The biology and non-chemical control of Wild-oat (*Avena fatua* L.)

W Bond, G Davies, R Turner
HDRA, Ryton Organic Gardens, Coventry, CV8, 3LG, UK

Wild-oat
(oatgrass)
***Avena fatua* L.**

Occurrence

Wild-oat is an introduced, annual grass weed of arable, waste and rough ground and roadsides (Clapham et al., 1987; Stace, 1997). It is common in most of England especially in the south and east, but scattered elsewhere. Wild-oat is found on all types of arable land, heavy, light, acid and alkaline (Salisbury, 1961). It occurs over a wide of range climatic regions but prefers cooler conditions and is a serious annual weed of temperate arable crops (Weber, 2003). Wild oat is a frequent birdseed alien (Hanson & Mason, 1985).

In Britain, wild-oat was a more serious weed after the Second World War than in the pre-war years (Dadd, 1956). It was also considered the most important agricultural weed in Canada in the 1950's (Frankton, 1956). Wild-oat is a common arable weed in Denmark (Streibig, 1988). In the UK, wild oat was considered to be more abundant in the 1990's than it had been in the 1960's (Marshall *et al.*, 2003). In 1993, a survey of the most important weeds, according to European weed scientists, ranked wild oat as an important weed in winter and spring cereals and winter rape (Schroeder *et al.,* 1993).

Wild-oat is troublesome in cornfields on land inclined to be heavy where it can emerge in enormous numbers (Long, 1938). According to a 1951 survey, wild-oat was a serious weed in all parts of England where wheat and barley were grown (Thurston, 1953). In 1953, almost 30% of winter cereals and 20% of spring cereals were heavily infested with wild-oat (Thurston, 1963). In a survey of weeds in conventional cereals in central southern England in 1982, wild-oat was found in 32, 25 and 43% of winter wheat, winter barley and spring barley respectively (Chancellor & Froud-Williams, 1984). In a study of seedbanks in some arable soils in the English midlands sampled in 1972-3, wild-oat was recorded in 56% of fields sampled in Oxfordshire and 44% of those in Warwickshire but never in large numbers (Roberts & Chancellor, 1986). In arable fields in France it is well represented in the vegetation but is less frequent in the soil seedbank (Barralis & Chadoeuf, 1987).

Seed from different habitats and even seeds from the same habitat may have different genotypes (Sharma & Vanden Born, 1978). Some populations have developed resistance to the graminicide diclofop-methyl (Putwain & Mortimer, 1989; Powles & Howat, 1990).

The forage quality of wild oat at the vegetative stage is comparable with that of rye (*Secale cereale*) (Bosworth *et al.,* 1985). Water leachate from the straw of wild-oat contains phytotoxic phenolic compounds that may inhibit the germination and growth of other plants (Tinnin & Muller, 1972). The wild-oat plant is a host of cereal cyst eelworm (*Heteroderma avenae*) and cereal stem eelworm (*Ditylenchus dipsaci*)

(MAFF, 1974; Franklin, 1970). It can also be infected with barley yellow dwarf virus and is attacked by several insects and fungi that attack cereals too (Thurston, 1970).

Biology

Wild-oat flowers from June to October (Long, 1938). The first panicles become visible above the cereal crop in early June but flowering and panicle production can continue up until harvest (MAFF, 1974). Wild-oat is normally self-pollinated but up to 12% out-crossing does occur (Sharma & Vanden Born, 1978). In the absence of competition a single well-tillered plant could produce up to 2,000 seeds. In a cereal crop, average seed production is 60 seeds per plant but seeds per m^2 may average 9,000 (Rolston, 1981). Spring barley reduced seed number per flower head slightly more than wheat but in spring beans seed numbers were much greater (Chancellor & Peters, 1970). In less competitive crops, an individual plant may produce 200 (Evans, 1958), 250 (Stevens, 1932), 450 (Stevens, 1957) or 500 seeds (Weber, 2003). The average seed number per plant is 138 according to Pawlowski *et al.* (1970). Other authors give the average seed number per plant as 100-150, with up to 500 in some plants but only 20-30 where competition is severe (Sharma & Vanden Born, 1978). The range of 1,000 seed weights given by different authors varies from 17.52 to 22.50 g (Stevens, 1932). Pekrun & Claupein (2006) give the 1,000 seed weight as 20.8 g.

Seeds become viable around 10 days after fertilization (Chancellor, 1982). Wild-oat seeds are shed as they ripen and this occurs over an extended period. The later a crop is harvested the more of the weed seed that is shed on the ground leaving less to contaminate the crop seed. In cereals, up to 66% of wild-oat seeds are shed before crop harvest and 20% are lost during the harvesting process (Metz, 1969). A further 2.5% of seeds are lost in the chaff and straw and 7.5% remain in the harvested grain.

Fresh seeds are dormant or rapidly become dormant but lose dormancy following after-ripening in warm dry storage (Sharma & Vanden Born, 1978). After-ripening occurs faster in seeds on the soil surface than those buried in soil (Bibbey, 1948). However, seeds possess a hygroscopic awn which twists and straightens with changes in humidity pushing the seeds down into cracks and crevices in the soil (Thurston, 1953). After 3 months burial in soil, shed seeds were all dormant (Murdoch & Carmona, 1993). In the autumn, the level of dormancy declined as enforced dormancy was relieved under favourable conditions. Dormancy was induced again in late spring. The level of dormancy in wild-oat seeds can vary between different strains or varieties from different locations (Sexsmith, 1967). The ambient temperature and availability of moisture during seed development can affect the level of dormancy too but this often has a genetic origin also (Chancellor, 1982; Peters 1982). Plants maintained at higher temperatures and lower moisture levels during seed development produced seeds with lower levels of dormancy (Sexsmith, 1969). Seeds from the secondary florets of the spikelet were more dormant than the larger seeds (Chepil, 1946).

Damage to the seedcoat can break dormancy by allowing more oxygen to reach the seed (Thurston, 1963). Pricking dormant wild-oat seeds promotes germination but the response is faster in petri-dish tests than in soil (Foley, 1987). An increase in water uptake was not responsible. Scorching of the seedcoat also encourages seeds to germinate (Thurston, 1953). Light may inhibit seed germination. Seed stratified outdoors in soil overwinter was exhumed and tested for germination in the light, in the dark and in the dark with a 5 second flash of light (Andersson *et al.,* 1997). Seed gave less than 4% germination in any of the conditions. However, in germination tests at 22^{o}C with seeds in darkness or continuous white light, there was 95% germination in the light and 90% in darkness (Tretyn *et al.,* 1988). When seeds were put to germinate under a leaf canopy or in diffuse white light there was 26% germination under the canopy and 72% in the light (Górski *et al*., 1977). Applications of nitrogen-containing fertilizers may break the dormancy of seeds exposed to high light levels (Hilton, 1984). In pot tests, applications of ammonium-containing fertilizer stimulated wild-oat germination and emergence in soil (Agenbag & de Villiers, 1989). However, high rates caused a temporary delay in seedling emergence.

In a study of particular lines of wild-oat, primary and secondary seeds from different parts of the panicle were sown in pots of soil outside (Peters, 1991). Outer seeds from the panicle were less dormant than the inner seeds. In the winter and spring period, a cold spell when soil temperature fell below 4^{o}C followed by a warm period stimulated a flush of seedling emergence. In the autumn, the effect of temperature was less clear, although, higher temperatures appeared to inhibit germination but the presence of soil moisture was critical to any emergence. In Petri-dish tests under a range of temperatures and osmotic potentials, wild-oat germinated faster and was less affected by osmotic stress than winter wild-oat (*Avena sterilis* L. ssp. *ludoviciana*) seed (Fernandez-Quinantilla *et al*., 1990). At temperatures over 20^{o}C, a greater proportion of wild-oat emerged than winter wild-oat, at temperatures below 10^{o}C the opposite was true. Between these temperatures the germination process was similar.

Wild-oat has two main periods for germination but odd seedlings may appear at anytime. There is a small autumn flush from September until early-November but the main flush is from March to early-May (Evans, 1958; Salisbury, 1961). For seed mixed in a 75 mm layer of soil in cylinders sunk in the ground the main period of emergence was January to May (Roberts, 1986). Most seedlings emerged in the second year of the experiment. Seed sown at different depths in soil that was cultivated or not, in pots and boxes in the field, emerged in winter when left on the soil surface (Froud-Williams *et al*., 1984). When sown at 25 mm without cultivation or at 75 mm and cultivated in February or June, emergence occurred in winter, spring and autumn. The optimum depth of emergence was 20-70 mm the maximum was 160 mm.

In greenhouse studies emergence was unaffected by depth of burial or fluctuating moisture levels (Boyd & Van Acker, 2003). Most seedlings originate from seeds in the top 80-100 mm of soil but some emerge from up to 150-240 mm deep (Rolston, 1981). Primary and secondary seeds showed a decrease in emergence of 10% and 23% respectively when buried at 100 mm deep in soil compared with 20 mm (Peters, 1986). Seedlings will emerge from seed buried at 230 mm in soil (Thurston, 1963). Seedlings from deeply buried seeds take longer to emerge and may be weaker initially. Elongation of the first internode, or mesocotyl, allows wild-oat seedlings to emerge from relatively deep layers (Weber, 2003; Sharma & Vanden Born, 1978). Seeds that are buried too deeply do not germinate and can remain dormant for several years until deep ploughing brings them up to the surface (Long, 1938). There does not seem to be a mechanism to prevent fatal germination at intermediate depths at which seeds will germinate but seedlings then fail to emerge. There is potential to use this to deplete soil seed reserves (Murdoch, 1983). Soil disturbance hastens the breaking of dormancy by exposing seeds to the air (Thurston, 1953).

In Sweden, wild oat is considered a summer annual (Håkansson, 1979). Seeds mixed with soil in the autumn, put in frames in the field, exhumed at intervals and put to germinate at alternating temperatures showed the seeds to have the lowest dormancy and greatest tendency to germinate in April/May and September/November. Many seedlings emerged in the autumn after sowing.

The timing of emergence in late winter/early spring is associated with minimum daily temperatures of 3^{o}C and a maximum of less than 17^{o}C (Murdoch, 1983). Higher minima of 6-7^{o}C give more rapid seedling growth. In crops of spring barley, the germination of naturally occurring wild-oat was spread over several weeks and was initiated by a rise in soil temperature to 6-7^{o}C (Chancellor & Peters, 1972). The earliest seedlings had the greatest chance of survival, tended to tiller more and produced more seeds. However, most seeds came from seedlings that emerged with, or within 3 weeks of, the crop. Initial seedling growth is slow but then speeds up (Sharma & Vanden Born, 1978). Wild-oat seedlings are frost sensitive until they reach the 3-leaf stage.

Persistence and Spread

Less than 20% of wild-oat seeds produce seedlings (Thurston, 1961). In land cropped annually the majority of seeds will survive for only 2-3 years due to germination following soil disturbance. Persistence is longer in undisturbed soil (Sharma & Vanden Born, 1978). Freshly shed seed incorporated into the soil can remain dormant but viable for up to six years (MAFF, 1974). The maximum survival period in soil was 61 months, possibly longer when buried deeply (Barton, 1962). Where seeds are left on the soil surface viability declines within a few months due to germination, predation and fungal attack (Froud-Williams, 1987). Where stubble cultivation was delayed until December, viable seed numbers on the soil surface declined by 67% (Cussans *et al.*, 1979). Shallow tine cultivations in September result in greater seed survival and higher seedling numbers in subsequent crops (Cussans *et al.*, 1987). However, the seeds are able to bury themselves by the twisting action of the awns during wetting and drying (Willis, 1954).

In Duvel's burial experiment, seed buried at 20, 55 and 105 cm survived only 1 year of burial (Toole, 1946; Goss, 1924). Depletion of seed buried in soil at different depths was mainly the result of germination (Murdoch & Roberts, 1982). Losses were similar at depths of 25, 75 and 230 mm. Seed buried in mineral soil at 130, 260 or 390 mm depth and left undisturbed retained 19, 12 and less than 1% viability after 1 year (Lewis, 1958). Up to 3% of seeds were viable after 4 years but none was viable after 20 years (Lewis, 1973). Seed buried in a peat soil at 260 mm for 1, 4 and 20 years did not survive for 1 year. Seed stored under granary conditions exhibited 50% viability after 1 year, 8% viability after 4 years but was not viable after 20 years. Wild-oat 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.

The seeds are capable of lying dormant in soil for many years, germinating only when conditions are favourable. Pasture that had been down for 5-10 years, when ploughed and sown with wheat was found to be infested with wild-oat (Long, 1938). Some farmers have reported that seeds can survive 70 years in undisturbed soil, germinating when the soil was disturbed again. Seeds sown in cultivated soil remained intact for 7 years but were shown to be viable for up to 5 years (Thurston, 1961). Seed numbers decreased rapidly in the first year under leys but this slowed and after 5 years viable seeds were still present (Rolston, 1981). It is suggested that a 1-year ley is as good as a longer ley for reducing wild-oat seed numbers in soil (Thurston, 1966). Murdoch & Roberts (1982) consider that losses under pasture are likely to be 25% per annum, while in continuous cereals losses of 87 to 94% per annum are likely. Miller & Nalewaja (1990) found that seed persisted longer at greater depth and at low N levels in soil. Seed viability at 0-10 mm depth declined rapidly at first then remained stable at 15% of original numbers for 3 years before viability gradually dropped to zero after 9 years. A few seeds persisted longer at 12-34 cm depth. It has been suggested that wild-oat would be less persistent under no-till where seeds are left on the soil surface open to predation and post-germination mortality.

Deeper burial favours longer dormancy and thus greater longevity (Nietschke, 1996). Seed has been shown to persist more following ploughing rather than tine cultivation (Wilson, 1985). Wild-oat seed was more persistent in winter than spring barley. With no new seeding, three years of barley cut for silage exhausted the seed reserve in the soil (Wilson & Phipps, 1985). Three years of grass leys allowed some seeds to survive in the soil and produce seedlings in a following wheat crop.

Wild-oat seed is spread naturally only a few metres from the parent by the swaying action of the inflorescence (Thill & Mallory-Smith, 1997). The point of detachment of the seed has an outer ring of small highly lignified cells and within this are thin walled parenchyma cells (Yeung *et al.*, 1987). The seeds detach readily, aided by the twisting action of the awn. These features are absent from the cultivated oat (*Avena sativa*) which does not shed its seeds so easily. In cereals, up to 66% of wild-oat seeds are shed before crop harvest and a further 20% are lost during the harvesting process (Metz, 1969). An additional 2.5% of seeds are lost in the chaff and straw and 7.5% remain in the harvested grain. There was a threefold increase in wild-oat seeds on the soil surface following combine harvesting (Wilson, 1972). In Poland, the use of the combine harvester has been blamed for the spread of wild-oats (Rola & Rola, 1976). While repeated cereal growing has led to a build up of wild-oat in situ, the widespread movement into new areas is due largely to the transport of seeds in contaminated cereal grain and straw (Elliott, 1972). An average of 100 wild-oat seeds have been found per bale of straw from weedy fields. All bales of straw from wild-oat infested fields contained some seeds (Wilson, 1970). Even when most wild-oat seed appeared to have shed before cereal harvest, there were still seeds recovered from the baled straw. It is important to prevent this ingress of seed onto a farm.

The drilling of contaminated cereal seed has been one of the main reasons for the spread of wild-oats (MAFF, 1974; Salisbury, 1961; Morse & Palmer, 1925). In the period between 1961 and 1968, wild-oat seed was found as a contaminant in around 2-10% 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 over 100 in a 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, it was found in 19% of samples (Tonkin & Phillipson, 1973; Rolston, 1981). Much of this was home saved seed. In the period 1978-1981, wild-oat seed was found in 7-16% of wheat and 13-21% of barley seed samples tested (Tonkin, 1982). Most wild-oat seed is shed prior to the harvest of cereals other than winter barley (Froud-Williams, 1987). Wild-oat was rarely found as a contaminant in seed of clover or cultivated grasses. A small percentage of samples of Italian ryegrass and meadow fescue have been found to contain one or more wild-oat seeds (MacKay, 1964). Contamination was mainly confined to samples of English origin. In a survey of seed contamination of grass seed in 1960-61, wild-oat seed was found in 4.2% of Italian ryegrass, 3.0% of tall fescue and 1.1% of meadow fescue seed samples tested (Gooch, 1963). It was also found in 2% of sugar beet seed samples tested.

Computer based mapping of wild-oat infestations has shown that patches remain relatively stable from year to year but expand 1-3 m on the leading edge in the direction of harvesting and cultivation (Wheeler *et al.*, 2001). Without control, the wild-oat population will increase annually by a factor of three on average (Selman, 1970). However, there can be considerable variation from year to year making it difficult to predict the future population on the basis of the current population.

Cereal straw can carry large quantities of wild-oat seed as can farmyard manure that contains cereal straw from infested fields. In silage most wild-oat seed loses viability due to the treatment process. There was no germination of wild-oat seed that had been ensiled for 8 weeks (Blackshaw & Rode, 1991). Rumen digestion by cattle generally killed the seeds after 8-24 hrs but there was a suggestion that this could be affected by diet. Kirk & Courtney (1972) found that up to 12% of wild-oat seed fed to bullocks was excreted in a viable condition. A small proportion of wild seeds remained viable after 12 weeks burial in manure heaps but not after 21 weeks. Seeds at the centre of the heap were killed more rapidly than those near ground level. In other studies, wild-oat seeds gave 10% germination after 47 hours digestion by cattle and no germination if then stored for 3 months in the manure (Zimdahl, 1993). The weed seed is also spread on or by farm machinery, especially combine harvesters and baling machines (Thurston, 1963). After 2 weeks of windrow composting at temperatures of 50-65^{o}C, 1% of wild-oat seeds were still viable but after 4 weeks all were killed (Tomkins *et al.*, 1998). Seed is killed when heated at 105^{o}C for 15 minutes but when heated at 100^{o}C up to 7% of seeds remain viable (Hopkins, 1936). 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 58-96% 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.

Management

Being closely related, conditions that favour cereals also favour wild-oats. A heavy infestation will compete vigorously with any cereal and reduce yields dramatically (Dadd, 1956). Control is through sowing clean seed, shallow cultivation in autumn to induce a proportion of seed to germinate, and deeper working in spring to kill the seedlings (Long, 1938). Harrowing may remove later germinating weeds as will hoeing in root crops. Young seedlings of wild-oat are susceptible to harrowing but tillered plants may break up and re-root (Thurston, 1953). If not too many wild-oats are present hand pulling may be feasible. In the past, most cereal growers relied on late cultivations to destroy seedlings and early harvests to avoid seed shed but this reduced crop yields (Thurston, 1963). The use of the combine harvester has left more wild-oat seed in the field than older harvesting systems that threshed the cereals off field. Some farmers turned hens onto the stubble to eat the wild-oat seeds. The hens eat the seeds on the soil surface and scratch up many that have become buried. Pigeons also eat large quantities of wild-oat seeds (Dadd, 1956). Wild-oat seeds recovered from the crop of a pigeon were found not to be viable. Other farmers relied on two or more cleaning crops between cereals. It has been noted that wild-oats are much less of a problem on farms that practice a rotation, especially one that includes cleaning and root crops.

Wild-oat and wheat compete for the same resources and are mutually exclusive (Martin & Field, 1987). The shoots have similar competitive ability but wild-oat is better able to compete in the root zone due to prolific development of crown roots. Cereal grown in narrow rows are more competitive against wild-oats than crops in wide rows. In winter wheat, crop density is an important factor in limiting seed production by wild-oat through its effect on weed weight (Wright, 1993). Seed production may be halved as crop density is increased from 60 to 195 crop plants per m^2.

Farmers should ensure that wild-oat seeds have been cleaned from combine harvesters and other harvesting machinery (MAFF, 1975a). They should check seed-cleaning machinery is operating correctly. All the wild-oat seeds removed by the seed cleaner should be burned and not fed to stock or tipped onto the manure heap. Never sow cereal seed containing wild-oats.

Hand-roguing of cereals is possible with weed populations of 400-500 wild-oat plants per ha (MAFF, 1974). Roguing should take 2.5–4 man hours per ha. Wild-oat plants must be removed completely otherwise the remaining tillers will be encouraged to produce panicles. The wild-oats must exceed the height of the crop to allow roguing, this generally occurs in early July (MAFF, 1975b). A team of roguers should work in line abreast 5 to 20 m apart depending on weed density, preferably with the sun behind them for ease of spotting the wild-oats. Unripe seeds of wild-oat are viable but non-dormant (Thurston, 1963). Destruction of hand-pulled wild-oats even with green panicles is therefore important. At low population levels and when potential influx is also low, eradication by hand roguing is both practicable and economic (Murdoch & Roberts, 1982).

Wild-oat seed does not germinate in summer therefore a summer fallow does not deplete the seedbank (Thurston, 1963). Crops sown after May are likely to have fewer wild-oats in them. Putting land down to leys for a minimum of 4 years will reduce the weed (Evans, 1958). After 6 years under grass in a long ley there was a dramatic fall in the number of wild-oat that germinated after ploughing (Selman, 1970). The loss of seed under leys is considered to be insufficient to completely prevent re-infestation (Roebuck & Field, 1978). A period of 8-9 years under pasture has been suggested as the period needed to eliminate wild-oat seed (Rolston, 1981). Seeds are said to persist for 6 years under grass, and seeds were still present after 4 years of winter barley (Froud-Williams, 1987). There can be total eradication of wild-oat in the seedbank over 3 years of spring barley cut for arable silage. Two years of a late-planted cleaning crop such as cabbage, Brussels sprouts or kale followed by a winter cereal will allow wild-oat seedlings to be killed prior to crop establishment as well as by inter-row cultivations (Willis, 1954). Any remaining plants growing in the winter cereal will hopefully be cut before further seed is shed.

The timing of cultivations can influence the survival of wild-oat. If large numbers of seeds are on the soil surface, delaying cultivation until December will reduce the seed burden (MAFF, 1974). Rotary cultivation of cereal stubble in early autumn resulted in a two to threefold increase in seedlings emerging the following spring compared with leaving cultivation until late autumn (Wilson & Cussans, 1972). When early cultivation was followed by ploughing, fewer seedlings emerged but more seeds persisted in the soil. Natural wastage of seed left on the soil surface increases with time (Rolston, 1981). Seeds of wild-oat left lying on cereal stubble declined considerably as the autumn progressed (Wilson, 1972). Predation of the seeds was only one factor in the seed losses. If the majority of seeds are already mixed in the soil, or the soil is too heavy to leave uncultivated through the autumn, cultivation soon after harvest will encourage some germination of buried seeds (MAFF, 1974). Seedlings can then be destroyed by further cultivations. If spring crops are sown late there may be an opportunity to kill off any early seedlings by cultural means. Delaying the date of crop sowing allows increased wild-oat seedling emergence before drilling (Nietschke, 1996). Delayed sowing of spring barley helps to control wild-oat (Selman, 1970). In spring barley, preparing the seedbed 3 weeks in advance of sowing and cultivating twice with spring tines gave good control of wild-oat (Roebuck & Hughes, 1972). However, in general cereal drilling is unlikely to be delayed due to the yield penalty of late sowing. Seedlings of wild-oat are smaller than those of cereals but soon catch up and exceed the crop (Thurston, 1963). The crop needs to be most competitive at this early stage.

In a comparison of different tillage regimes in winter cereals, wild-oat was favoured by reduced cultivations (Pollard & Cussans, 1981). When changes in the numbers of wild-oat seeds were monitored in successive crops of spring barley, tine cultivations resulted in greater seedling numbers than ploughing initially (Wilson, 1981a). Where ploughing rather than shallow cultivation was practiced the wild-oat seeds persisted and became a long-term problem. Harvesting the spring barley early for silage prevented further seed shed and in subsequent years it was the ploughing treatment that had higher seedling numbers as a result of unearthing buried seeds. In the absence of seed shed, seed numbers in the soil declined to a low level within 3-4 years. Deeply buried seeds remain viable for longer. In spring barley grown at wide (20 cm) and narrow (10 cm) row spacing and high and low seed rates, wild-oat growth was reduced at the narrow row width and high seed rate (Bate *et al.,* 1970). This resulted in reduced seed production by the weed and particularly affected the wild-oat plants growing along the crop row.

Stubble burning after cereal harvest destroyed many freshly shed wild-oat seeds on the soil surface. However, the seed is relatively resistant to heat, withstanding 115^{o}C for 15 minutes. But burning is no longer an option. A novel way to use sunlight for direct weed control involves using a curved freshnel lens to concentrate sunlight into a narrow band at the soil surface. The wheeled device is pulled slowly along between crop rows to wither and burn off the inter-row weeds or kill exposed weed seeds. Under the full mid-day sun the mean soil surface temperatures was 309^{o}C with a 20 second exposure (Johnson *et al.,* 1990). The germination of wild-oat seed left on or near the soil surface was reduced by this treatment but 2% of seeds remained viable. In India, soil solarization for 30 days reduced wild-oat seed in soil by up to 95% to a depth of 5 cm (Arora & Yaduraju, 1998).

Schematic population cycles for wild-oat have been drawn up to aid management of the weed (Wilson, 1981b). Seed production will vary with the crop and with time of emergence in relation to the crop. Emergence of wild-oat later than the crop will reduce seed numbers significantly. Many of the seeds are shed during the harvesting process and mortality on the soil surface can be high even in the absence of stubble burning. Over 75% of wild-oat seeds on the soil surface of undisturbed stubble can die or disappear by December (Roebuck & Field, 1978). Natural deterioration rather than seed predation accounts for most losses. Early cultivation after harvest has given higher seed populations in soil than when cultivations are delayed for 2-3 months. This can result in 2-3 times more seedlings emerging in spring. Once in the soil, seeds may germinate, remain dormant or perish. This is influenced by the frequency and nature of cultivations. Seeds that germinate may or may not then survive to return fresh seed back to the soil and begin the cycle again.

In a study of the effect of the residues from harvested crops, wheat and field pea residues promoted wild-oat germination and subsequent growth (Purvis *et al.*, 1985). There was more rapid emergence of the weed in the presence of wheat, pea, oilseed rape, sunflower or sorghum residue. In laboratory tests, leachate from composted household waste decreased the germination of wild-oat seed (Ligneau & Watt, 1995). In pot tests, however, covering the seeds with up to 3 cm depth of compost did not reduced seedling emergence.

Models are available that could be used to predict seedling emergence of wild oat in the field (Cousens & Peters, 1993). Mathematical models for the calculation of the rates of change in the size of weed infestations may be used to simulate weed management scenarios for wild-oat (Mortimer *et al.*, 1978; Mortimer & Putwain, 1981, Manlove et al., 1982). The threshold density for wild-oat in wheat in eastern Australia based on an extended critical density/weed control model was 8 plants/m^2 (Auld & Tisdell, 1987). However, contamination of the cereal grain with wild-oat seed may reduce the economic value of the crop further than the model anticipates and could even lead to rejection (Cousens *et al.*, 1985).

Frit flies (*Oscinella frit*) will cause damage to wild-oat as well as cultivated oats (Van Emden, 1970). The oat leaf spot fungus (*Pyrenophora avenae*) has been found to kill seedling wild-oats (Moore & Thurston, 1970).

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