practice

Using non-inversion tillage in first wheats after potatoes

Volunteer potatoes are becoming less of a problem in the rotation due to increased predation.

Using a range of active ingredients to control chickweed

ALS-resistant chickweed is not widespread on the farm. Chickweed seed is persistent in the seedbank and multiplication rates are high.

Suggested improvements

Controlling chickweed seedbanks in the upper layer of soil

Chickweed seeds survive for over five years, so it is important after ploughing to leave the old seeds at depth and not disturb them. Seed return is managed by stale seedbeds before drilling, and all subsequent seeds are left on the surface. Spring barley crop allows a long period to control emerging chickweed as it emerges over winter.

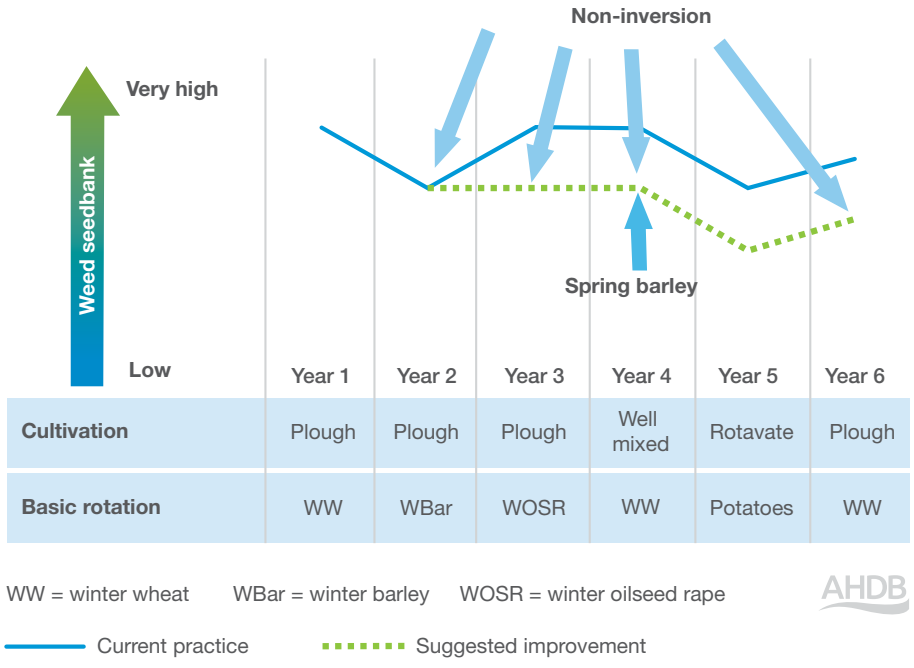


Figure 7. Impact of cultivation and rotation on the weed seedbank

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Further information

The latest guidance, project reports and other information can be accessed via **ahdb.org.uk/arable-weeds**

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Produced for you by:

AHDB
Middlemarch Business Park
Siskin Parkway East
Coventry
CV3 4PE

T 024 7669 2051
E comms@ahdb.org.uk
W ahdb.org.uk

If you no longer wish to receive this information, please email us on **comms@ahdb.org.uk**

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