# BLACK-GRASS (*ALOPECURUS MYOSUROIDES*): WHY HAS THIS WEED BECOME SUCH A PROBLEM IN WESTERN EUROPE AND WHAT ARE THE SOLUTIONS?

Stephen Moss, Harpenden, UK, highlights the importance of understanding the agro-ecology of this annual grass-weed, not only in explaining the problem it poses in arable crops, but also in formulating effective, long-term management solutions. Stephen Moss Consulting E-mail: alopecurus@aol.com

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## Introduction

Black-grass (*Alopecurus myosuroides*) occurs in over 60 countries worldwide but its occurrence as a major annual grass-weed of arable crops is very largely confined to Western Europe (CABI, 2017). However, here it is one of the most problematic weeds of autumn sown crops, largely as a consequence of widespread, evolved resistance to herbicides. Heap (2017) lists 14 countries with herbicide resistant populations, including Belgium, Denmark, France, Germany, Netherlands and the UK, the first country where resistance was detected, in 1982 (Moss & Cussans, 1985). Black-grass is becoming an increasing problem in eastern and northern Europe too, with resistance confirmed in the Czech Republic in 2008, Poland in 2010 and Sweden in 2011. Although often considered a relatively 'new' weed, it was recognised as a 'very troublesome weed among wheat' over 175 years ago (Sinclair, 1838). However, black-grass has certainly become more widespread and more problematic to control during the last 50 years. Why is this?

Changes in arable cropping and tillage systems have encouraged black-grass and also, as a consequence, intensive use of herbicides for its control. This over-reliance on herbicides, combined with limited use of non-chemical control methods, has resulted in widespread resistance, especially to post-emergence acetyl-CoA carboxylase (ACCase) and acetolactate synthase (ALS) inhibiting herbicides. Since the 1970s, farmers had grown accustomed to the regular introduction of effective new black-grass herbicides. However, no major new herbicide with a novel mode of action has been commercialised for over 30 years (Duke, 2012) and most, but certainly not all, farmers now accept that there is no simple 'chemical solution' for controlling resistant black-grass.

With declining performance of post-emergence herbicides, farmers have had no option other than to use more pre-emergence herbicides, which tend to be less resistance-prone, combined with much greater reliance on non-chemical control methods. However, while the adoption of integrated weed management (IWM) strategies is laudable, it has largely been out of necessity, rather than as a measured way of reducing pesticide use, which is European Union policy.

The author has been involved in research on black-grass for over 40 years, and this article highlights his beliefs that effective management solutions can only be achieved through a good understanding of the agro-ecology of the weed. In addition, farmers need to adopt a longer-term view and accept that 'quick' fixes are unlikely to be effective.

## Agro-ecology of black-grass

Black-grass is an annual grass-weed propagated solely by its seeds with a single generation a year. It is favoured by water-retentive soils, so tends to be more of a problem on heavier clay or silt loam rather than on lighter sandy or gravelly soils. A considerable amount of research has been done on the agro-ecology of black-grass within arable cropping systems and some key aspects are summarised in Table 1. Although these are based largely on UK studies in wheat dominated rotations, they are also relevant to other countries with a similar climate and agronomic system.

Much of the information presented in Table 1 is based on old field studies but there is no evidence to suggest it is not equally relevant today. This is an important point; obtaining field data on weed agro-ecology is time consuming and expensive but good data are likely to have durability, so are worth the investment.

The first three factors listed in Table 1, seedling emergence patterns, depth of emergence and seed longevity, will all regulate the black-grass population within the crop. Knowledge of seed shedding pattern is relevant to interventions aimed at minimising seed return. The last two factors, population dynamics and competitive ability, are directly relevant to long-term control strategies.

The practical implications of these six factors have direct relevance to understanding, not only why black-grass has

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**Table 1.** Six key aspects of the agro-ecology of black-grass based on studies in winter wheat crops. Sources: Naylor, 1972; Moss, 1980, 1983, 1985; Holm *et al.*, 1997; Blair *et al.*, 1999; Bond *et al.*, 2007; Moss *et al.*, 2010.

| | Life cycle factor | Mean or Typical value |
|---|---|---|
| 1 | Seedling emergence patterns | 80% of the total is in early autumn (September/October mainly) |
| 2 | Seedling depth of emergence | Seedlings can only emerge from seeds within 5 cm of the soil surface |
| 3 | Seed longevity in soil | 74% decline per year; only a small proportion survive 5 years burial |
| 4 | Seed shedding pattern | Mid-June to mid-August with peak in July; most shed pre-harvest |
| 5 | Population dynamics | Plant populations can increase by >10 fold per annum; >95% control needed annually to prevent populations increasing |
| 6 | Competitive ability | 5% yield loss at 12 black-grass plants $m^{-2}$; >50% yield loss possible |

become a problem, but also in formulating solutions. The relevance of these different aspects of agro-ecology will be highlighted in the following sections. The challenge is to use such information to reduce populations to more manageable levels.

## The problem

Black-grass has become an increasing problem in the UK in the past 40 years for four main reasons. These are also relevant, to a greater or lesser extent, in other Western European countries too:

1. More crops sown in autumn, especially winter cereals and oilseed rape
2. A trend towards sowing earlier in the autumn
3. Greater use of minimum tillage instead of ploughing
4. Widespread herbicide resistance

### *More crops sown in autumn*

Oilseed rape, mainly sown in August or early September, was first grown extensively in the UK in the mid-1970s, with over 55,000 ha being sown in 1977. Now, about 600,000 ha are sown each year, more than a 10-fold increase. Wheat area, again mainly autumn sown, has increased from about 1.2 million ha in the mid-1970s to just under 2 million ha in recent years (FAO, 2017). The total UK arable area, including horticulture, was about 4.7 million ha in 2016 and the main crops grown are shown in Figure 1.

In 2016, cereals and oilseed rape accounted for about 80% of the cropped area and about 66% of all crops were sown in autumn (mainly Aug/Sept/Oct). Why is this so relevant? The predominantly autumn seedling emergence pattern of black-grass (Table 1) means that the amount that emerges within the crop is very dependent upon crop sowing date. Autumn sowing results in a high proportion of black-grass plants emerging within the crop rather than before sowing, when they could more easily be destroyed. **The trend to growing more autumn sown crops has increased the threat from black-grass.**

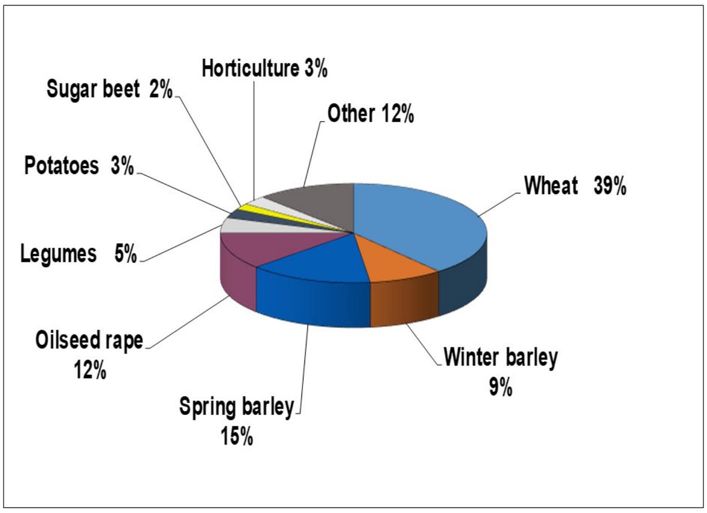


**Figure 1.** UK cropping areas at 2016 harvest (Defra 2017).

### *Sowing earlier in the autumn*

The increase in autumn sown cropping has also been associated with a trend towards ever earlier sowing. Oilseed rape is mainly sown in August or early September but during the last 40 years the trend towards earlier sowing of winter wheat has been dramatic (Figure 2).

In the mid 1970s, fewer than 5% of winter wheat crops were sown in September whereas, in recent years, over 40%, and sometimes over 50%, of crops have been sown

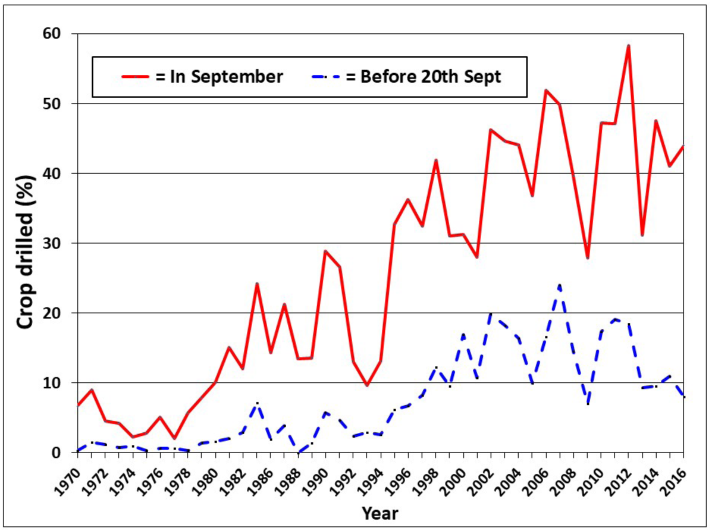


**Figure 2.** The proportion of winter wheat crops in England sown in September, and before 20th September, 1970 – 2016 harvest years. (Crop Monitor, 2017).

in September – a 10-fold increase. The proportion of wheat crops sown very early, prior to 20 September, also increased up until about 2000. However, the proportion of crops sown in September seems to have stabilised and there is evidence of a decline in the proportion sown very early. This is almost certainly due to the recognition that early sowing favours black-grass. Ever-earlier autumn sowing exacerbates the problem associated with more autumn cropping by increasing further the proportion of black-grass that emerge within the crop. **The trend to earlier sowing in autumn has led to more serious black-grass infestations within the crop.**

**Photo 1. Black-grass (*Alopecurus myosuroides*) in a winter wheat crop.**

### *Greater use of minimum tillage*

Tillage systems have changed during the past 40 years too. Straw burning was an effective method of killing 40 – 80% of freshly shed black-grass seeds but restrictions on its use, culminating in the practice being banned in the UK in 1993, resulted in more ploughing because of the need to incorporate large quantities of straw to avoid blockages of seed drills. However, since 2000, there has been a steady increase in the use of non-inversion cultivations due to the introduction of more effective straw choppers on combine harvesters, improved cultivation equipment and drills capable of operating effectively in seedbeds containing large quantities of chopped straw. This change has been driven primarily by a need to increase work rates, reduce labour requirements and costs. More recently, the potential benefits to soil health from using reduced cultivations have become more widely recognised. In contrast to ploughing, shallow tillage or direct drilling retains most freshly shed seeds within the critical 5 cm surface layer of soil from where seedlings can readily emerge (Table 1). ***Where there is substantial fresh seed return*, shallower tillage increases the potential black-grass infestation within the crop.**

### *Herbicide resistance*

The three factors above, which all favour black-grass, would be of no consequence if herbicides used within crops could be relied upon to kill black-grass effectively. Unfortunately, black-grass is now the most important herbicide-resistant weed in Europe, occurring in at least 14 countries (Heap, 2017). In the UK, resistant populations were first found in 1982 but now occur on virtually all of the estimated 20,000 farms in 35 counties where herbicides are applied regularly for its control (Hull *et al*., 2014). This very high incidence of resistance appears to be unmatched by any other weed species and country worldwide.

ACCase target site resistance is present in most populations, but at varying frequencies, and is conferred most frequently by mutations at the Ile-1781 codon position (Delye, 2010; Knight, 2015). ALS target site resistance is also increasing and is conferred by mutations at both the Pro-197 and Trp-574 codon positions which appear to occur at approximately equal frequency (Marshall & Moss, 2008; Marshall *et al*., 2013; Knight, 2015). However, enhanced metabolic non-target site resistance, affecting both ACCase, ALS and many other herbicides, appears to be the commonest mechanism.

The frequency of multiple resistance can be demonstrated by results from tests on 122 black-grass samples tested in 2013. Of the 122 populations, 98% showed resistance to at least one herbicide, with 75% resistant to mesosulfuron plus iodosulfuron, 84% resistant to cycloxydim, 66% resistant to pendimethalin and 46% resistant to all three herbicides (Hull *et al*., 2014).

**Table 2.** Year of commercial introduction into the UK for 41 herbicides with activity against black-grass. Resistance has been demonstrated to all herbicides shown in bold. * = sold in mixture with other herbicides. Based on Lockhart *et al*., (1990).

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 1956 | **simazine** | 1971 | **chlorotoluron** | 1982 | **metazachlor** | 1997 | **flupyrsulfuron*** |
| 1958 | **atrazine** | 1971 | propyzamide | 1982 | **chlorsulfuron*** | 2001 | **sulfosulfuron** |
| 1958 | barban | 1974 | **ethofumesate** | 1983 | napropamide | 2001 | **tepraloxydim** |
| 1962 | paraquat | 1974 | carbetamide | 1984 | **quizalofop-ethyl** | 2001 | **flufenacet*** |
| 1964 | **tri-allate** | 1974 | glyphosate | 1986 | **imazamethabenz** | 2002 | **propoxycarbazone** |
| 1965 | nitrofen | 1975 | **isoproturon** | 1990 | **fenoxaprop** | 2003 | **mesosulfuron*** |
| 1967 | trifluralin | 1975 | **flamprop** | 1991 | **cycloxydim** | 2006 | **pinoxaden** |
| 1968 | **terbutryn** | 1976 | **diclofop** | 1993 | **tralkoxydim** | 2006 | **prosulfocarb** |
| 1968 | **methabenz.** | 1979 | **pendimethalin** | 1994 | **propaquizafop** | 2007 | **flumioxazin** |
| 1969 | **metoxuron** | 1981 | **fluazifop** | 1995 | **clodinafop** | 2009 | **pyroxsulam*** |
| | | | | | | 2013 | **clethodim** |

**Photo 2.** The challenge posed by herbicide-resistant black-grass: only 20% control was achieved in this wheat crop despite >£100 ha$^{-1}$ spent on a sequence totalling 360 g flufenacet ha$^{-1}$, 120 g diflufenican ha$^{-1}$, 600 pendimethalin ha$^{-1}$ and 12+2.4 g mesosulfuron+iodosulfuron ha$^{-1}$.

Declining performance of post-emergence ACCase and ALS herbicides, due to resistance, has resulted in greater use of pre-emergence herbicides such as flufenacet, pendimethalin, prosulfocarb, flupyrsulfuron and tri-allate. Many farmers use mixtures or close sequences of three to five different active ingredients, but all pre-emergence herbicides are affected by resistance to some degree, although resistance tends to be partial and builds up slowly (Moss & Hull, 2009; Hull & Moss, 2012; Ducker *et al*., 2016). However, their efficacy is dependent also on adequate soil moisture and this unpredictable source of variation, combined with resistance, means that it is doubtful whether reliance on pre-emergence herbicides alone for control of black-grass is sustainable in the longer-term.

Forty-one herbicides have been introduced for black-grass control during the last 60 years (Table 2). Only one, clethodim, has been introduced in the last eight years and that was first commercialised over 25 years ago elsewhere in the world. Some of the herbicides listed were capable of achieving close to 100% kill of black-grass in favourable conditions. However, resistance has evolved to most of these herbicides since 1982 and, while rarely causing complete failure, reduces efficacy and results in more variable control.

**Increasing resistance to most existing herbicides, and lack of new modes of action, means that herbicides alone can no longer be relied on to control black-grass effectively.**

## The solution

With the benefit of hindsight, the increase in the proportion of arable crops sown in late summer and autumn (principally oilseed rape and winter wheat), combined with a trend to ever-earlier sowing and more minimum tillage, meant that increasing problems with black-grass were inevitable. However, what could not be predicted was how rapidly and widely multiple-herbicide resistance would evolve. This problem was compounded by farmers' over-reliance on herbicides and the lack of new herbicide modes of action. Consequently, this emphasis on chemical control was not sustainable, as is also the case with many other weeds worldwide (Shaner & Beckie, 2014).

If these factors encouraged black-grass, then the solution is obvious – do the opposite; sow crops later and reduce dependency on herbicides. Diversity is the key to successful long-term black-grass management with greater use of non-chemical methods of control and less reliance on herbicides (Shaner, 2014). An integrated weed management (IWM) approach is needed, in which as many tactics as possible are used to combat weeds. In this way, less reliance is placed on herbicides and so selection pressure for resistance should be reduced

Many non-chemical methods of weed control are available, and recent reviews of IWM include Beckie (2006), Norsworthy *et al*. (2012), Harker & O'Donovan (2013) and Melander *et al*. (2013, 2017). Table 3 summarises the major non-chemical methods available for control of black-grass in winter cereals based on a comprehensive review of over 50 field experiments (Lutman *et al*., 2013).

The mean level of control for each method is modest compared to what would be expected from herbicides in the absence of resistance. The wide range for each method shows how variable non-chemical control can be – in some cases 'negative control' was achieved. Herbicides will continue to have an important role to play too, as resistance often results in reduced herbicide activity, rather than no activity at all. However, if

**Table 3.** The efficacy of non-chemical methods for control of black-grass based on a review of over 50 field experiments (Lutman *et al*., 2013).

| | % control black-grass | | |
|---|---|---|---|
| **Method** | **Mean** | **Range** | **Comments** |
| Ploughing | 69% | –82% to 96% | Rotational ploughing has considerable benefits |
| Delayed autumn drilling (by 3-4 weeks from mid-September) | 31% | –64% to 97% | The later the better – but increased risk |
| Higher seed rates | 26% | +7% to 63% | The higher the better – but lodging issues |
| More competitive cultivars | 22% | +8% to 45% | Useful, but marginal effects |
| Spring cropping | 88% | +78% to 96% | Effective; challenging on heavy soils; may need repeating for several years; limited herbicides |
| Fallowing/grass leys | 70–80 % per year (of seedbank) | | Absence of new seeding critical |

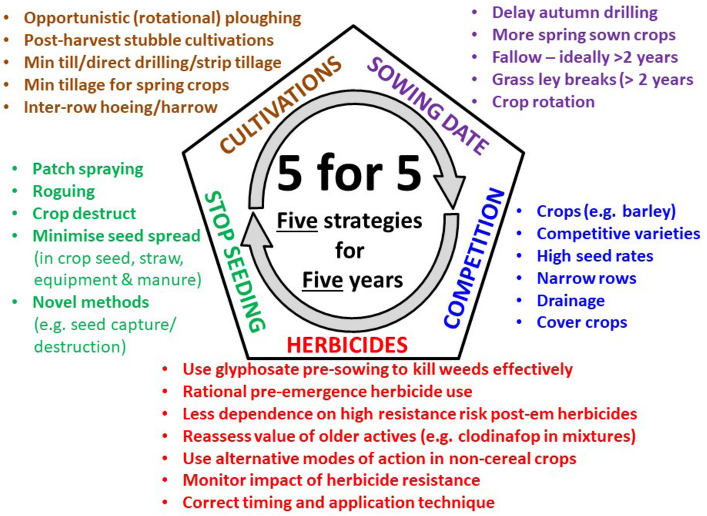


**Figure 3.** The '5 for 5' initiative to combat black-grass.

control from herbicides continues to decline as a consequence of increasing resistance, greater control will be required from non-chemical methods to maintain the same overall high level of control (>95%) required to prevent populations increasing and minimise crop losses (Table 1). **The aim must be to integrate the use of *several* non-chemical control methods, in combination with herbicides, to improve overall control**.

## The '5 for 5' initiative

This is a new UK initiative aimed at encouraging farmers to adopt comprehensive strategies to tackle black-grass by maintaining a planned, integrated approach at the individual field level for at least five years. Why five years? Because this is how long it takes to reduce the black-grass seed burden in the soil substantially, providing new seed production is minimised (Table 1). The *relatively* short seed persistence of black-grass is its one weakness – '5 for 5' aims to exploit this.

Farmers are encouraged to plan a strategy for each field involving all five of the main components shown in the diagram (Figure 3).

There is no single 'best' blueprint – the most appropriate strategy will vary from field to field. Farmers are also encouraged to: ***Record*** the amount of black-grass, and its location, in every individual field to quantify progress; ***Review*** progress annually to identify the most effective strategies; ***Revise*** the plan if necessary, but not to expect dramatic improvements within only 1 or 2 years.

In essence, 5 for 5 is all about: refining existing control strategies rather than relying on unproven new 'gimmicks'; recognising that beating black-grass requires a multi-year commitment at the individual field level; and being more proactive and disciplined in tackling black-grass.

## Implementation of IWM – a history of failure?

Globally, integrated weed management (IWM) has been actively promoted as a means of reducing dependence on herbicides, but the uptake of these technologies has been poor (Shaner & Beckie, 2014). Researchers often fail to understand why farmers do not adopt more non-chemical methods of weed control. Compared with herbicides, non-chemical methods are often more complex and time-consuming to manage, less effective, more variable and less predictable, more labour intensive, more risky (to advisor as well as farmer), more expensive for the level of control achieved and there is often little visible evidence of success (Moss, 2010). It should come as no surprise then, that farmers are tempted to delay adoption of IWM when the costs (in time and inconvenience, as well as money) are immediate, while the benefits may take a long time to become apparent and are less predictable (Hurley & Frisvold, 2016).

It is significant that most of the strategies for control of black-grass detailed in Table 3 were researched and actively promoted 40 years ago but it is only in recent years that there has been widespread uptake. This has been out of necessity due to a lack of effective chemical alternatives. This experience with black-grass in the UK mirrors global experience that little is done to manage herbicide-resistant weeds until they start to cause a significant problem (Shaner, 2014).

## What is needed?

Black-grass has become a problem for reasons that now seem obvious – a combination of more autumn cropping, earlier sowing and widespread herbicide resistance. The technical solutions are equally clear and well researched, but require a commitment to a strategy lasting at least five years. The problem is that many of the alternatives to herbicides incur greater costs, diminished returns or both penalties. The challenge is implementing a strategy without seriously jeopardising financial returns.

Morse (2009) stressed that, while research is an important part of the overall strategy, there must be greater recognition of what farmers are able and willing to 'do'. A key aim must be a greater recognition of the part played by farmers and their advisors in decision making. This requires more emphasis on the social, psychological and economic drivers on the decision making process. The importance of these aspects is being recognised more widely and, in 2016, a special edition of Weed Science containing 12 papers on the 'Human dimensions of herbicide resistance' was published (Weed Science **64**, Special Issue).

It is vital that the very considerable research effort worldwide produces sound, practical weed management strategies which are easily implemented by farmers (Shaner, 2014). There has been too much emphasis on academic studies at the expense of research and extension activities more directly related to tackling the problem in the field. Although IWM has had limited success in terms of its adoption by farmers, it does have a very successful history in terms of its adoption by scientists, pressure groups and policy makers (Morse & Buhler, 1997). This shameful situation must change. The real challenge is now not technical – it is sociological, psychological and economic.

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