MANAGING HERBICIDE RESISTANT WILD OATS – OPTIONS AND ADOPTION

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Summary A range of integrated weed management (IWM) techniques can be used to minimize herbicide resistant wild oat (*Avena* spp.) populations in southern Australian cropping systems. Herbicides will continue to be the most potent component of any integrated management system for wild oats, irrespective of herbicide resistant biotypes. However, effective herbicide technology needs to be combined with cultural strategies so as to preserve existing herbicide options. Components of an IWM system for wild oat management include herbicide rotation, a range of cultural techniques including crop rotation, and good agronomic practices. Unfortunately, most cultural options are either costly or lack sufficient control to warrant significant adoption. By adoption of IWM strategies in which herbicides are the dominant but not exclusive control technology, sustainable, long term wild oat control should be ensured.

INTRODUCTION

Wild oats are important weeds in virtually all cropping regions of the world. In Australia, two species predominate, *Avena fatua* L. and *A. ludoviciana* Durieu (synonym *A. sterilis* ssp. *ludoviciana*) (Thurston and Phillipson 1976), causing estimated annual losses of $A100 million (Medd 1996). Both species are well adapted as crop weeds (Stubbs 1956), comprising asynchronous germination, variable seed dormancy mechanisms, and seed shedding characteristics. Wild oats are highly competitive, often causing substantial crop yield loss and in some seasons can be important grain contaminants. They are also noted for their potential to harbour crop pests and diseases.

Since the registration of diclofop methyl in the late 1970s, aryloxyphenoxypropionates (APPs) and cyclohexanediones (CHDs) herbicides have been widely utilized in Australian cropping systems. This has resulted in the emergence of resistant wild oat populations (Piper 1990, Mansooji *et al.* 1992). Two initial patterns of resistance have been recorded: resistance only to diclofop methyl or; a high resistance to all APPs and a low resistance to CHDs (Holtum 1992). In a survey of north eastern Victoria, 6% of 1992 cropping paddocks contained diclofop methyl resistant wild oats (M. Walsh personal communication), compared with 4% of 1993 cropping paddocks sampled in the mid-north of South Australia (Nietschke *et al.* 1996a). In southern New South Wales the level of diclofop methyl resistant wild oats had marginally increased from 3% in 1991 to 5% in 1994 (J. Broster personal communication). Although there has been no assessment or characterization of wild oat resistance in Western Australia, observations from screening services indicate variable resistance to APPs (J. Holmes personal communication). The increased incidence of wild oat resistance poses future management difficulties and the need for a more integrated approach to weed control in southern Australia.

This paper reviews world-wide control options relevant to managing wild oats in southern Australian cropping systems. The strategies being adopted by farmers to minimize herbicide resistant wild oats are also discussed.

WILD OAT CONTROL METHODS

It is now widely held that a range of control techniques should be used in an integrated manner (IWM) for sustainable control of recalcitrant weeds such as wild oats. IWM may consist of various combinations of methods. Where appropriate, these options are discussed with reference to the management of herbicide resistant populations.

Herbicides A range of selective herbicides are utilized for the control of wild oats in Australian cereal and broadleaf crops (Table 1). Non-selective herbicides (paraquat, diquat and glyphosate) can also be used for spray-topping, as discussed below.

The Group A herbicides, APPs and CHDs are the most widely used in field crops, as they also target annual ryegrass (*Lolium rigidum* Gaud.), which regularly co-exists with wild oats. However, several non Group A options are available, the most important including triallate (used in cereal and broadleaf crops), simazine (lupins and faba beans), flamprop methyl (wheat, triticale and safflower), imazethapyr (faba beans and field peas) and diuron (lupins and field peas). Furthermore, simazine and atrazine can be utilized for wild oat control in triazine resistant canola. The range of herbicides available permits flexibility in application timing (pre- or early post-emergence), and rotation of both chemical groups and crops. Rotation between chemical groups, so as to slow the onset of resistance to any single group, is widely recommended as a means of prolonging herbicide efficacy in Australian agriculture.

Spray-topping Wild oat herbicides are generally regarded as cost effective tools for conserving crop yield, but cannot be solely relied upon for population control (Medd 1996). Because of staggered recruitment, late emerging seedlings will escape herbicide treatment, irrespective of whether pre- or early post-emergence herbicides are used. Seed produced from these plants, together with those which survive treatment, ensures seed bank levels are maintained or even increased. However, two registered methods, pasture-topping and crop-topping directly target seed production through the use of non-selective herbicides, in pastures and pulse crops respectively. Research currently being undertaken by Matthews *et al.* (unpublished) in South Australia found that paraquat applied for two successive years (at the beginning of seed shed), reduced the seed bank by 55% in a wheat-field pea rotation.

In wheat crops, the late application of selective post-emergence herbicides applied at the early wild oat tiller elongation stage was found to be a promising strategy to minimize seed production (Medd *et al*. 1992, 1995, Nietschke *et al.* 1996b). The preferred herbicides for this technique are flamprop methyl, or its isomer, flamprop-*m*-methyl. As these are Group K options, the tactic provides opportunities for both decreasing populations (by reducing seed production and the replenishment of seed banks), and managing the resistance selection pressure and resistance build-up through judicious rotation with the more popular Group A alternatives. It has been suggested this method be referred to as selective spray-topping and steps are currently being undertaken to register the herbicides for this purpose.

Table 1. Selective herbicides for control and suppression of wild oats (adapted from Chambers 1995).

Group	Active constituent
A (APPs)	Clodinafop-propargyl, diclofop methyl, fenoxaprop-*p*-ethyl, fluazifop-*p*, haloxyfop, propaquizafop, quizalofop-*p*-ethyl
A (CHDs)	Clethodim, sethoxydim, tralkoxydim
B	Imazethapyr
C	Atrazine, diuron, metribuzin, simazine
D	Pendimethalin, trifluralin
E	Triallate
F	Amitrole
K	Flamprop methyl, flamprop-*m*-methyl

Sanitation Because wild oats do not naturally disperse, we consider sanitation to be an essential component of cultural control. In mixed farming systems, the spread of wild oats can be attributed to transportation in fodder (Thomas *et al.* 1984), straw (Wilson 1970), use of contaminated grain (Elliott and Attwood 1970), or dispersal by agricultural machinery. Immigration of wild oats can be prevented by planting clean seed, cleaning harvest and tillage equipment between fields, and covering grain trucks used to transport grain (Thill *et al.* 1994). Naber *et al.* (1996) found such measures to be vital for the success of a wild oat eradication program in the Netherlands.

Cultivation The effects of tillage on the population dynamics of wild oats are complex and varied (Navarrete and Fernandez-Quintanilla 1996). However, various trends are evident in the literature. Deeper burial of wild oat seed favours the maintenance of dormancy, thus prolonging longevity. If seeds are brought to the surface by subsequent tillage, they are released from dormancy and become available for recruitment. Consequently, wild oat populations tend to increase more under pre-sowing cultivations than practices which involve no or minimal soil disturbance during seedbed preparation, such as direct drilling (Medd 1990, M. Walsh personal communication). Wilson (1978) and Wilson and Phipps (1985) found that wild oat seed banks declined more rapidly using tyned implements compared with deep ploughing. The use of conservation tillage practices thus seems the most appropriate for wild oat management in Australia.

Delayed seeding Delaying the date of seeding allows control of emerged seedlings, thus reducing wild oat infestation levels in the subsequent crop. This was successfully demonstrated by Whybrew (1964) in the UK. However, under most Australian conditions, delayed seeding inflicts a grain yield and/or quality penalty and is therefore considered an uneconomic control method. Although delayed seeding is impractical, a sensible compromise is to plant fields with the worst wild oat populations last, as recommended by Thill *et al.* (1994).

Crop competition Competitive interactions between wild oats and crops are a complex subject. Several agronomic factors will influence the extent to which crop yield is reduced by wild oats, and the amount of wild oat seed returned to the soil (Thill *et al.* 1994). Crops and crop cultivars differ in competitive ability with wild oats (similar indications have been described by Lemerle *et al.* (1995) with annual ryegrass). Increasing the seeding rates of cereal crops generally reduces wild oat competition and seed production (Radford *et al.* 1980, O'Donovan and Sharma 1983), whilst shallow planting of quality seed gives the crop maximum competitive advantage in the early stages of growth (Cussans and Wilson 1976). Crops sown in narrow row spacings are equal to, or, more competitive with wild oats than widely spaced crop plants (Thill *et al.* 1994). Maximizing crop competitiveness is especially pertinent for wild oats as wild oats are the most competitive annual grass of wheat in southern Australia (Poole and Gill 1987).

Fertilizer use and placement Interference studies between wild oats and cereals have shown variable yield responses to nitrogenous fertilizers (Cousens and Mortimer 1995). In Victoria, M. Walsh (personal communication) found the addition of fertilizer (nitrogen and phosphorus), failed to achieve any reduction in weed growth and development, indicating no competitive advantage to either the crop or weed. Watkins (1971) demonstrated that nitrogen fertilizer can stimulate wild oat emergence before sowing, but has little effect as a long term means of reducing wild oat infestations. Banding nitrogen fertilizer near the crop seed appears to favour the crop, and is thus preferable to broadcasting fertilizer which favours wild oat growth (Thill *et al.* 1994).

Windrowing Windrowing crops prior to wild oat seed fall may lead to greater seed retention and capture at harvest. However, as captured seed is usually carried with the cereal grain, the cost of re-cleaning wild oat contaminated grain must be evaluated against the potential benefits (Matthews 1994).

Weed seed collection at harvest Evidence from overseas suggests that seed capture is achievable with chaff collectors (Thill *et al.* 1994). In the UK, Wilson (1970) was able to catch 84% (in the grain bin) of the total seed produced in an early maturing winter barley crop. These results do not seem particularly relevant to Australian conditions, but suggest harvest time, environment and even wild oat species/biotypes may influence seed catching efficacy. The vast majority of wild oats shed their seed before or during grain harvest and only a small proportion is able to be caught (either in a separate collection unit or grain bin) at harvest (Nietschke *et al.* unpublished). Therefore, seed collection would appear to hold little promise as an effective control tactic.

Crop stubble burning Wild oat seed can be destroyed on the soil surface by burning crop stubble (Wilson and Cussans 1975, Nietschke *et al.* 1996b). Additionally, burning can stimulate surface seed emergence by modifying seed dormancy of the survivors (Whybrew 1964, Nietschke *et al.* 1996b). Whybrew (1964) and Wilson and Cussans (1975) in the UK concluded that stubble burning by itself will not prevent population growth. This is almost certainly the case for Australian agriculture and, in any event, the practice is discouraged because of the recognised benefits of stubble retention. Periodic burning does have a place for disease management, so if disease and weed pressures coincide (especially if herbicide resistant wild oat plants have set seed) it could be a useful crop protection adjunct.

Crop rotation Wild oat infested crops, cut for hay or silage before seed shed, can greatly reduce seed rain (Cussans and Wilson 1976, Thill *et al.* 1994). In the UK, continuous spring barley cut for silage reduced wild oat emergence to nil after three years (Wilson and Phipps 1985). The green manuring of crops should be an equally effective control method if wild oat re-growth and seed production is prevented. Diverting to a pasture phase also provides the opportunity to reduce seed production, either by strategic grazing, mechanical slashing or herbicide use (Jenkinson 1976, Bentley 1990). However, pasture seed banks are generally not depleted to the same extent as under arable cropping situations, due to the lack of soil disturbance (Thurston 1966, Wilson and Phipps 1985).

In northern Australia, Philpotts (1975), Wilson *et al.* (1977) and Martin and Felton (1993) effectively reduced wild oat seed reserves through clean winter fallowing in association with a rotation from wheat to sorghum. Fernandez-Quintanilla *et al.* (1984) similarly demonstrated the value of summer break crops and winter fallowing in a Mediterranean climate. Conversely, continuous winter cereals do not reduce wild oat populations and probably neither do winter cereal-chickpea rotations, due to the poor competitive ability of chickpeas (Medd 1996).

An important incentive for rotating to winter broadleaf crops is the availability of cheaper Group A herbicide options for grass weed control. Furthermore, these herbicides generally have a broader target spectrum. A logical management plan should attempt to keep these herbicide options effective by using non-Group A herbicides in the cereal or pasture phase of rotations.

ADOPTION OF INTEGRATED WILD OAT MANAGEMENT STRATEGIES

In devising IWM strategies to manage herbicide resistant wild oats, two scenarios need to be considered: those where resistance has been incurred, and those where resistance has still to occur. Although the incidence of resistance is increasing, at most less than 6% of cropping paddocks in southern Australia are affected. In these paddocks, growers should be urged to adopt strategies which annihilate the resistant populations so as to avoid the spread of resistant seed. Methods such as crop removal for hay, silage or green manure are clearly appropriate salvage operations. These measures are justified on the basis that wild oat seed banks are quickly purged if seed input is eliminated.

Where resistance is not yet evident, (the majority of cases), emphasis should be placed on adopting IWM strategies which avoid or minimize selection for herbicide resistance. The driving force for this policy is the need to preserve all available options, especially herbicide choices given that few new products are imminent, and to avoid more expensive solutions.

Herbicide rotation Upon discovery of Group A resistant wild oats in Canada, the early extension emphasis was placed on herbicide rotation to manage resistance (Goodwin 1994). Likewise, many farmers in southern Australia have relied on herbicide rotation to initially manage the problem, especially in continuous cropping systems where there are few effective cultural control options.

Because herbicide resistance in wild oats is currently confined to the APPs in Australia, the rotation to other chemical groups (including CHDs), is imperative to minimize further APP resistance. Evidence that this is occurring comes from increased sales of major non Group A avenacides. For example, sales of triallate and flamprop methyl have steadily increased in southern Australia over the last few years- partially due to the threat of Group A resistance (M. Edmondson personal communication, J. Holmes personal communication). Unlike annual ryegrass, there has been minimal incidence of CHD resistant wild oats, and recommended rates of CHDs are effective on most APP resistant populations. Thus, the usefulness of CHDs (and other herbicide groups) to minimize complex resistance patterns may be prolonged through prudent herbicide choice and use.

However, sole reliance on herbicide rotation to avert resistance is not recommended for wild oat control. Experience from overseas demonstrates that simply rotating out of one class of chemistry into another, does not prevent CHD, multiple or cross resistance in wild oats (Heap *et al.* 1993, Morrison *et al.* 1995). Although these patterns of wild oat resistance have not been identified in Australia, they will undoubtedly appear unless avenacides are integrated with cultural control measures.

Cultural control Farmers are advised to adopt cultural strategies to minimize herbicide resistant wild oats, but in reality few do. This is due to most avenacides being highly effective on APP resistant wild oats and few cultural options are economically attractive and or sufficiently effective to warrant adoption. Cutting crops and selling them for hay currently provides good returns. However, the early shedding habit of wild oats requires cutting to be undertaken relatively early to prevent seed production, resulting in reduced hay yield. Practices which incorporate a pasture phase, green manure crop or winter fallow in a crop rotation provide the opportunity to prevent wild oat seed production and significantly deplete the seed bank. However, these options are perceived as uneconomical. In northern Australian cropping areas the practice of winter fallowing is deemed viable, because a summer crop (e.g. sorghum) can be grown to subsidise the income lost from no winter crop. The practices of windrowing and weed seed collection at harvest are poor wild oat control measures. Likewise, the burning of crop stubble is not a highly effective control technique.

The lack of cost effective cultural control methods means growers must embrace sound agronomic principles as part of an IWM program to minimize herbicide resistance. Many of these techniques are readily adopted because of their simplicity. For example, fields with the heaviest wild oat populations are planted last at seeding. The trend toward conservation tillage practices (e.g. direct drilling) which reduce soil disturbance and prevent seed burial, ensure wild oat seed longevity is minimized. Crop competition is an important IWM tool, and Australian farmers are becoming more conscious of utilizing competitive crops and cultivars, along with the value of increased crop seeding rates for weed suppression.

Sanitation methods are generally under-adopted in Australia and should be widely advocated as a basis to IWM for wild oats. Its importance along with weed mapping cannot be disputed. Thill *et al.* (1994) notes that continually monitoring fields for heavy wild oat patches, zone or area management can be adopted if infestations are recognised in certain areas of the field.

Conclusion A range of herbicide and cultural control techniques can be utilized for wild oat management in southern Australian cropping systems. Herbicides are the favoured strategy as they provide immediate, cost effective control and farmers are comfortable with the efficacy achieved. However, it is important that cultural strategies also be incorporated into an integrated system to help slow the onset of herbicide resistance. Unfortunately, these techniques are either costly or lack sufficient control to warrant significant adoption. The challenge remains for farmers to combine as many cultural options with favoured herbicide methods, plus good agronomic practices, to minimize the incidence of herbicide resistant wild oats.

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