ECONOMIC BENEFITS OF POPULATION MANAGEMENT: A CASE STUDY FOR WILD OATS

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Summary A simulation model is used to examine the economic impact of a range of management strategies for control of wild oats. Of the seven options examined, those which involved measures to directly reduce seed production minimized wild oat seed bank populations and, as a consequence, gave the greatest economic benefit. A pre-emptive annual decision rule based on marginal costs and benefits gave the highest economic returns. The implications of these findings in relation to current crop threshold decisions, population monitoring and maintaining flexible options are discussed in the context of developing more efficient methods of managing weed populations in cropping systems.

INTRODUCTION

The Cropping Systems Program of the Co-operative Research Centre (CRC) for Weed Management Systems aims to reduce the impact of weeds on farm productivity and profitability by developing sustainable management programs which optimize the integration of biological, chemical and ecological approaches for annual crop and pasture systems in the wheat-sheep zone of southern Australia. A basic premise of this charter is that by lowering weed populations, farm profitability will be improved. There are few examples in Australian agriculture which have examined this premise.

Wild oats is a major weed of cropping systems throughout Australia and is a priority weed targeted by the CRC. Most occurrences of wild oats in Australia involve mixed infestations of *Avena fatua* L. and *A. ludoviciana* Durieu (syn. *A. sterilis* subsp. *ludoviciana*). Recent work by Medd *et al.* (1995) has demonstrated that wild oat populations can be dramatically reduced in the wheat phase of a rotation by the integrated use of seed kill tactics. This involves the late application (at GS 31, Zadoks *et al.* 1974) of flamprop methyl, specifically to reduce wild oat seed production. It is an additional management option and does not substitute for the need to undertake yield conservation measures of pre- or early post-emergence applications of herbicides. It is known also that wild oat populations can be significantly reduced by rotating to a summer crop, such as sorghum, because wild oat seed production is prevented by clean winter fallowing (Philpotts 1975, Martin and Felton 1993).

In this paper we use a simulation model to test the hypothesis that by minimizing seed bank populations the economic benefits from the management of wild oats will be maximized.

MATERIALS AND METHODS

A simulation model was constructed to track the size of the seed bank population over a ten year period and assess the economic benefits of seven alternative control strategies, these being:

a. No annual control.
b. Plant kill control only, applied annually.
c. Seed kill control only, applied annually.
d. Plant plus seed kill control, applied annually.
e. Summer crop rotation with no annual weed control during the wheat phase.
f. Summer crop rotation with annual plant kill control applied during the wheat phase.
g. Annual decision, to determine whether to use no control, plant kill only, seed kill only or plant and seed kill combined.

For options (a)–(d) and (g), the farming system is a continuous wheat crop. For options (e) and (f) the rotation used is three years of wheat followed by a winter fallow, sorghum crop, winter fallow and another three years of wheat. For the annual decision option (g) the optimal annual strategy is determined by comparing the marginal benefits from plant kill, seed kill and combined plant and seed kill in the following year. The option which gives the highest marginal benefit in year t+1 is implemented in year t. If the options give negative returns in year t+1, i.e. the marginal cost exceeds the marginal revenue, then no control option is implemented in year t.

The critical state variable which measures the impact of control on population size is the seed bank. Figure 1 depicts the annual dynamics of wild oats, which reproduces only by seeds. In a generation, some seeds germinate giving rise to seedlings, some of which survive and mature, reproduce, die and deposit seed to the seed bank. To capture the asynchronous germination behaviour of wild oats in a season, three cohorts (illustrated by the arrow streams) are simulated.

We assumed an initial seed bank size of 500 seeds m^{-2} for all options. It is expected that in any season 50% of the seed bank will germinate in the proportion of 30%

cohort 1, 60% cohort 2 and 10% cohort 3. The residual seed remains dormant, but decays or loses viability such that 25% is carried over and is available for germination in the following year.

Survivorship of plants is assumed to vary for the different management options, as indicated in Table 1.

The fecundity equations used for estimating reproduction by the wild oat population are those estimated by Medd *et al.* (1995). Under the no control and plant kill options seed production (y) (seeds m^{-2}) for each cohort is estimated as follows, where x is wild oat plant density (plants m^{-2}):

cohort 1: $\ln y = 8.6 \ln x(0.74 + 0.88 \ln x)^{-1}$

cohort 2: $\ln y = 7.6 \ln x(1.2 + 0.8 \ln x)^{-1}$

cohort 3: $\ln y = 6.8 \ln x(2.0 + 0.67 \ln x)^{-1}$

When a seed kill strategy is adopted seed production for all cohorts is given by the equation:

$\ln y = 7.42 \ln x(2.04 + 0.66 \ln x)^{-1}$

The proportion of seed produced which enters the seed bank (seed rain) also depends on the management option, and is indicated in Table 1. Wheat yield loss from wild oats is a function of the density of mature wild oat plants. The following yield loss due to competition used by Medd and Pandey (1990) has been adopted in this analysis:

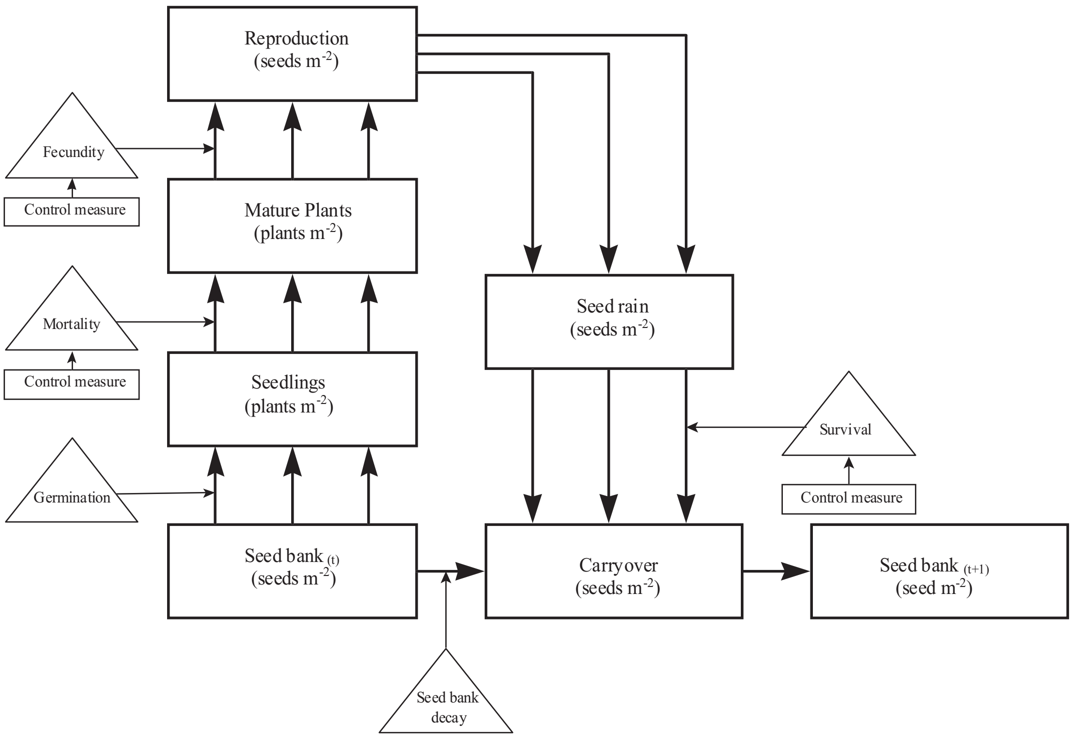

Figure 1. Population dynamics of an annual life cycle of wild oats, depicting three cohorts.

Table 1. Plant mortality and seed rain survival values assumed for cohorts and management options.

	No control (%)	Plant kill (%)	Seed kill (%)	Plant and seed kill (%)	Summer crop (%)
Plant mortality – cohort 1	85	85	85	85	100
Plant mortality – cohort 2	15	75	15	75	100
Plant mortality – cohort 3	75	75	50	75	100
Seed rain survival – 1	60	50	20	20	0
Seed rain survival – 2	60	50	20	20	0
Seed rain survival – 3	60	50	20	20	0

Loss = *YW*/(*a*+*bW*)
where *Y* is the weed-free yield (Table 2), *W* is the density of wild oats (plants m^{-2}) and $a = 104.4$ and $b = 1.22$ (from Martin *et al.* (1988)).

The herbicide rates for the plant kill and seed kill strategies are as follows:

Plant kill: Triallate at 2 L ha^{-1}
Seed kill: Flamprop methyl at 2.25 L ha^{-1} plus Uptake of 0.5% v/v.

The cost of the herbicide treatments, active ingredients plus application costs, is given in Table 2. Wheat and sorghum prices were calculated as five year averages over the period 1990-91 to 1994-95 (ABARE 1995). Yields and variable costs for wheat and sorghum were derived from Patrick (1994, 1995).

RESULTS AND DISCUSSION

Without annual control of wild oats the seed bank increased from 500 seeds m^{-2} to over 4500 seeds m^{-2} by year 10 (Figure 2a). If the plant kill only option involving the annual application of triallate is adopted, the seed bank still increased to approximately 3000 seeds m^{-2} by year 10. This demonstrates the ineffectiveness of relying solely on plant control measures, as shown by Martin and Felton (1993).

Alternatively, both the seed kill and combined plant and seed kill options resulted in rapid declines in the seed bank to negligible seed numbers by year 10 (Figure 2b), as previously indicated by Medd *et al.* (1995). The annual decision rule resulted initially in an identical decline in the seed bank to that for the combined plant and seed kill option, but by year 5 the decline resembled that for seed kill only. Rotation options resulted in substantial temporary declines in populations when sorghum was grown, but was not as effective in controlling wild oat seed bank populations overall as options involving seed kill.

The economic analyses provided net present values (annual gross margins discounted to reflect returns ($A ha^{-1}) in present day dollar values) for each control option. The annual decision rule was the preferred option for controlling wild oats as it returned the highest net present value of $A815 ha^{-1} (Figure 3). The optimal strategy determined by this option was to conduct plant and seed kill in years 0, 1, and 6, plant kill only in years 2–5, seed kill only in years 7 and 9, and in other years no control at all.

The combined plant and seed kill and seed kill only options also performed well returning net present values

Table 2. Data used in economic analyses.

Wheat price ($A t^{-1})	133.00
Sorghum price ($A t^{-1})	139.00
Wheat yield (t ha^{-1})	2.25
Sorghum yield (t ha^{-1})	3.75
Wheat variable cost ($A ha^{-1})	118.38
Sorghum variable cost ($A ha^{-1})	154.04
Herbicide cost – plant kill ($A ha^{-1})	25.40
Herbicide cost – seed kill ($A ha^{-1})	19.31

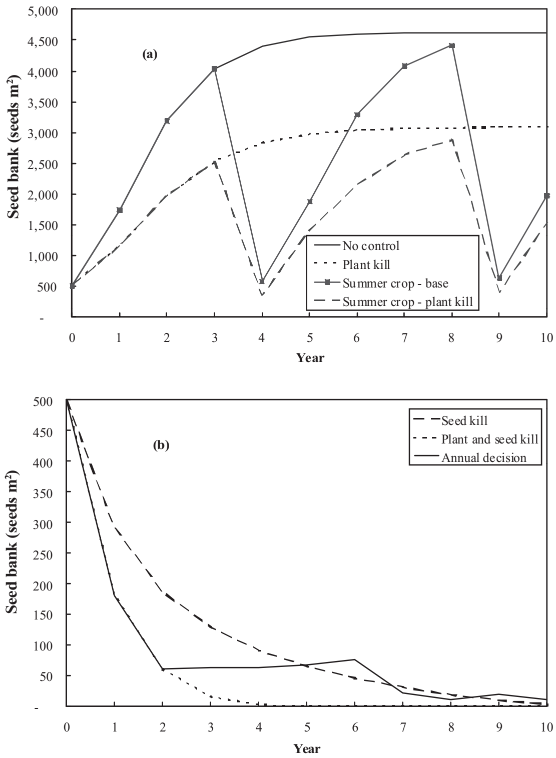

Figure 2. Seed bank dynamics for management options (a) without seed kill and (b) with seed kill options.

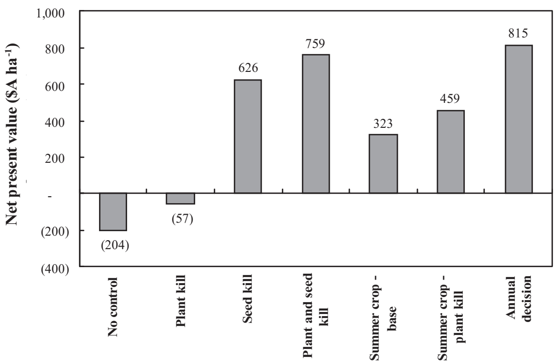

Figure 3. Net present values of all management options.

of $A759 and $A626 ha^{-1} respectively (Figure 3). The summer crop rotation options gave intermediate returns while the no control and plant kill only options returned negative net present values.

The hypothesis that economic benefits can be maximized by minimizing seed bank populations is clearly acceptable for wild oats. In this case, the optimum economic benefits arose from the annual decision policy, but this option did not result in the lowest seed bank population. This clearly demonstrates the need to consider the marginal costs of weed control along with the marginal benefits associated with reducing the impact upon yield when making weed management decisions. To satisfy this condition the decision rule cannot be a fixed threshold. Furthermore, decisions have to pre-empt future effects on the seed bank, and not be locked to current crop gross margin considerations. To this end there is a problem, as commercial testing techniques for monitoring seed bank populations have yet to be developed.

The findings of this study suggest that farming systems which rely on annual therapeutic treatment of highly competitive weeds, such as wild oats, are unsustainable because of the failure to contain weed populations. By rotating wheat with a summer crop, better control of weed populations was achieved, albeit temporarily, and reasonable economics benefits resulted. This rotation is in fact the most widely adopted farming system in the north-eastern grain belt. In practice, the rotation does not allow farmers to respond freely to market opportunities as decisions and flexibility are constrained by the level of wild oat infestation.

The development of seed kill techniques which directly allow seed production to be reduced opens the way for more efficient management of this recalcitrant weed. The ability to rapidly deplete seed banks not only maximizes economic benefits but it eases decision making and allows more flexibility to pursue alternative farming options, avoiding potential opportunity costs of forced rotations. The seed kill option has another important advantage of providing better management opportunities to avoid the development of herbicide resistance in wild oats, as discussed by Nietschke *et al.* (1996).

We conclude that the charter of the CRC for Weed Management Systems to improve farm profitability by reducing weed populations, which was largely based on intuition, is vindicated, at least for wild oats. The success of this venture for other weeds and farming systems will rest on developing incisive, integrative and affordable technology. That is the challenge.

ACKNOWLEDGMENTS

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