The biology and non-chemical control of black-grass (*Alopecurus myosuroides* Huds)

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Black-grass
(black couch, black twitch, hungerweed, rat-tail, mousetail grass, slender foxtail)
***Alopecurus myosuroides* Huds**
(*Alopecurus agrestis* L.)

Occurrence
Black-grass is a native, annual grass weed of arable land often troublesome in cornfields on heavy soil (Long, 1938; Morse & Palmer, 1925). It is scattered throughout the UK but rarely occurs outside of the arable situation. It is abundant in SE England but is a casual in the North (Clapham *et al*., 1987). It is most abundant where the mean July temperature exceeds 15^{o}C (Thurston, 1972). It has not been recorded on land above 1,000 ft (Salisbury, 1961). While black-grass appears to be a lowland species this may be partly a reflection of the distribution of arable land (Naylor, 1972b). In early surveys of Bedfordshire, Hertfordshire and Norfolk, black-grass was universally distributed over different soil types but was rare on chalk and was typically found on heavy clay (Brenchley, 1911; 1913). It remains chiefly confined to heavy land, occurring only occasionally on sandy or gravely soil but has begun to appear on chalk.

Black-grass is most abundant in winter crops especially cereals (Riepma, 1953). It was also associated with peas and beans (Brenchley, 1920). It occurs in the main cereal growing area of Britain south and east of the Trent, Severn and Exe (MAFF, 1975). The potential distribution of black-grass has been mapped using botanical survey and soil survey data (Firbank *et al.*, 1998). The probable distribution was seen to be mainly in southern and eastern Britain. The species is often found spreading into arable fields from the hedge bottom (Marshall, 1985; 1989). In a 3-year set-aside, black-grass frequency increased with increasing distance from the field edge (Rew *et al.*, 1992).

In a survey of weeds in conventional cereals in central southern England in 1982, black-grass was found in 33, 15 and 7% of winter wheat, winter barley and spring barley respectively (Chancellor & Froud-Williams, 1984). A study of changes in the weed flora of southern England between the 1960s and 1997 suggests that black-grass has become more common (Marshall *et al.*, 2003). In a study of seedbanks in some arable soils in the English midlands sampled in 1972-1973, black-grass was recorded in 56% of fields sampled in Oxfordshire and 78% in Warwickshire sometimes in large numbers up to 64,500 seeds per m^2 (Roberts & Chancellor, 1986). In seedbank studies in arable fields in France, black-grass was well represented in the seedbank and in the emerged vegetation (Barralis & Chadoeuf, 1987).

Early records suggest that black-grass was once planted as a forage grass but was refused by most cattle (Naylor, 1972b). Albino seedlings occur at a frequency of 1 in 4000 (Brenchley & Warington, 1936). Populations of black-grass have developed with resistance to the widely used 'fop and dim' graminicides and this has contributed to its increase in conventional cereal crops (Clarke & Moss, 1989; 1991). Resistance to the herbicide chlortoluron has also been reported (Putwain & Mortimer, 1989). Populations vary in the extent of resistance to a number of herbicides and plants may show cross-resistance to more than one herbicide (Moss, 1990).

Black-grass suffers from ergot (*Claviceps purpurea*) and this can result in contamination of the grain at harvest leading to rejection of the crop (MAFF, 1975; Moore & Thurston, 1970). It is the same strain of ergot that infects wheat. Spring emerging black-grass is more likely to suffer ergot due to flowering date coinciding with spore release (Thurston, 1976). It is more of a problem when there is heavy rain at flowering time of the weed (Orson, 1989).

Biology

Black-grass flowers from May to August, sometimes into October (Long, 1938; Morse & Palmer, 1925). It is both self-fertile and cross-pollinated. The pollen is wind borne. The flower heads appear above the cereal crop in May and June. After the first ears or heads are formed, side branches may arise from above ground nodes and develop additional flower heads (Thurston, 1972). Seed numbers per head can vary from 80 to 127 (Moss, 1981b). Seed production per plant may range from just 50 up to 6,000 seeds, the greatest number on plants germinating in early autumn (MAFF, 1975). Seed numbers per plant decrease with increasing plant density (Moss, 1987). The seed ripens quickly and is shed before the harvest of most of the crops in which it grows. Shedding occurs from late June to late August (Moss, 1983; 1981b). In winter cereals, seed is mainly shed in July (Moss, 1978). Most of the seed has been shed by the time of winter wheat harvest but only 50% by winter barley harvest. Any seeds that remain unshed at harvest can contaminate the harvested grain. Seed viability ranges from 45 to 77% (Moss, 1981b). The viability of seed shed at the start and end of shedding is lower than that of seed shed at the peak time.

Black-grass seeds may be all dormant when shed (Thurston, 1972), or some may be able to germinate soon after shedding while others remain dormant for a few months. Seeds at the end of shedding are more dormant than those that mature earlier (Froud-Williams, 1985). Seeds reach their maximum germination potential 3 to 6 months after shedding (Barralis *et al.*, 1970. Seed sown in pans of field soil germinated almost immediately, 97% in the first year, indicating little natural dormancy (Brenchley & Warington, 1930). Seeds naturally-occurring in field soil, concentrated down by washing/sieving and put into dishes, germinated best in conditions where the temperature fluctuations were around 16^{o}C (Warington, 1936). When temperature fluctuations were no more than 1^{o}C seed germination was 50% lower. Seed that did not germinate in the first year rarely survived to produce seedlings in the following year. Usually the majority of seeds germinate within 1 year of shedding but some become dormant when buried deeply or in waterlogged soil (Thurston, 1964). However, large differences have been found in the germinability of seed from different populations of black-grass (Naylor & Abdalla, 1982). A germination value for one population may not be representative of other populations.

Light and fluctuating temperatures stimulate germination. Light has more effect on dormant seeds, non-dormant ones are less sensitive (Thurston, 1972). Seeds generally lose their innate dormancy after 2 months dry storage. In laboratory tests, irradiation with red light enhanced germination (Froud-Williams, 1981). The overall optimum germination temperature was 8°C. Germination was curtailed above 20°C (Froud-Williams, 1985). Other studies suggest that germination starts at 5°C and reaches a peak at 17°C but ceases above 30°C (Naylor, 1972b). The optimum germination temperature according to Barralis *et al.* (1970) was 15°C. Maximum germination in soil requires a high moisture content close to field capacity. In laboratory studies to provide data for a population model the minimum germination temperature was estimated to be 0°C (Colbach *et al.,* 2002a). The rate of germination increased with light and seed age. Seed germination proportion and rate was increased by dry storage and by imposing short dry periods after imbibition (Colbach *et al.,* 2002b). Long dry periods after imbibition decreased germination .

In the field, there are two peaks of germination, autumn and spring, but weather conditions in the autumn may delay germination until spring (Thurston, 1972; Salisbury, 1961). If conditions are favourable most seeds germinate in late October and early November (Thurston, 1964). There is then a small flush of seedlings in spring, which is increased if autumn germination has been prevented (Thurston, 1976). Seed dormancy is enforced by waterlogged soil (Naylor, 1972b). The timing of flushes of emergence will also vary with prevailing weather conditions and the timing of cultivations. In winter cereals, around 80% of black-grass germinates in the autumn from September to November (Moss, 1985). Seeds normally germinate best near the soil surface and burial can result in some degree of dormancy. Germination and growth are better on fine particle soils (Thurston, 1972).

Seed sown outside in pots and boxes of soil germinated throughout the year, but germinated mainly in autumn and winter when left on the soil surface (Froud-Williams *et al.,* 1984a). Emergence was much less when seed was sown at 25 mm with no further cultivation. Seed sown at 75 mm and cultivated in February germinated mainly in spring and autumn. If cultivated in June, emergence was mainly in summer and autumn. In other studies, seed sown on the soil surface gave 48% germination, seed sown at 25 mm deep gave 8% germination and seed sown at 150 mm did not germinate until exhumed (Froud-Williams *et al.,* 1984b). The extent of germination of exhumed seed depended on the time of year that germinability was tested. In the tests at alternating temperatures, germination was greatest in the light or when seeds were transferred from dark to light.

In the field, over 95% of seedlings emerged from the top 30 mm of soil, and more than 50% emerged from the surface 10 mm (Cussans *et al.,* 1979). A small number of seedlings have been found to emerge from 100-120 mm deep and there have been claims that seedlings have emerged from seeds buried at 175 mm (Thurston, 1972). Emergence of black-grass seedlings decreased with increasing depth of burial in soil soils of different aggregate size (Cussans *et al*., 1996). Total emergence was lowest in fine soil conditions. Light penetration is likely to be less in fine particle soils. In preliminary tests, black-grass seed germination was six times greater when exposed to light. Emergence studies have shown that 60-70% of the seedlings in a flush are derived from seed that is less than a year old (Naylor, 1972b).

Seminal roots develop from the seeds when they germinate but adventitious roots that form near the soil surface soon take over (Thurston, 1972). The plant remains shallow rooted, allowing seedlings to withstand waterlogged conditions in the autumn (Naylor, 1972b). Seedling growth stops at 5°C. Young seedlings of black-grass can withstand –8°C of cold but are killed at –10°C (Barralis & Chadoeuf, 1970). Tillered seedlings can withstand the lower temperature but freeze at –25°C, however, they recover when temperatures become milder and go on to flower. Black-grass appears to be a species with a partial requirement for cold vernalization (Chauvel *et al*., 2002). Vernalization requirements are not absolute but flower induction is earlier in vernalized plants. There may be differences both within and between populations. Autumn germinating seedlings produce many tillers in a flat rosette, spring emerging seedlings grow upright and have fewer tillers (Thurston, 1972).

Persistence and spread

The decline of seed in soil is reported to be greatest in the first year after shedding but appreciable numbers remained after 4 years whether in cultivated or uncultivated soil (Froud-Williams, 1987). Around 80% of seeds in soil are lost each year and less than 6% are still viable after 2 years (Moss, 1987). Most seed is lost between shedding in July and cereal drilling in October. Only a part of the loss is due to germination. If seeds are ploughed down deeply they appear to retain viability for some time (Long, 1938). Nevertheless, two thirds of emerged seedlings come from seed less than one year old. Black-grass seed sown in the field and followed over a 5-year period in winter wheat or spring barley showed an annual decline of around 80% (Barralis *et al.*, 1988). Emerged seedlings represented 15% of the seedbank. Seedling emergence declined considerably after year 3 of the study.

Seed buried in mineral soil at 13, 26 or 39 cm depth and left undisturbed retained 22, 10 and 53% viability respectively after 4 years but none was viable after 20 years (Lewis, 1973). Seed buried in a peat soil at 26 cm for 1, 4 and 20 years retained only trace viability after just 1 year. Seed stored under granary conditions exhibited 34% viability after 1 year, 7% viability after 4 years and was no longer viable after 20 years. Black-grass seed may remain viable for 11 years in soil and 13 years in dry storage (Thurston, 1972). Dormancy is induced in black-grass seeds present in waterlogged soil (Barralis *et al.*, 1970). This is released by cycles of alternate wetting and drying. In dry storage, seed viability began to decline after 8 years but was still at 25% after 9 years. In studies with black-grass seeds buried at 2.5, 10.0 or 17.8 cm deep in soils with different water tables, many of the seeds recovered after 1 month of burial had sprouted and less than 30% of seeds germinated when tested (Lewis, 1961).

Black-grass patches remained relatively stable in their positions in arable fields over a 10-year period (Wilson & Brain, 1991). The grass exhibited little ability to spread to new areas but persisted in the established areas of infestation.

In the period between 1961 and 1968, black-grass seed was found as a contaminant in around 2% of seed samples of wheat, barley, oats and rye tested for purity by the Official seed Testing Station, Cambridge (Tonkin, 1968). Most of the contaminated samples contained very low numbers of seeds but some had several hundred in an 227 g sample of grain. In a survey of weed seed contamination in cereal seed in drills ready for sowing on farm in spring 1970, black-grass seed was found in 3% of samples (Tonkin & Phillipson, 1973). All of these were home saved seed. In the period 1978-1981, it was found in 16-21% of wheat and 3-14% of barley seed samples tested (Tonkin, 1982). The relatively early shedding of black-grass seed should reduce the likelihood of contamination of most cereals except winter barley (Froud-Williams, 1987).

It is particularly difficult to separate out black-grass seed from the seed of cultivated grasses. MacKay (1964) found black-grass seed occurred in 4 to 23% of grass seed samples between 1951 and 1964. It was particularly frequent in meadow fescue. In grass seed of English origin in 1960/61 and 1963/64 there was a similar level of frequency in seed samples. It was most frequent in samples of meadow and tall fescue. In grass seed of English origin tested in 1960-61, black-grass seed was found in 12.9% of perennial ryegrass, 10% of Italian ryegrass, 12.5% of cocksfoot, 6.3% of Timothy, 19.3% of meadow fescue, 4.9% of red fescue and 27.2% of tall fescue samples (Gooch, 1963). It was found less frequently in grass seeds of Scandinavian origin. Black-grass has also occurred as a contaminant of clover seed.

Black-grass seed has been found in cattle droppings (Salisbury, 1961). However, seed is rarely reported to survive passage through the digestive system of birds and other animals (Thurston, 1972).

Management

Black-grass is favoured by winter cropping with cereals and oilseed rape. The greater the proportion of autumn crops in the rotation, the more serious the black-grass problem. It is a difficult weed to control because so many black-grass seeds are shed at or prior to crop harvest. Combine harvesting leaves the crop standing longer in the field than previous harvesting systems, allowing more seed to be shed (Naylor, 1972b). In the past, straw burning caused considerable losses in the freshly shed seed in stubble but burning is no longer allowed (Froud-Williams, 1987; Moss, 1979). Disposal of straw by burning reduced seed numbers more than baling and removal of the straw (Moss, 1978; Wilson *et al.,* 1989). Spreading and burning straw reduces seed numbers by 50% and increases the likelihood that the others will germinate (Moss, 1987). Where there had been seed shedding and the straw was then baled the seed population in soil increased 9-fold while the increase was just 3-fold following burning.

Methods of straw disposal that involve minimal cultivations will normally result in a build up of black-grass particularly on heavy soils (Turley *et al.,* 1996). Rotational ploughing, 1 year in 3, will help to keep the grass in check but if an infestation is allowed to reach an excessive level, annual ploughing may be required for several years running.

Shallow ploughing and surface tillage after harvest will encourage seeds to germinate freely. Large numbers of seedlings can then be destroyed by ploughing. In any subsequent root crop, thorough cultivations will destroy many young black-grass plants. In wheat, small seedlings are killed by harrowing when the soil is dry. Black-grass is not tolerant of soil disturbance at the seedling stage. Trampling and the compaction of wet soil around the young plants also check their growth (Naylor, 1972b). Crop rotation will aid control (Riepma, 1953). Black-grass germinates primarily in autumn-winter and has been found to decrease markedly following a series of spring cereals (Rademacher *et al.,* 1970).

In the past, drilling dates for winter wheat were mid-October to mid-November. More recently this became late-September to mid-October (Moss, 1985). Early drilling of winter cereals leads to severe infestations both because it coincides with peak emergence, and because the weed has time to become fully tillered before winter (MAFF, 1975). Sowing cereals before 25 October has been shown to increase black-grass infestations, sowing after 5 November has led to a decrease. However, there may be a substantial loss in yield if winter wheat is drilled after mid-November. With winter beans the optimum drilling dates are similar to those of cereals but winter oilseed rape needs to be sown at the end of September. Infestations are often worse on badly drained, heavy soils where there is a high proportion of winter cropping. Black-grass has a preference for very wet soils during germination (Riepma, 1953). Improvements in land drainage may lead to a reduction in the severity of infestations but the weed will still remain a problem for some time and the cost may not be justified.

In a 4-year experiment with winter wheat crops, black-grass populations were favoured more by direct-drilling and tine cultivations than by ploughing (Moss, 1981a). Ploughing did not prevent some increase in the weed population but the infestation remained at a relatively low level. Black-grass emergence tended to be shallower on the direct-drilled plots than on the ploughed or tined plots but even on the ploughed land, most seedlings emerged from within the surface 50 mm of soil. Tine cultivations alone will not control all the black-grass seedlings in winter wheat (Moss, 1985). Some seedlings are likely to re-establish in the crop. Infestation levels of 30, 100 and 300 black-grass plants per m^2 reduced winter wheat yield by 13, 32 and 36% (Naylor, 1972a). A density of up to 10 plants per m^2 of black-grass did not reduce the above ground dry weight of winter wheat. However, if left uncontrolled, seeding would result in severe infestations in future crops. When yield loss is compared at different sites and in different years there can be significant variability in the crop losses at similar weed densities (Blair *et al.*, 1999). It was noted that control of black-grass could be deferred until mid-March without yield loss. In winter wheat, earlier emerging black-grass has a greater effect on crop yield (Snaydon, 1982). Root competition by the weed on the cereal and by the cereal on the weed is more intense than shoot competition (Exley & Snaydon, 1992). Root competition is partially alleviated by N fertilizer.

Where seed had been shed in the previous crop, it was calculated that 80-90% of black-grass plants in a direct-drilled winter wheat crop came from recently shed seeds (Moss, 1980). When there is only a small reserve of seeds in the soil ploughing generally reduces the level of fresh seed infestations while tine cultivations leave many seeds in the surface layers of soil (Moss, 1979; 1984). On a field that had suffered repeated black-grass infestations for many years, ploughing brought up previously buried seeds that germinated in large numbers. The prolific rates of seed production mean black-grass can increase rapidly in just one year.

In general, infestations of black-grass in winter wheat are more serious on tine cultivated and direct drilled than on ploughed land (Cussans *et al.*, 1979). In direct-drilled crops, where seed shedding has been prevented, fewer black-grass seedlings will emerge in the following crop if the land is not ploughed. If the land is ploughed the number of seedlings that emerge will be the same whether seed shedding had been prevented or not. Black-grass populations would decline rapidly if direct-drilling combined with the prevention of seed shedding was continued.

Cool damp weather during the maturation of black-grass seed is thought to increase the dormancy level of the seed. After a cool damp summer germination may be protracted or delayed with more seedlings than is usual emerging after cereal drilling. In these circumstances it may be appropriate to plough when there has been significant seed shedding to bury the seed and avoid a problem, at least in the short term. When the weather is hot and dry or hot and damp during mid June to mid July the seed is less dormant. Black-grass seed exhibits substantial natural mortality if left on the soil surface (Cussans *et al.,* 1987). In the presence of adequate soil moisture the shed seed will germinate rapidly and a delay in soil cultivation and cereal drilling will provide an opportunity for the maximum seed loss.

Since black-grass builds up in autumn sown cereals, an autumn fallow is ideal for ridding the soil of the seeds (Brenchley & Warington, 1930). Seed numbers in soil were reduced by over 75% following a 1-year fallow and by 95% following a 2 year fallow (Brenchley & Warington, 1933). The land was ploughed, disked and harrowed during the fallow period. Under cropping with winter wheat for the same period, seed numbers gradually increased. Successive fallowing every five years over a 15 year period did not reduce seed numbers overall (Brenchley & Warington, 1945). Although numbers dropped after fallowing, the survivors germinated in the following winter wheat crop and seed numbers built up rapidly before the next fallow year. Apart from in the first crop after fallowing, there is little benefit unless subsequent seeding can be reduced or prevented. An extended fallow period of 4 years reduced seed numbers in soil initially but numbers rapidly built up again in subsequent cereal crops (Brenchley & Warington, 1936).

In winter wheat the choice of cultivar and sowing rate can have a marked effect on blackgrass ear numbers (Blake, 2006). Cultivars that tiller well and achieve an early ground cover reduce blackgrass head numbers the most and the effect is greater at high seed rates. In spring cereals early sowings suffer worse black-grass problems but delaying sowing reduces the yield potential of the crop. Black-grass is less competitive in the spring crop but it can be a significant source of fresh seed. Crops sown at a narrow row spacing (18 cm) suppress black-grass growth more than those sown with rows wider apart (35 or 53 cm) (Naylor, 1972b). The weed is also important in winter beans, winter oilseed rape, and seed crops of brassicas, sugar beet and grass. Infestations in grass seed crops are very difficult to control. Mowing or grazing in the first year may be required to prevent the black-grass seeding and reduce the infestation in the second year.

In studies of dry heat on imbibed and dry black-grass seed, the time to cause seed death was 5 minutes at 100^{o}C and 40-50 seconds at 200^{o}C (Cussans *et al.,* 1987). At 400^{o}C, seeds were dead after 10 seconds exposure. In a study of the effect of soil heating, imbibed seeds in trays of moist soil held at 75 or 100^{o}C for 12 hours lost viability but at 56^{o}C the results were variable and seed viability was reduced by around 58-65% after 0.5-16 days (Thompson *et al.,* 1997). Seed held at 204^{o}C for 7.5 minutes or at 262^{o}C for 5 minutes was killed.

There have been attempts at devising methods for determining the extent of likely black-grass infestations ahead of cropping and for devising the best control strategy. It has been shown that there is a significant relationship between the number of black-grass seedlings emerging in soil samples in the glasshouse and the level of infestation that developed in the field (Naylor, 1970a). The assessment of the weed seed content of a soil sample is used to calculate the weed predictive index (WPI) of a field (Naylor, 1970b). Over 90% of seedlings emerged from the top 25 mm of soil in the field and samples should be taken from this layer to get reliable results prior to drilling a crop. A population model has been developed to determine the effect of soil tillage and other factors on the level of black-grass infestations in winter cereals (Cussans & Moss, 1982). The model suggests that to prevent a likely build-up of black-grass under minimum tillage systems the land should be ploughed every 5 years. A simple lifecycle based demography model has been adapted to help in developing threshold-based weed management strategies for black-grass (Munier-Jolain *et al.*, 2002). Although intended for chemical control measures it could form the basis for a non-herbicide system. Zanin *et al.*, (1993) determined the economic threshold for black-grass in winter wheat to be 7-12 plants per m^2. However, the winter mortality of black-grass is variable from year to year and site to site and this can affect predictions of yield loss in winter cereals (Storkey *et al.*, 1997). It may be better to delay assessments to obtain more reliable predictions.

Strategies to deal with herbicide resistant black-grass may be relevant to non-chemical management systems. They consist of ploughing at least once every 4-5 years, including spring-sown crops in the rotation, and delaying autumn sowing to allow a higher proportion of seedlings to emerge and be hoed off prior to sowing winter cereals (Clarke & Moss, 1991).

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