Proc. VII. Int. Symp. Biol. Contr. Weeds, 6-11 March 1988, Rome, Italy.
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Relevance of Seed Kill for the Control of Annual Grass Weeds in Crops

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Abstract

Annual grass weeds such as *Avena* spp. (wild oat) (Poaceae) and others are among the most troublesome and important weeds of winter cereals in Australia. Although these weeds can generally be adequately controlled within a crop, they persist as a problem from year to year, limit management options and act as a reservoir for a number of important crop diseases. For these reasons, better methods are needed to attain long term control. The ability to produce large amounts of seed and the brevity of longevity are notable characteristics common to these weeds. A generalized simulation model of the population dynamics of wild oat is used to investigate the importance of these factors in relation to weed persistence and to compare seed and plant kill strategies for long term control. In all the combinations tested, seed kill of 25% or greater led to marked reductions in population size. The use of seed pathogens is suggested as one means of attaining seed kill. Although the possibilities for classical biocontrol of these weeds are remote there is potential for attacking seeds using inundative means.

Introduction

Winter cereal growers throughout the world continue to be plagued by annual grass weeds; more so since the adoption of conservation farming techniques (Wicks 1985). In the southern Australian wheat belt there has been an upsurge in *Lolium rigidum* Gaud. (annual ryegrass), *Avena* spp. (wild oat), *Phalaris* spp. (annual phalaris species), *Bromus* spp. (annual brome grasses), *Hordeum* spp. (barley grasses), and also *Vulpia* spp. (silver grasses) in the high rainfall zone. Wild oat and annual phalaris species, particularly *P. paradoxa* L. are the main grass weeds of winter cereals in northern New South Wales and Queensland.

These weeds compete strongly with establishing crops and most act as a reservoir for a number of important crop diseases (Rovira 1987). Cost to the Australian wheat industry, just of wild oat and ryegrass, is estimated to exceed $M100. Although these weeds can generally be controlled to some degree, they persist as problems from year to year and limit management options. The annual cost of control can be up to $50/ha. For these reasons, strategies that give long term control would be desirable. To achieve this, however, better control methods will need to be developed.

One characteristic common to these weeds is their ability to produce large amounts of seed but few studies have investigated the importance of this factor in relation to population changes and weed persistence. Furthermore, since seed longevity does not exceed about four years, the role of carry-over of seed populations versus seed production also needs to be investigated.

In this paper, a generalized simulation model of the population dynamics of *Avena fatua* L. (wild oat) (Poaceae) is used to analyse patterns of demographic behaviour and to compare strategies of controlling the production of seeds in conjunction with current plant control methods. The option of controlling seeds is briefly discussed around biocontrol possibilities, especially the use of seed borne pathogens to regulate populations of annual grass weeds in crops.

The Model, Assumptions and Values

The object of modelling the population characteristics of wild oat was to provide an analytical framework to enable an assessment of the concept of directly controlling seeds during the cropping phase. To achieve this, a model capable of simulating a range of management scenarios was required.

The general structure of the model is illustrated in Figure 1 showing the life history of wild oat broken into four compartments. The seed bank in the soil is conceived as a pool of seeds of mixed ages from which seedlings emerge in waves during the annual life cycle since recruitment is not synchronised (Quail & Carter 1968, Amor 1985). Three age groups or cohorts of plants are recognised: those which emerge during the fallow period prior to planting the crop, ones which emerge after crop planting up until completion of post-emergence herbicide treatments, and those that emerge after herbicide treatment. The fates of each of the three cohorts are simulated independently through emergence, plant kill and fecundity events up to seed production whence all seeds produced are pooled. Transitional probabilities, representing an average outcome for each process, are used to produce seedlings ($E_{1...3}$) as well as to provide for plant kill ($K_{1...3}$) and kill of newly-produced seeds (SK). After emergence is completed a further loss of seeds from the bank simulates losses through predation, death etc., before newly produced seeds are deposited in the seed bank.

Demographic transitional probabilities were calculated from field experiments (Medd, unpublished data) which involved a detailed census of buried seeds, seedling emergence, plant survivorship and plant reproduction in a range of tillage and control regimes over four years. Values used in the model have per m^2 dimensions. Recruitment values generally ranged from 25 to 50% of the seed bank. Two recruitment scenarios for each end of this range were simulated by varying the proportion and periodicity of emergence in the three cohorts (Table 1). Up to 5% (but generally zero) plants survived fallowing, whereas up to 25% of plants survived in the second and third cohorts. In practice, plant kill in cohort two could result from both density dependent and herbicide effects whilst that in cohort three would be due mainly to density dependent forces. Plant kill and fecundity values used in the simulation are given in Table 1. Seed kill was treated as a variable, ranging from 0 to 80% and the annual loss of seeds from the seed bank set at a constant 65%.

The model started with 1000 seeds in the seed bank. Total seed bank present after five years is used to compare changes in populations and to determine the impact of controlling plants versus newly produced seeds.

Results and Discussion

Populations of wild oat increased between 2.5 and 8 fold in three of the four recruitment scenarios tested with the most lenient levels of plant kill coupled with zero seed kill (Fig. 2b,c,d). These levels of 95, 80 and 75% plant kill for the three cohorts respectively would be unacceptable in practice, except where there is no recruitment before sowing and total recruitment is restricted to 25% of the seed bank (Fig. 2a). If recruitment within the crop is doubled, plant kill in the crop (i.e., for cohort two) has to be increased to 90% in order to achieve a similar reduction in the seed bank (Fig. 2b).

When recruitment occurred in the fallow (cohort 1) almost complete control of those plants in conjunction with 90 and 75% kill of cohort 2 and 3 plants respectively was required to bring about a decline in the seed bank (Fig. 2c,d). In the case of 50% total recruitment, with 95, 90 and 75% plant kill for the three cohorts, the seed bank changed little from the starting value (Fig. 2d). Under the same levels of plant kill the seed bank increased when total recruitment fell to 26% (Fig. 2c). This result is attributed to the larger carry-over of seeds in the bank due to lower overall recruitment.

The widely-accepted practice of killing all plants in the fallow is borne out in these findings. These plants are the most fecund and accordingly have a greater potential to contribute to population growth. Furthermore, high levels of plant kill (around 90%) of plants recruited soon after the crop is sown is also required in order to attain negative population growth.

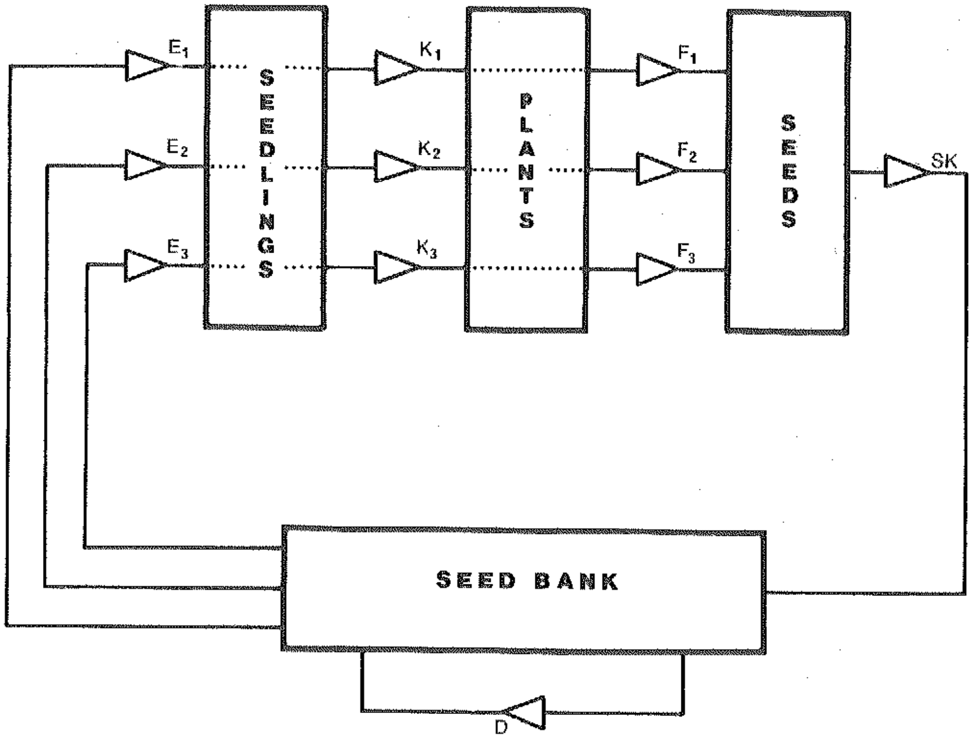

Figure 1. Structure diagram of the population dynamics of *Avena fatua* L. showing seedling, plant, seed production and seed bank compartments for three cohorts: plants recruited in the fallow (E_1), in the crop up until spraying (E_2), and after spraying (E_3), along with their respective plant kill ($K_{1..3}$) and fecundity ($F_{1..3}$). SK and D are transitional probabilities for seed kill and seed bank loss, other than through recruitment.

Currently, three approaches are integrated to manage annual grass weeds in winter cereal crops: killing plants both before and after sowing the crop reducing weed vigour via crop competition and reducing populations by rotating crops and herbicides. With wild oat, for example, tillage and/or herbicides may be used to destroy the weed in fallows. Within the crop, control is possible by using either pre- or post-emergence herbicides along with optimum cultural practices for time of sowing, crop density, fertilizer inputs, crop cultivar and so on (Medd 1987*a*) to make the crop more competitive towards the weed. Crop rotation with a winter broadleaf crop or pasture is a further important management option. In some regions switching to a summer crop rotation is an effective alternative when wild oat populations become excessive (Philpotts 1975).

In all instances investigated, seed kill in association with plant kill lead to marked reduction in populations (Fig. 2). In the United Kingdom, Wilson *et al.* (1984) calculated that 75% reduction in seed production was necessary to contain wild oat populations. Our simulations suggest that the UK estimate is of the right order to effectively contain populations, but clearly marked reduction in populations can be achieved with between 25-50% seed kill, depending on initial population size (Fig. 2).

Few techniques have been developed for controlling seeds. Burning of stubble, burying of seed by deep inversion cultivation and increasing the frequency of shallow cultivation may all enhance seed 'decay' of annual grasses (Medd 1987*a*,*b*), but are all incompatible with the objectives of conservation farming. Within the crop there is no technology available for killing seeds other than by indirect methods such as competition. During the non-crop phases of a rotation e.g. pasture, seed production by grass weeds can be controlled by 'spray-topping' (Jones *et al.* 1984).

Table 1. Recruitment, plant kill, and plant fecundity values used in simulating population changes in *Avena fatua* L.

Parameter	Cohort 1	Cohort 2	Cohort 3
Recruitment (E) from seed bank (%)	0	20	5
	0	45	5
	15	10	1
	15	30	5
Kill (K) of plants (%)	95 [1]	80	75
	95	90	75
	100	90	75
Fecundity (F) (seeds/m^2)	[2] $118\,x^{0.87}$	$22\,x^{0.87}$	$4.3\,x^{0.87}$

[1] Plant kill = zero when recruitment is zero.
[2] Where x = plant density.

Seeds are known to host abundant mycofloras, including many species of fungi which are selectively pathogenic (Agarwal and Sinclair 1987). The potential of such organisms for biological control of seeds has to date been little explored. Two broad groups of seed borne fungi are recognisable: those that infect seeds on the developing inflorescence, *vs.* those which invade seeds after development either in storage or in the soil. The former, being aerially transmitted, are perhaps more manageable from the point of view of inundative application techniques. However, storage type pathogens applied to the soil could conceptually be equally as effective by attacking seed banks.

Biological control of grass weeds in cereal crops offers few opportunities for using classical methods due to the risks associated with specificity. Quarantine regulations are such that importation of any potential candidates would almost certainly be denied.

Consequently the inundative approach utilizing endemic organisms offers perhaps the only feasible opportunity for biocontrol of weeds in cereals.

If technology is to be improved for controlling grass weeds in cereals, it is concluded that research would be better directed towards increasing the control of seed production rather than towards increasing plant kill, based on findings from this simulation exercise. Killing plants will always be the favoured option as it removes the competitive force. However, technology for plant kill is already refined and complex and the marginal costs of further units of kill will be high. More precise and rigid management skills would also be demanded to achieve near perfect plant control. On the other hand, technology capable of providing even 50% seed kill would have a bigger impact on the control of populations and would perhaps be easier to achieve in practice than further increases in plant kill.

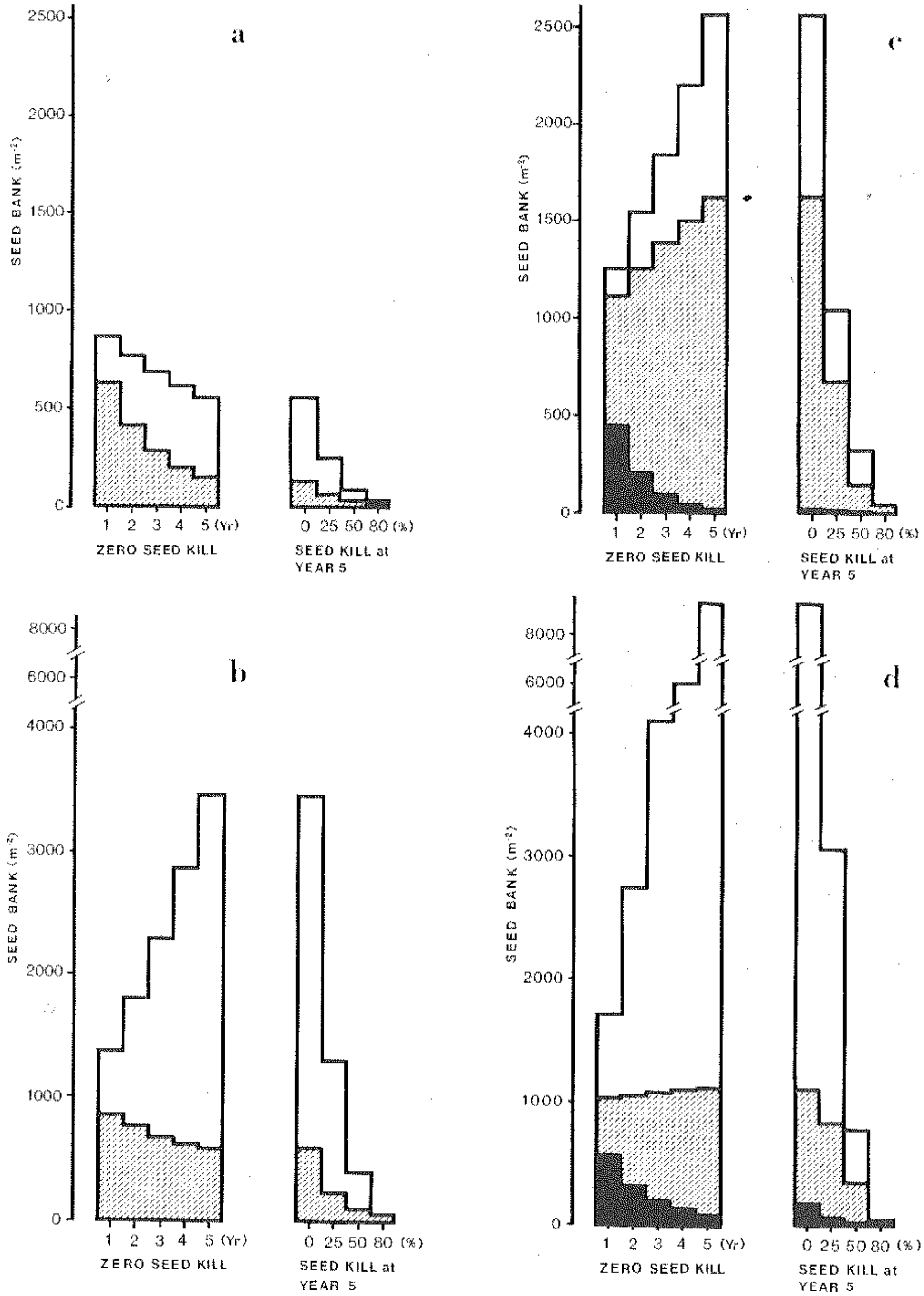

Figure 2. Seed bank (per m^2) changes for four recruitment patterns and range of plant and seed kill scenarios on *Avena fatua* L. The left histogram in each sub figure shows changes in the seed bank over five years with zero seed kill. The right histogram shows the seed bank at year five with an annual kill rate of 0 to 80% of newly produced seeds. Scenario values for a. to d. are: a. $E_{1...3}$ = 0, 20, 5%, open bars - $K_{1...3}$ = 0, 80, 75%, and stippled bars - $K_{1...3}$ = 0, 90, 75%; b. $E_{1...3}$ = 0, 45, 5%, K values as for a.; c. $E_{1...3}$ = 15, 10, 1%, open bars - $K_{1...3}$ = 95, 80, 75%, stippled bars - $K_{1...3}$ = 95, 90, 75%, and black bars - $K_{1...3}$ = 100, 90, 75%, stippled bars - $K_{1...3}$ = 0, 90, 75%; d. $E_{1...3}$ = 15, 30, 5%, K values as for c.

Acknowledgments

We are grateful to Kim Jones and Barry Kay for valuable technical assistance with the demography experiments, and to Belinda Gersbach for preparing the figures. This research was supported with a grant from the Australian Wheat Research Council.

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