

Conservation tillage and weed revolutions

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Weed problems in agriculture are ever-changing. The available control methods have unquestionably improved during this century due to mechanization and the advent of organic herbicides. However, despite the inventiveness of current weed control technology, few species have been eliminated and the problems revolve. Shifts in weed flora are part of the folklore of weed science and indeed have taken place throughout agricultural history. Species shifts mostly happen slowly and are rarely caused by a single factor. This is clear from a European study which shows that the interaction of herbicides, fertilizers, the form of tillage, crop types and cropping sequences has forced the evolution of regional weed floras (Haas and Streibig 1982). But a recent worldwide change, the upsurge in annual grass weeds, has been promulgated by conservation tillage practices in winter cereal production (Wicks 1985). It is this problem and its manifestation in the southern Australian wheat belt that is focused on in this paper. Whilst this is not the only change that has occurred it has become an important obstacle in farming systems that aim to conserve soil resources. Furthermore, it serves to illustrate how weeds continue to turn full circle on man.

Troublesome annual grasses in the southern Australian wheat belt are annual ryegrass (*Lolium rigidum*), wild oats (*Avena* spp.), annual phalaris species (*Phalaris* spp.), annual brome grasses (*Bromus* spp.), barley grasses (*Hordeum* spp.), and also silver grasses (*Vulpia* spp.) and possibly winter grass (*Poa annua*) in the high rainfall zone. These are not new introductions so, to begin to understand why they have ingressed, it is necessary to examine how farming practices have altered and to determine the biological features of weeds that have enabled them to adapt to the new farming practices. Some strategies for overcoming annual grass weed problems are discussed.

Differences in conservation farming practices

Conservation tillage is a collective term for practices that eliminate some or all operations involving soil disturbance.

In so doing, three possible weed control functions of tillage are reduced or lost: control within the crop (e.g. inter-row cultivation), control of weeds during the fallow (i.e. during the non-crop period), and the animation of propagules (i.e. to stimulate germination within the seed bank). Benefits could be expected from the latter two functions when using conventional tillage.

The substitution of herbicides for tillage during the preparation of land for cropping probably gives an equally efficient control of weeds within the fallow, although this has not been closely studied. Plants that survive pre-crop preparations are more difficult to kill because of size tolerance to normal rates of post-emergent herbicides.

One of the time honoured roles of tillage has been to stimulate weed emergence prior to sowing the crop—to animate seeds and, subsequently, control them. This role is completely lost in direct drilling and chemical fallow systems and is only partly applied with reduced tillage techniques. Clearly, if weeds emerge there are alternatives to tillage for controlling them but for the moment there is no feasible practice that can substitute for the animating role of tillage.

Pre-emergence herbicides are not widely used for grass control in conservation tillage for several reasons. Firstly, they mostly have a narrow spectrum, for example, chlorsulfuron and pendimethalin are registered for annual ryegrass but not for other annual grasses. Some need thorough soil incorporation (e.g. trifluralin) which opposes one of the main objectives of conservation tillage. Furthermore, the pre-emergence herbicides can be inactivated by herbage and stubble residues, the retention of which is a desirable practice in these systems. To some degree this may be overcome by applying doses above currently recommended rates, but this is still subject to test. Moreover the cost effectiveness of this option may be doubtful.

All these factors have meant an increased reliance on post-emergence control of weeds. Generally these herbicides have greatest efficacy on small plants and crop tolerance diminishes after early tillering. But here

again there are no broad-spectrum herbicides that will control annual grasses in winter cereals. In contrast, several recently developed herbicides can control selectively a wide spectrum of grasses in broadleaf winter crops. Consequently, there has been a resurgence of interest in crop and herbicide rotation, resulting in a wider range of winter crop species being grown in southern Australia. Under conventional tillage, annual ley pastures were the main rotational alternative. Ley pastures are still widely used in conservation tillage systems and techniques such as spray topping have been developed to minimize seeding of annual grasses in the final year of the pasture rotation. Spray topping involves the application of non-selective herbicides when the majority of inflorescences contain seed in the soft dough stage. As emphasized by Haradine (1986), the timing of herbicide application is critical and careful attention to grazing management is required to ensure synchronization of flowering in the weed population for optimal results.

With conservation tillage, crops can be sown immediately following opening rains which means that they are often planted earlier than is the case with conventional tillage. This can give crop yield advantages because of the longer growing season compared with lower potential yields expected from late-sown crops. However, early growth rates are generally considerably reduced in crops established using conservation tillage techniques, particularly direct drilling (Gates *et al.* 1981). Consequently, the main effect of early sowing may be to offset tardy crop establishment. Several consequences concerning weeds result from early sowing. Firstly, weeds can establish under less competitive stress from the crop if its growth is retarded. Secondly, the speed of weed emergence may be favoured relative to crop emergence. There are a number of reasons for this, for example, weed seeds may already have begun germinating when the crop is planted, or warmer soil temperatures may invite differential responses favouring weeds.

Other notable differences between conservation tillage and conventional methods are that in conservation tillage a larger proportion of weed seed remains on or near the soil surface. Tillage, if used, is mostly with tined implements to avoid trash inversion and this results in minimal deep burial of seed. It is not clear whether the retention of surface stubble affects the behaviour of weed seeds.

Biological features involved in weed adaptation

This group of grass weeds which behave as winter annuals emerge and reproduce within the life span of the crop. Like the cereals they tiller and can adjust their reproductive yield according to the resources available. They differ however, by maturing before the crop and shed most of their seed before the crop is harvested. Apart from these general features their biological behaviour tends to vary. For instance, they display a wide range of species specific emergence patterns and seed longevity, and seed dormancy varies between and within species. As already mentioned, there is no one registered herbicide that will control these grasses selectively in winter cereals and, in addition, herbicide resistance has occurred in ryegrass (Heap and Knight 1982) and barley grass (Powles 1986), indicative of their biological diversity.

It would seem, therefore, that broad biological features are responsible for the build-up of annual grasses in conservation tillage systems. Since the seed is the perennating organ of annuals, either seed carryover via a seed bank or the influx of fresh seed is necessary for these grasses to persist.

Seed bank carryover effects

A number of factors, particularly dormancy, influence whether seeds persist as viable propagules or disappear from the seed bank. Loss from the seed banks is by seed germination, death through metabolic failure or predation, or export from the soil. The sum of these fates over time gives a 'decay' curve. The inverse at any one time gives the number of seeds persisting.

The decay function of seeds in the cultivated layer of arable soils has been shown to be either exponential (Roberts 1970; Egle and Chandler 1983) or hyperbolic (Burnside *et al.* 1981). The rate of decay seems to vary among species but Lewis (1973) concluded that seeds of few grass species persist longer than four years. However, this depends on the expression of seed dormancy. In *Bromus diandrus*, for example, innate dormancy is weakly expressed and almost all seeds will germinate after a short period of after-ripening (Cheam 1986a; Harradine 1986). Whilst a small percentage of seed entered induced dormancy, carryover of low populations of seed was due more to enforced dormancy. Even so, seeds of this species are not well adapted for sur-

vival since only under cool moist soil storage conditions did longevity exceed 18 months (Cheam 1986b). Similarly, populations of *Avena fatua* which lacked innate embryo dormancy persisted less than two years regardless of depth of burial (Zorner *et al.* 1984). This contrasts with studies of *A. fatua* genotypes having innate or induced embryo dormancy which acted to prolong longevity. In one study 5% of seeds were viable after 4 years (Wilson 1985) and 1% of another seed population persisted after 7 years (Banting 1966). With *Poa annua*, Roberts and Feast (1972) found that 12% of seeds survived after 6 years (averaged over three depths of burial in disturbed and undisturbed soils). In these cases there is some indication that dormancy is favoured by deep burial, thereby increasing longevity. Longevity appears to be shortened as a result of seed burial in species which lack innate dormancy or are devoid of mechanisms that enable dormancy to be induced. Here the indications are that unburied seeds survive for longer periods due to enforced dormancy (see Froud-Williams 1983; Cheam 1986a and Harradine 1986 in relation to *Bromus* spp.).

There is strong evidence that germination of seeds accounts for a large proportion of seed bank decay. Non-dormant seeds are free to germinate and will do so if supplied with favourable environmental conditions. This is the point at which tillage has most effect for it may enhance the release of seeds from dormancy as well as improve the availability of optimal microsites for germination; together these speed up seed bank decay. Roberts (1970) showed that the decay was most rapid with multiple tillage. Seasonal timing of tillage is not necessarily important (Roberts and Potter 1980; Roberts 1984) but the choice of tillage implement can affect the rate of decay (e.g. Wilson 1978; 1985), most probably due to depth of burial effects. Zorner *et al.* (1984) found, for instance, that deeply buried seeds of *A. fatua* were more likely to germinate than seeds at shallow depths whereas those seeds closer to the surface tended not to germinate but lost viability, possibly due to metabolic failure. When seeds germinate but fail to produce seedlings this loss mostly goes unnoticed; it is often termed 'fatal' germination and there is a growing realization that it contributes significantly to decay. This also is influenced by depth of burial and interacts strongly with seed size and quality. For example, more than half the seeds of *A. fatua*

germinating at a depth of 75 mm and almost all seeds buried at 230 mm failed to produce seedlings (Murdoch 1983). Wilson (1985) observed >85% loss of buried *A. fatua* seeds, further indicating the vulnerability of seed populations when deposited at depth. Based on the behaviour of wild oats, burial of small seeded species would seem to enhance the prospects for fatal germination due to their limited endosperm reserves. There is little doubt that fatal germination is also related to soil type and bulk density (Egle and Chandler 1983).

Burning also affects grass seed longevity. For example, seeds of *A. fatua* (Wilson and Cussans 1975) and of *Alopecurus myosuroides* (Moss 1980) lying on the surface were killed by burning the stubble. The effect is temperature dependent and is governed by the amount of stubble, the speed of the fire and the moisture content of the seed. Imbibed seeds and those covered by even shallow layers of soil suffered less mortality and were seemingly less dormant as a result of burning. The fire residues appeared also to provide a more favourable seedbed for germination.

Factors affecting seed production

The importance of seed production versus seed bank carryover in regard to the persistence of wild oats in the UK has been highlighted by Wilson (1978). Inputs to seed banks are either from imports (herein ignored) or from seed production by plants that survive or escape treatment within the crop. Seed production depends initially on the recruitment (establishment) of plants and henceforth on their growth to maturity. Survival, growth and reproduction are influenced both by environmental and density-dependent factors whereas recruitment is mainly under environmental control.

It is abundantly evident from the above discussion that seed burial affects recruitment. Whereas most recruits arise from shallowly buried seeds, those placed at the extremes (i.e. on the surface or buried deeply) are less liable to produce plants (Roberts 1984). With this group of weeds, most recruitment comes from seed that is less than one year old. But, generally, recruitment is not a limiting factor even though mostly only a small proportion of seeds in the soil emerges annually. It is not uncommon for annual emergence to be <10% of the viable seed bank (Roberts 1981; 1984) and sometimes can be as low as <1% (Roberts and Ricketts 1979).

Of much greater importance in cropping cycles is the timing of recruitment. Among this group of grasses two broad emergence patterns are evident. Recruitment is either a single event, as is the case for *B. diandrus* (Cheam 1986a; Harradine 1986); or it has an initial wave followed by smaller periodic emergence events, generally occurring through to spring, as in *Avena* spp. (Amor 1985). Where recruitment is staggered there is a high probability of some plants avoiding control since late post-emergence control is not possible due to the lack of crop tolerance.

A major factor contributing to the production of seed is weed survival. Only under exceptional conditions is it possible to obtain >90% in-crop control of weeds. Generally, up to 25% of weeds survive post-emergence treatment. Clearly this fraction is capable of reproduction, even though the growth and fecundity of individuals may be retarded by treatment.

Species fecundity varies from a few seeds to several hundred per plant and, like crop plants, is density dependent. For example Radford *et al.* (1980), using a mixed population of *Avena* spp., found that seed production per unit area was similar for all weed densities at low crop density. Weed seed production declined for all densities of the weed as crop density increased, especially in low weed populations. Seed production of *Lolium rigidum*, likewise, remained high over a wide range of densities with mixtures of wheat (Rerkasem *et al.* 1980). Time of emergence and soil moisture and fertility are other factors which influence the fecundity (Peters 1982). Between 90 and 100% of seed produced by *A. fatua* in crops of spring barley was produced by early emerged plants (Peters 1984). Seed production and quality can also vary according to the environmental conditions prevailing during seed maturation (Moss 1983).

Conclusion

A considerable range of options is available for weed control in conservation farming. There is no overall prescription; it is a matter of assessing the weed problem on a field basis and determining which are the most appropriate techniques to apply in that situation. Invariably weed-control schedules are aimed principally at minimizing crop yield loss attributable to competition, and rightly so. It is equally apparent that these practices concentrate on killing plants; a trend exacerbated in conservation farming

by eliminating practices that contribute to seed bank decay, along with a heavier reliance on in-crop control. These deficiencies have been uppermost in allowing annual grasses to invade.

To correct this, weed-control decision making needs to incorporate the concept of population management since the carryover of weed propagules together with the influx of new seed affects future decisions. This does not require the development of new techniques but calls instead for the harnessing of practices in an integrated fashion to optimize both crop yield and weed population suppression. In this regard there are few comprehensive aids to assist producers in their decision making. However, assessment of the amount of population regulation attained from given inputs of control is now possible at a research level by using models, opening the way to a more analytical approach to weed management on the farm (Medd 1987).

Fine tuning of management systems undoubtedly leads to improved weed control but will not necessarily eliminate weed problems. This is borne out by two published examples (Doyle *et al.* 1985; Cousens *et al.* 1986). From this it must be concluded that available techniques are manifestly incapable of eliminating weeds, no matter how precisely they are integrated. The single reason for this is their failure to disrupt seed cycles adequately. Although attempts to regulate seed populations directly have so far met with only partial success (Medd 1985), they amply demonstrate that it is possible. Research along these lines is strongly advocated for the annual grasses since they are not well adapted for long-term storage in the soil.

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