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Biological control of weeds in crops: a coordinated European research programme (COST-816)

H. MÜLLER-SCHÄRER[1]* and P.C. SCHEEPENS[2]
[1]*Institute of Plant Biology, University of Fribourg, Pérolles, CH-1700 Fribourg, Switzerland*
[2]*DLO-Institute for Agrobiology and Soil Fertility (AB-DLO), PO Box 14, 6700 AA Wageningen, The Netherlands*

For dominant weed species that are difficult to control by traditional means, the development of new, selective, control methods that can be implemented in integrated pest management (IPM) is essential. Here, biological control can be the appropriate means of control due to its high degree of selectivity and environmental safety (direct control value). The biocontrol strategy is based on a detailed analysis of the crop environment and, thus, provides a fundamental tool for developing sustainable agroecosystems (indirect, heuristic value). The successful application of biological weed control will lead to substantial reductions in pesticide use and, thus, will also contribute to the conservation, augmentation and utilization of biodiversity in agroecosystems, an explicit objective of IPM. Only cooperative and concerted efforts, such as those envisaged by COST, will allow the effective completion of weed biocontrol projects within a reasonable period of time. At present, over 25 institutions from 14 countries are participating in this COST action. The following six objectives have been defined for COST-816: to bring together European institutions, to promote a programme for scientific research and exchange, to draw up a general protocol for biological weed control in Europe, to integrate biological control into general weed management strategies, to establish a protocol to resolve potential conflicts of interest and to establish a list of agricultural weed species in Europe for biological control. Three principal methods of biological weed control are used in COST-816: the inoculative or 'classical' approach, the system management approach and the inundative or microbial herbicide approach. Initially, *Amaranthus* spp., *Convolvulus arvensis*/*Calystegia sepium*, *Chenopodium album* and *Senecio vulgaris* were chosen as target weeds, each being the subject of a working group. A fifth working group on the control of *Orobanche* spp. control is in preparation. This concentration on a few target weed species has greatly stimulated cooperation and facilitated technology transfer between the research groups.

Keywords: Biological control; weeds; crops; pathogens; insects; coordinated European research programme.

Biological control of weeds in crops: a novel approach for Europe

Weeds are a constant component of agroecosystems and, through the ages, man has tried to control them by various methods. During the past five decades, chemical control methods have predominated, because they are effective and supposedly inexpensive (Zimdahl, 1993). For a long time it was believed that chemical control was the only solution for all weed problems. However, the increasing incidence of pesticide resistance and a growing awareness of the negative side-effects have resulted in a shift in crop protection approaches. The recognition of the need to protect biodiversity and increasing consumer demands for environmentally friendly agriculture have further contributed to the development of sustainable agroecosystems.

At a United Nations conference (UNCED, 1992) it was decided that integrated pest management (IPM) should become the standard in crop protection. IPM aims to reduce and keep harmful organisms to below damaging levels, by employing all available means and restricting the use of chemical pesticides to a minimum. To reach this goal in weed control, the 'clean crop' option will have to be replaced by one that considers weed control mainly as the management of the crop's environment to reduce weed-induced yield losses (Watson, 1992). For dominant weed species that are difficult to control with traditional means, the development of new, selective weed control methods that can be implemented in IPM is essential. Situations where it is necessary to control single weed species in crops have been discussed by Müller-Schärer (1995) and Gressel *et al.* (1996). They range from weed populations resistant to favoured herbicides to problem weeds preferentially selected in ecologically based production systems,

*To whom correspondence should be addressed.

such as the maize-grassland (Ammon and Bohren, 1990; Pfirter *et al.*, 1997). In these cases, biological control can be the appropriate means of control due to its high degree of selectivity and environmental safety. Its aim is not to eradicate plant species but, by deliberately using specific natural antagonists (mainly plant pathogens and insect herbivores), to shift the balance in competitive weed–crop interactions in favour of the crop. In this regard, biological control agents must be seen as stress factors, not as weedkillers and biological weed control as an integral part of a well-designed pest management strategy, not as a cure by itself (Müller-Schärer, 1995; Müller-Schärer and Frantzen, 1996).

Reasons for a coordinated research programme for Europe

In Europe, there is little tradition of using natural enemies to suppress weeds (Julien, 1991; Müller-Schärer and Wyss, 1994; Müller-Schärer, 1995). This can be explained, in part, by the fact that the traditional approach in biological weed control is directed against alien weed species. Thus, in Australia, the USA, Canada and New Zealand, which all have a long tradition in the biological control of weeds, the most serious weed problems are caused by imported species. As most of these weeds originate from Eurasia, European researchers have generally been involved in biological control projects against them. In contrast, most weed problems in Europe are caused by native weed species (Schroeder *et al.*, 1993) which have, so far, not been targeted for biological control.

More recently, repeated interest has been expressed by members of the Working Group on Biological Control of Weeds, a main subject area of the European Weed Research Society (EWRS), to use the expertise gathered in projects for overseas and to coordinate activities on biological weed control in Europe. This intention is paralleled by the fact that most European countries must now try to reduce pesticide application levels without satisfactory alternatives being available. In addition, herbicide resistance is increasing in importance in most European countries. Clearly, there is a need for concerted actions to develop new control stategies.

Long-term, interdisciplinary and international research is a prerequisite of biological weed control, as many weed species are widespread and the biological control strategy often involves exchange of their natural enemies. The benefits can then easily be shared among many European countries. Moreover, only cooperative and concerted efforts will allow the effective completion of weed biocontrol projects within a reasonable period of time. COST actions, as discussed below, provide the ideal framework for such cooperation.

Aims of the research programme

The following six objectives have been defined for this COST action.

(1) To bring together European institutions interested in cooperative investigation of the potential of biological weed control in crops.
(2) To promote a programme for scientific research and exchange: in order to concentrate efforts, only four weed complexes of major importance were designated for detailed study in the initial programme. These were selected according to their abundance and economic importance in European crop systems (Schroeder *et al.*, 1993) and their suitability for biological control, based on the criteria listed in Harley and Forno (1992) and Peschken and McClay (1992). They are *Senecio vulgaris* L. (Asteraceae), *Amaranthus* species (Amaranthaceae) (*Amaranthus retroflexus* L., *Amaranthus hybridus* L., *Amaranthus cruentus* and *Amaranthus bouchonii* Thell.), *Chenopodium album* L. (Chenopodiaceae) and *Convolvulus arvensis* L. and *Calystegia sepium* L. (Convolvulaceae). These species also allow consideration of a wide spectrum of applications with regard to the biology and origin of the target weeds (annuals/perennials and native/introduced), the target crop systems (annual/perennial) and the methods used in biological weed control (see below). Studying the underlying principles of biological weed control, in particular investigations of agent–weed population dynamics are of primary importance. The two most important issues in selecting potentially successful weed biological control agents from the natural antagonists associated with a given target weed are the host specificity and effectiveness. The host specificity *sensu lato* includes traits which 'guarantee' a restricted host range (safety) and those associated with the evolution of resistant weed populations (preference/pathogenicity), i.e. when specific plant genotypes are preferred and suffer more from attack than other genotypes (sustainability of control). Effectiveness relates to the assessment of the agent's dispersal capacity and its impact on plant performance variables and, subsequently, on weed populations, i.e. on the weed density and biomass.
(3) To draw up a general protocol for biological weed control in Europe: with regard to the research procedure, the production and commercialization of microbial herbicides, the importation of foreign control agents into Europe and their establishment in various European countries.
(4) To integrate biological control into general weed management strategies: this involves the cooperation of scientists from private industry, universities and

research stations working in areas such as plant population biology, genetics, physiology, weed science, agronomy, plant pathology and entomology, as well as formulation and fermentation chemistry. In order to increase the stress on the target weed, special attention must be given to various interacting factors such as the crop–weed resource competition via choice of the crop variety, the crop spatial arrangement, the crop population density, irrigation placement and timing and fertility sources and placement (Smith, 1995) in order to elaborate crop- and site-specific solutions.

(5) To establish a protocol to resolve potential conflicts of interest: the assessment of the status of a particular plant species which may differ between government agencies, agricultural and recreational associations and individuals. Increasingly in recent decades, such conflicts have entered the legal and political arena (see e.g. Freeman and Charudattan, 1985; Turner, 1985). Public responses need to be invited on proposed biological control programmes, in order to allow decisions which are in the common interest.

(6) To establish a list of further agricultural weed species in Europe for biological control, such as parasitic *Orobanche* species or grasses such as *Alopecurus myosuroides* Hudson and *Bromus sterilis* L., with the aim of initiating new projects. Because of their great importance in Mediterranean countries and a lack of effective control methods, a working group on *Orobanche* spp. is being formed in COST action 816.

Organization, management and activities

COST is the acronym for the French equivalent of European Co-operation in the Field of Scientific and Technical Research. It is, principally, a framework for R & D cooperation, allowing for both the coordination of national research projects and/or the participation of third countries in European Community programmes. Today, COST cooperation involves 25 member countries, including the 15 EU member states. COST actions consist of basic and pre-competitive research as well as activities of public utility (Anonymous, 1996). Four basic principles underlie COST mechanisms: (1) all COST member countries, as well as the European Commission, can propose COST actions, (2) participation in these projects is voluntary and 'à la carte', associating only interested countries, (3) projects are funded nationally – the coordination costs (scientific secretariat, contribution to meetings and seminars, exchange of researchers, etc.) are funded both by the participating countries and by the European Commission and (4) a COST action aims to coordinate national research at a European level (concerted action). The work undertaken by each action is administered by a management committee.

In contrast to European Community research programmes, this form of collaboration does not require an agreed overall research policy. It focuses on specific themes for which there is particular interest in the COST countries.

COST action 816 is the result of a Swiss proposal submitted to the COST Secretariat in Brussels in May 1992. The draft Memorandum of Understanding (MoU), which forms the legal basis of the action was approved by the COST Committee of Senior Officials in June 1993. The MoU was signed in Brussels on 2 February 1994 by Belgium, Denmark, Germany, Hungary, Switzerland, The Netherlands and the UK, thus constituting the official start of COST 816. The action was approved to extend over a 5 year period for the initial phase of the project.

During the first 2.5 years of the action, 25 institutions from 13 countries (the above-mentioned plus Croatia, France, Norway, Spain, Italy and the Slovak Republic) and the Weizman Institute of Science, Rehovot, Israel (a non-COST country) have joined the action.

The management committee, composed of one or two national delegates (scientific experts and active participants) from each signatory state, plans and supervises the work done during the implementation phase. Together with the Scientific Secretary (elected by the European Commission), it is responsible for setting the priorities of the action, for coordination of the research undertaken in the participating countries and for the budgeting of the coordination of the action. The delegates, formally designated by the relevant authorities in their country, have the role of coordinator for the action in their own country. The management committee generally meets twice a year.

Four working groups have been constituted, centred around the four target weed complexes. The working groups meet when necessary and coordinate and discuss their scientific work. These activities are reported regularly by their convenors. The formation of a fifth working group on *Orobanche* spp. is in hand.

Short-term scientific missions, ranging from 3 to 30 days, are funded. These aim to strengthen the existing networks by allowing scientists to go to a laboratory in another COST country to learn a new technique or to make measurements using instruments and/or methods not available in their own laboratory.

Workshops and conferences, in general one per year, are organized by the management committee to consider broad-based subjects relevant to most of the research projects. External, world-leading experts may be invited to discuss topics relevant to the action and the results elaborated within the action. Such meetings are, in general, open to the whole scientific community and act as a showcase for the activities of the action. Our first workshop, held in October 1995 in Delémont, Switzerland, considered 'Genetic Variation in Weed Populations: Implications for the Biological Control of Weeds'. This topic has been identified as being most important both in optimizing the effect of biological control agents and minimizing the development and build-up of weed populations resistant to the control agents. The second workshop on 'Application and Formulation of Biological Herbicides' was held at IACR Long Ashton Research Station, Bristol, UK in September 1996. Formulation and delivery techniques are of utmost importance for the successful implementation of the inundative or microbial herbicide approach by optimizing the efficacy and efficiency of the control agent. A third workshop will be held on July 1997 at Nitra, Slovak Republic, on 'Integration of Biological Weed Control into Pest Management Strategies'. It will serve to further concentrate our efforts on specific crop situations, where the target weeds need to be controlled. This will allow the elaboration of crop-specific, optimal combinations of the biological control agents with the general pest management measures applied.

Further information on the action, including details on recent and planned activities, are available on the Internet (http://www.unifr.ch/plantbio/cost816).

Biological weed control methods used in COST action 816

All biological control involves the use, in some manner, of natural enemies to suppress pest population densities to levels lower than they would otherwise be (Van Driesche and Bellows, 1996). With regard to weed biocontrol, the underlying ecological principles are that natural enemies can limit weed populations and that many of these natural enemies have a limited host range. Several authors have classified biological methods of weed control (Schroeder, 1983; Charudattan, 1988; Wapshere *et al.*, 1989; Harley and Forno, 1992) and, generally, the following have been distinguished: classical or inoculative, inundative, augmentative, conservation and broad spectrum. Broad-spectrum control through grazing of polyphagous herbivores such as sheep, goats and cattle has shown some potential in suppressing pasture weeds. It is, however, not suitable for the control of specific weed species in crop systems and therefore will not be discussed further.

COST action 816 concentrates on three principal methods of biological weed control.

(1) The 'inoculative' or 'classical' approach aims to control naturalized weeds by the introduction of exotic control organisms from the weed's native range. They are released over only a small area of the total weed infestation and control is achieved gradually. Successful control depends on favourable conditions promoting an increase in the control agent's population, the establishment of epiphytotics and, thus, reduction of the target weed population. Weeds of rangeland, waterways and semi-natural areas (extensive agriculture) have been controlled using the inoculative approach with specific phytophagous arthropods and pathogens. In some situations, the inoculative approach has also been used to control weeds in crop land. A well-known example is the control of *Chondrilla juncea* with *Puccinia chondrillina* (Cullen and Kable, 1973; Cullen, 1976). In COST action 816, the inoculative approach is one method being investigated for the control of the introduced annual *Amaranthus* species (Bürki *et al.*, 1997).

(2) More recently, the 'system management approach' of biological weed control has been described (Müller-Schärer and Frantzen, 1996). It is related to the conservation and augmentative approaches distinguished by some authors. These terms, however, are interpreted differently, vaguely defined and have been applied, so far, in only a few cases (Charudattan, 1988). The augmentative approach has mainly been viewed as being intermediate between the inoculative and inundative methods (Charudattan, 1988; Hasan and Ayres, 1990). The term system management approach has been proposed to emphasize its qualitative aspects which are related to the cautious manipulation of a weed–pathogen system or weed–insect system. Its aim is to shift the competitive weed–crop relationship in favour of the latter, mainly by stimulating the build-up of a disease epidemic or insect outbreak on the target weed population (Müller-Schärer and Frantzen, 1996). It excludes disruptive events, such as the introduction of exotic control organisms (classical approach) or the mass release of inoculum (inundative approach). This approach is still *in statu nascendi* and serves as a research model for the control of the annual *S. vulgaris* using a widely distributed, naturalized rust fungus (cf. Müller-Schärer and Frantzen, 1996; Frantzen and Hatcher, 1997).

These two ecologically based approaches depend on and provide fundamental knowledge of the mechanisms underlying plant–natural enemy interactions at the individual and population levels as well as a detailed analysis of the crop environment (Müller-Schärer, 1995). In this way, they also contribute a heurisitic value by providing a fundamental tool for successful management of weed populations and for developing sustainable agroecosystems.

(3) The inundative or bioherbicide method uses periodic releases of an abundant supply of the control agent over the entire weed population to be controlled.

Such biological agents generally are manufactured, formulated, standardized, packaged and registered like chemical herbicides. Compared to the other two approaches, this approach is characterized by higher application costs and a relatively short time period to achieve a potential control success (Charudattan and DeLoach, 1988). Microbial herbicides, so far, have focused on fungi (mycoherbicides) and have been mainly used to control weeds in crops (Julien, 1991) but have also been envisaged for the control of weeds in non-crop situations, such as *Eichhornia crassipes* (Charudattan, 1986). For this approach, further research into the formulation and application technology is of prime importance (Greaves *et al.*, 1997). In COST action 816, the inundative/mycoherbicide approach is being researched for control of the annual *C. album* (Scheepens *et al.*, 1997), the two perennial bindweeds, *C. arvensis* and *C. sepium* (Pfirter *et al.*, 1997) and as a further option to control *Amaranthus* species (Bürki *et al.*, 1997).

For all the target weeds selected, consideration will be given to both the use of biological control to reduce weed interference with the current crop (therapeutic control) and to the limitation of subsequent weed populations by reducing seed output (preventive control). Biological control will only work if it is compatible with other control measures. Hence, the integration of selected biocontrol measures into general IPM practices is an integral part of all the projects in COST action 816.

Achievements, challenges and outlook

During the first 2.5 years since its inception in February 1994, the action has been successful in bringing together many European research groups, intending to cooperate in investigating the potential of biological weed control in crops. The action has attracted researchers from academia, governmental institutions and private industry covering a wide spectrum of disciplines. Many of the countries participating had no experience in weed biocontrol projects prior to their participation in the action. This great interest in this innovative control strategy is very encouraging and clearly shows that 'the seed has fallen on fertile soil'. On the other hand, it is not surprising that, at present, financing is assured for only a limited number of new projects. New projects began more easily in countries with well-developed biological weed control programmes, such as The Netherlands, Switzerland and the UK.

Cooperation within the framework of COST has allowed the establishment of well-coordinated research procedures and efficient project management (through workshops and management and working group meetings). Short-term scientific missions have mainly been approved for inexperienced researchers in biological weed control to obtain knowledge of appropriate technologies and methods from research in well-established laboratories and projects. The concentration of activities to only a few target weed species has greatly stimulated cooperation and facilitated technology transfer between the research groups.

It is our conviction that applied ecology is not a short-cut in a scientific process, but an extension and application of theoretical and fundamental ecology. An understanding of the mechanisms underlying the interactions between species is an indispensable prerequisite for any attempts to manipulate habitats. This specifically applies to the biological control of weeds, a discipline of applied plant ecology.

Therefore, up to now, the focus has been on basic research into the interactions between the target weeds and their natural antagonists in order to determine specific weed problems and potential control agents and to elaborate the most suitable biological control approach. These have been identified for three of the four target weeds.

The major challenge for the years ahead will be to apply these findings in the development of practical weed control solutions. Besides these scientific tasks, we will continue elaborating a general protocol for the biological control of weeds in Europe, including suggestions to resolve potential conflicts of interest, in particular when the introduction and use of foreign control agents are envisaged. Through the achievements of this action, we hope to promote a better appreciation of the value and safety of the innovative pest control approach for sustainable agriculture.

The vast range of expertise, including plant ecology, weed science, agronomy, plant pathology and entomology, as well as fermentation, formulation and application technology is a great strength of our action. The established collaboration between them through COST-816 liberates a huge research potential. This action will certainly contribute to a better, more realistic assessment of the potential of biological weed control in crops and will hopefully lead to practical control solutions for some of the target weeds in due time. The successful application of biological weed control will lead to substantial reductions in pesticide use and, thus, will also contribute to the conservation, augmentation and utilization of biodiversity in agroecosystems, an explicit objective of IPM.

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