

BIOLOGICAL CONTROL OF WEEDS: A DISCUSSION OF DIFFERENT METHODS AND THE CHOICE OF TARGET WEEDS

K.L.S. HARLEY

Division of Entomology, CSIRO,
Private Bag No. 3, P.O.
Indooroopilly, Brisbane, Q. 4068, Australia.

Summary. Classical biological control, biological control by augmentation of insect or nematode enemies and biological control by application of endemic pathogens as mycoherbicides are discussed in relation to their applicability to control of annual and perennial weeds, native and introduced weeds, and weeds of cultivation. Defining priorities in the choice of weeds as targets in biological control programs should take account of likely degree of control, cost effectiveness and any conflict of interests. Reference is made to the cost of weeds and possible benefits from different biological control methods.

INTRODUCTION

In a recent review of the cost of weeds Vere and Auld (1982) cited aggregate losses worth thousands of millions of dollars, while in several regions of the world losses in specific crops were of the order of hundreds of millions. Furthermore, they estimated that weeds caused a reduction of potential world crop yields 2.5 times greater in undeveloped countries (at 25%) than in countries with an intermediate development of agriculture. These losses contribute to one-third of the world's population suffering malnutrition and 10 million persons being at risk of dying from starvation each year.

Biological control, which is one of several techniques for reducing world weed problems, has been defined by DeBach (1964, p9) as "the study and utilization of parasites, predators, and pathogens for the regulation of host population densities." The first significant program for biological control of a weed was initiated in Hawaii against lantana (*Lantana camara* L.) in 1902. However, it was the outstanding success of the Australian program against prickly pears (*Opuntia* spp.), which began in 1920, that established biological control as an important weed control method (Huffaker, 1971). Increasing costs of herbicidal control, the usually transient nature of non-biological methods of control and public concern regarding pollution and quality of the environment, are partially responsible for the increasing interest in and use of biological methods to control weeds. Increased emphasis on biological control in weed management is also reflected in research into augmentation of introduced and/or indigenous insect enemies of weeds and the use of endemic pathogens as mycoherbicides. Today biological control is widely accepted as an important means of weed control and is considered an option in the control and management of most weeds. However, efficient utilization requires consideration of the methods available. This paper discusses these methods and their application and identifies some areas where more research is required.

TERMINOLOGY

There are three major methods within the framework of biological control.

1. Classical biological control refers to the introduction and permanent establishment of host-specific natural enemies of a weed. It is not reversible

and control agents will spread to occupy all the ecoclimatically favourable areas occupied by their host plant, the target weed.

2. Augmentation of insect or nematode enemies refers to the mass production and regular liberation of indigenous or introduced host specific enemies for control of a weed. These insect or nematode species may persist from year to year but without augmentation population levels are low and do not control the weed.

3. Mycoherbicides are usually endemic, host specific plant pathogens which effectively control a target weed when applied as massive inoculations to overcome or compensate for natural constraints to their epidemic development in nature.

CHOICE OF TARGET SPECIES

Host-specific natural enemies can be found for use against most weeds. However allocation of resources and defining of priorities must be in accord with the likely degree of control, cost effectiveness and any conflict of interests.

(a) Likely degree of control. The best results will be obtained when methods are selected on the basis of the biology and ecology of a weed and with a knowledge of the potential control agents which are available. Characteristics of a weed which determine, in part, its suitability for biological control and the likely degree of control using different methods are whether:-

- (i) it is native or introduced
- (ii) it is perennial or annual
- (iii) it occurs in cultivated or uncultivated areas.

Harris (1974) proposed a system which was subsequently modified by Goeden (1983), for rating insects which are candidates for classical control of a weed. The insect receiving the highest score is likely to be the most effective, but neither system forecasts if any species will, in fact, control the target weed.

Agents for classical biological control of perennial weeds usually disperse from establishment foci throughout regions ecoclimatically suitable to the agent. Effective species become permanently established, reduce the abundance of the target weed to an acceptable level and prevent recurrence of pest infestations. Control of a weed throughout its range usually requires a complex of agents adapted to different ecoclimatic conditions and variations in the weed. There has been debate for and against introducing complexes of agents but Hassell(1978) showed that additional species would either coexist with the agent first released or replace it and that either outcome would cause the equilibrium density of the host to decline.

Classical biological control is particularly well suited to introduced, perennial weeds of uncultivated areas. Annual weeds are less likely to be controlled than perennial species as agents must possess some mechanism, e.g. diapause, to survive the season when their host plant is unavailable. Mortality during this period may be high, especially if the period is abnormally prolonged and/or climatic conditions are severe. Sometimes this explains the failure of an agent in a particular country even though it has been successful in another, e.g. a weevil (*Perapion antiquum* (Gyllenhal)) successfully controlled emex (*Emex australis* Steinheil and *E. spinosa* (L.) Campd.) in Hawaii but was

unsuccessful against these weeds in Australia (Julien, 1981). Furthermore when annual weeds infest cultivated land a large proportion of their insect enemies, particularly those which diapause in the soil, may be killed during cultivation.

The effectiveness of an agent may also vary according to the extent to which other factors are stressing the weed. An increase in total stress load will result in greater effectiveness. For example, ragwort *Senecio jacobaea* L. has been controlled by cinnibar moth, *Tyria jacobaeae* L. in Atlantic Canada but not in British Columbia where climatic factors are less severe (Harris, 1981).

Recent research into augmentation of insect enemies of a weed indicates that this method is better suited to control of annual weeds and weeds of cultivation. Augmentation of early season populations of host specific insect enemies of a weed by releasing large numbers of insectary-reared individuals will help overcome off-season population depression and may result in effective control (Frick and Garcia, 1975).

The application of mycoherbicides may be regarded as a particular form of augmentation and is particularly well suited to control of native weeds (Hasan, 1980) and weeds of cultivation. Mycoherbicides have considerable potential for controlling weeds of annual crops which are difficult to control by other means and where specificity, immediacy and completeness of control are paramount. Application of massive doses of inoculum may kill 95-100% of a target weed (Templeton *et al.*, 1979).

Likely degree of control therefore depends on the biological control method adopted, characteristics of the target weed and the available suite of potential control agents.

(b) Cost effectiveness. Losses attributable to weeds and the actual costs of control total many billions of dollars (Batra, 1981). These losses and costs must be considered when allocating research priorities. While direct losses such as reduced plant and animal production may be fairly readily assessed, indirect losses caused by, for example, impaired human health and degradation of the environment, are much more difficult to measure. In a biological control program research costs are influenced significantly by the strategy adopted, the state of knowledge regarding the target weed and its natural enemies, and whether the weed has been the subject of a biological control program in another country.

When little is known about a weed and its natural enemies, the research required to implement classical biological control using insects may take 11 to 13 years (Andres, 1977). It may take more research to clear a plant pathogen for use as a control agent than an insect as the interrelations between plants and insects are better understood than those between plants and pathogens. Successful classical biological control results in the abundance of the target weed being reduced to a level at which it no longer constitutes a problem or causes economic loss. Natural enemies maintain this situation indefinitely and expenditure on control of the weed ceases or becomes negligible.

The augmentation of insect enemies of a weed necessitates rearing massive inundative numbers for field liberation on a seasonal, often annual, basis. In certain situations the resulting "managed" insect population may have advantages over "unmanaged" populations characteristic of classical control, but usually the necessity for continued input into an augmentation program outweighs any

advantages. Costs of augmenting insect enemies of weeds have not been defined (Garcia and Frick, 1975) but in many situations the cost/benefit may be unattractive. Augmentation of insect enemies may be considered for control in situations where losses justify high and continuing expenditure and/or where changing circumstances may require control measures to be modified or stopped.

The cost of production of mycoherbicides propagated *in vitro* should compare favourably to that of conventional herbicides but the cost of tests required under environmental protection legislation may offset expected benefits (Andres, 1977); costs of application should be similar. Cost effectiveness is likely to be more favourable than with augmentation using insects.

An indication of the cost effectiveness of a successful program is provided by Batra (1981) who estimated that accruing benefits approximated \$300 million per weed species controlled biologically. Marsden *et al.* (1980) included biological control of skeleton weed (*Chondrilla juncea* L.) in their assessment of returns on Australian agricultural research. Estimated benefits from biological control of the common narrow-leaved form over the period 1960 to 2000 was 290.2 million Australian dollars (discount rate 10%). Highly favourable social investment criteria for weed control suggest that research/control costs could rise substantially before the social benefits of such expenditure became questionable (Vere and Auld, 1982).

(c) Conflict of interests is the third important consideration in allocating priorities for biological control of weeds. A corollary of the definition that "a weed is a plant growing in the wrong place" is that, where it is growing in the right place, it has a use and a value. The weediness of a particular species can thus depend on the value judgements of individuals or groups. For example, in Australia where most graziers regard Paterson's curse (*Echium plantagineum* L.) as a very serious pest, other graziers and apiarists view it as beneficial. Also there is strong opposition to a proposal to control the weed blackberry (*Rubus fruticosus* L. s. lat.) in Australia because of its use by apiarists and the fruit industries based on cultivated varieties. On the other hand many weeds, e.g. Noogoora burr (*Xanthium pungens* Wallr.) and spiny emex (*Emex australis*), are unlikely to find any protagonists.

The considerable conflict of interests surrounding any proposal to implement classical biological control of a native weed were reviewed by DeLoach (1978). The situation is often less complex with introduced weeds although fierce conflicts of interests relating to a weed growing in different, or even the same, situations may arise (Andres, 1980, 1981). Questions of conflict of interests are difficult to resolve but should be decided for the benefit of the majority.

Augmentation of insect enemies or use of mycoherbicides may be appropriate means of control for highly contentious weeds, as these methods may be applied in one region without influencing another and may be discontinued at will.

Weeds for which there are no protagonists should not necessarily have higher priority, but resolution of conflict of interests may greatly prolong the lead-time in a classical biological control program and add considerably to the total cost.

RESEARCH NEEDS

The difficulty of deciding which plants are in fact weeds, the variation in the status of a weed between and even within regions, and the extraordinary difficulty of obtaining realistic estimates of costs and losses, means that researchers and policy makers have very little quantitative information on which to base decisions.

Usually only crude information is available on losses caused by a particular weed and there has been very little progress in evaluating degradation of the environment by weeds. Research which addresses these problems will assist with allocation of priorities and determination of appropriate methods in weed control.

In classical biological control research into the pre-release evaluation of potential agents requires greater support. The methods of augmentation of insect enemies of a weed and of mycoherbicides are in their infancy. Underpinning of all methods of biological weed control by a massive input of resources for basic research is long overdue and should be accorded the highest priority. Until basic research is given such support many promising areas of applied research will remain untapped.

As stated by Vere and Auld (1982 p.39) "In a global context, the objective of primary production continues to be one of increasing food and fibre production to meet the needs of a rapidly growing world population. It is certain that weeds impose significant constraints on the attainment of this objective. The essential purpose of weed research/control must therefore be to improve the production efficiency of existing agricultural resources and inputs." Consumers can be the major beneficiaries of extensive weed control programs and in developing countries social rates of return from agricultural research and innovation are extremely high (Vere and Auld, 1982).

For many weeds, biological control alone or integrated with other control methods, is the key to safe, economical and effective control.

ACKNOWLEDGEMENTS

I thank Mr. A.D. Wright for constructive criticism of the manuscript.

LITERATURE CITED

- Andres, L.A. 1977. Aquatic Botany 3: 111-123.
 Andres, L.A. 1980. Proc. V. Int. Symp. Biological Control Weeds, ed E.S. DeFosse. CSIRO, Melbourne. pp.11-20.
 Andres, L.A. 1981. Biological Control in Crop Production, ed. G.C. Papavizas, Allanheld, Osmun, Totowa. pp. 341-349.
 Batra, S.W.T. 1981. Biological Control in Crop Production, ed. G.C. Papavizas. Allanheld, Osmun, Totowa. pp. 45-59.
 DeBach, P. 1964. Biological Control of Insect Pests and Weeds, ed. P. DeBach, Reinhold Publishing Corporation, New York 844 pp.
 DeLoach, C.J. 1978. Proc. IV. Int. Symp. Biological Control Weeds, ed. T.E. Freeman. University of Florida, Gainesville. pp. 39-50.

- Frick, K.E. and C. Garcia. 1975. *Annals Entom. Soc. Amer.* 68: 7-14.
- Garcia, C. and K.E. Frick. 1975. *Annals Entom. Soc. Amer.* 68: 15-18.
- Goeden, R.D. 1983. *Protection Ecology* 5: 287-301.
- Harris, P. 1974. *Proc. 3rd Int. Symp. Biol. Control Weeds*, ed A.J. Wapshere. CAB, Slough. pp. 75-85.
- Harris, P. 1981. *Biological Control in Crop Protection*, ed. G.C. Papavizas. Allanheld, Osmum, Totowa. pp. 333-340.
- Hasan, S. 1980. *Rev. Pl. Pathol.* 59: 349-356.
- Hassell, M.P. 1978. Princeton University Press, New Jersey 237 pp.
- Huffaker, C.B. 1971. Plenum Press, New York 511 pp.
- Julien, M.H. 1981. *Proc. Fifth Int. Symp. Biological Control Weeds*, ed. E.S. DeFosse. CSIRO, Melbourne. pp. 507-514.
- Marsden, J.S., G.E. Martin, D.J. Parkam, T.J. Ridsdill Smith and B.G. Johnston. 1980. *Returns on Australian Agricultural Research*. CSIRO, Canberra 107 pp.
- Templeton, G.E., D.O. TeBeest and R.J. Smith. 1979. *Ann. Rev. Phytopathol.* 17: 301-310.
- Vere, D.T. and B.A. Auld. 1982. *Protection Ecology* 4: 29-42.