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Opportunities for biological weed control in Europe

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Abstract. The development and application of biological weed control offer great opportunities not only for farmers, nature conservationists and other vegetation managers but also for institutions and companies that wish to sell plant protection services and products, and for the general public that demands safe food and a visually attractive and diverse environment. Despite the obvious opportunities for biological weed control, few control agents are actually being used in Europe. Potential agent organisms have features that make them particularly strong and useful for biological control, but they also have weaknesses. Weaknesses include a too narrow or too wide host specificity, lack of virulence, or sensitivity to unfavourable environmental conditions.

Developing specific knowledge on the interaction between weeds and potential biological control agents, as well as expertise to increase the effect of control agents and so achieve sufficient weed control in a cost-effective manner, should have the highest priority in research programmes. From 1994 to 2000 most ongoing research on biological weed control in Europe was combined in a cooperative programme. This COST Action concentrated on the interactions between five target crop weeds and their antagonists (pathogens and insects), on further characterisation of the specific blems and potential control agents and on the most suitable biological control approach.

The next major challenge will be to apply the findings provided by COST-816 to the development of practical control solutions. The leading objective of a new concerted research programme with European dimensions will be to stabilise or even promote biodiversity in the most important European ecosystems by integrating biological weed control in the management of these systems.

Key words: biological weed control, selective weed control, bioherbicide, pathogens, insects, narrow host spectrum, biodiversity, coordinated European research

Strengths and weaknesses of biological weed control

Biological weed control is defined here as the deliberate use of natural enemies and plant pathogens (agent organisms) to reduce the population density of a target plant species below its economic injury level (Boyetchko, 1997). Mainly based on the way in which the agent organisms are used, three fundamentally different approaches have been recognised in the biocontrol of weeds (Müller-Schärer et al., 2000):

- the inoculative or classical approach aims at control of naturalised weeds by one or several introductions of exotic control organisms from the weed's native range until is has become successfully established. After its establishment, no attempts are made to increase or to reduce the population of the agent. Traditionally, principally insects and only few plant pathogenic fungi have been the agent used in this strategy;
- the inundative or bioherbicide approach aims at weed control by release of an abundant supply of the control agent over the entire weed population to be controlled. To obtain sufficient efficacy of the agent, the application has to be repeated each growing season or even several times per crop cycle. Mainly indigenous plant pathogens have been used in this manner to control native weeds;
- the system management approach, which is related to the conservation and augmentative approaches (Müller-Schärer and Frantzen, 1996; Frantzen et al., this issue), aims at cautious manipulation of a weed-pathogen or weed-insect system by stimulating the build-up of a disease epidemic or insect outbreak on the target weed population. The application of a relatively low dose of inoculum to start an epidemic or outbreak will be necessary to reach a high enough level of the agent organism. Most efforts have focused on the use of native pathogens or insects to control native weeds.

As with all other weed control approaches, biological control has both strong and weak points. From the point of view of the agent organisms themselves, strong features that make them particularly useful for biological control are their inherent capability to damage their target weed, their selectivity in the choice of host plants, and the relative ease with which they can be reproduced and applied to the environment. The most obvious weaknesses of potential agent organisms may be their inability to reduce plant growth to acceptable levels (lack of virulence) and their sensitivity to environmental factors of which relative air humidity and temperature are the most important (Kempenaar and Scheepens, 1999). For the development of classical biological control it is important to recognise agent organisms that have strong features with respect to host specificity, virulence, and ability to survive and build up a high population density in their new environment. Weaknesses of the agent organism will irrevocably lead to failure of biological control. The agent can be successful even if it is not specific, but if it affects non-host plants, public perception will consider it as a failure. For the other two approaches, it may be possible to overcome weaknesses of the control agent by modifying the environment or mode of application (Greaves et al., 1998).

Opportunities, limitations and threats of biological weed control

The development and application of biological weed control offer great opportunities for everyone who is directly confronted with weed problems (farmers, nature conservationists and other vegetation managers), but also for research organisations and companies that want to sell plant protection services and products, and for the general public (Charudattan, 1999). The development of biological control can also be confronted with serious limitations and threats. Whether a feature of biological control is an opportunity or a threat may may depend on the position of the observer.

The narrow host range of agent organisms makes them potentially useful in many crops, conservation areas and non-crop areas. This high degree of host specificity means, on the one hand, a great opportunity for managers of these environments because the agent prevents crop losses and conserves species diversity. On the other hand, a limitation for a conservationist or farmer is that once a weed species or a fraction of a weed population is removed by a highly selective agent, it may be replaced by other weeds that are more difficult to control. The same limitation is valid for a research organisation or a plant protection company, neither can claim to offer a solution for a weed problem with a selective agent if the problem consists of a complex of weed species.

One of the most serious limitations is the general lack of knowledge on specific herbivorous insects and weed pathogens and how they interact with their host, both at the individual plant, and at the population level. The absence of written information may be an advantage only for producers of bioherbicides, because it gives them the opportunity to patent their product and so monopolise the market (Weston, 1999).

An opportunity in the selection of a potentially effective biocontrol agent for a given target weed is that only relatively few species have to be evaluated, because nature has already pre-selected for us. This is certainly true if we compare the selection of a biocontrol agent with that of herbicides for which tens of thousands of compounds are tested on plants, by trial and error, to find one product that is suitable for the market. However, with the present state of knowledge, the selection process for potential biological control organisms is rather complex and requires highly qualified personnel. This may change when more expertise becomes available on how to increase the efficacy of biocontrol agents, and how the effects of unfavourable environmental conditions can be overcome.

The most serious threat of classical biological weed control is that agent organisms from other continents move to non-target species after introduction. This issue is discussed again and again at international meetings (e.g. International Symposium on Biological Control of Weeds, Bozeman, USA, 1999; IOBC Meeting at Montpellier, France, 1999). Clearly, risk assessment studies are an important and integrated issue of all current and future weed biocontrol projects. With the inundative or system management approach, if the control agent is already present in the environment, it needs not necessarily to be specific (e.g. DeJong et al., 1990).

Legislation is an opportunity to ensure the safe use of biological control. Plant quarantine laws usually prohibit the importation of exotic organisms unless they are kept in a containment facility or have been proven safe to non-target organisms. Such laws can become a limitation to biological control if interpretation of the law is done by bureaucrats and not by plant protection specialists. For the use of plant pathogens as bioherbicides, most countries require registration according to a pesticide law. This is an opportunity for biological control because having passed the registration the product label, more or less, guarantees the efficacy of the product to the target weed(s) and its safety to non-target organisms. The demands set by the authority often do not presume that the biocontrol agent is already present in the environment. This being so, the fact that the market for the bioherbicide is not big enough to earn back the registration costs in a reasonable period of time, can be a limitation to development.

A European frame-work programme on biological control of weeds

To control key weeds biologically in different habitats has been shown to be a realistic approach. To make biological weed control available for the end-user, much interdisciplinary research on efficacy, safety and cost effectiveness is needed. Unfortunately, so far, the research input to develop and refine biological methods has been relatively low. In that respect it was important that from 1994 to 2000 most ongoing research on biological weed control in Europe was put together in a framework programme (COST-816), which was subsidised by the Commission of European Communities (Müller-Schärer and Scheepens, 1997). COST-816 focused the attention on a few relevant weed species in crops. The Action attracted researchers from academia, governmental institutions and private industry, covering a wide spectrum of disciplines. Signatory countries were Belgium, Croatia, Denmark, France, Germany, Hungary, Italy, Norway, Slovakia, Spain, Sweden, Switzerland, The Netherlands, United Kingdom, and the non-COST-members National Research Centre, Cairo, Egypt and Weizmann Institute of Science, Rehovot, Israel. Not only ongoing projects were brought under the umbrella of COST but, as a result of the COST Action, new national- and EU-funded projects were established.

Objectives

The main objectives of COST-816 were:

- to gather European Institutions that intend to co-operate in investigating the potential of biological weed control in crops;
- 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;
- to establish a list of further European weed species for biological control.

Cooperation within the framework of COST has allowed the establishment of well coordinated research procedures and an efficient project management (through workshops, management committee and working group meetings). The focus of activities initially on only four, later five target weeds has greatly stimulated cooperation and facilitated technology transfer between research groups.

The Action has concentrated on basic research into the interactions between the target weeds and their natural antagonists in order to characterise the specific weed problems and potential control agents, and to elaborate the most suitable biological control approach.

Working groups

Research was initially focused on only four target weeds or weed complexes: *Amaranthus* spp, *Chenopodium album* L., *Senecio vulgaris* L., *Convolvulus arvensis* L. / *Calystegia sepium* (L.) R.Br. Four working groups were formed for each of the target weeds. In 1997, *Orobanche* spp. were included as a 5th target complex. Based on the personnel knowledge of the authors, approximately 80% of research activities on biocontrol of European weeds were enclosed in the five working groups at the end. Working groups regularly met (1–2 times per group per year). The achievements of the working groups are described in separate papers in this issue of BioControl.

Scientific missions and workshops

Short-term Scientific Missions proved to be a powerful tool to bring expertise from one participating institute to another or from an expert outside biological weed control to a COST-816 working group.

Five workshops were organised, each on a different theme. Each theme was equally important for all working groups and all biocontrol approaches and provided a good platform for the exchange of knowledge and ideas between working groups.

- 1st COST-816 Workshop on genetic variation in weed and pathogen / insect populations: implications for weed biocontrol; CAB-IIBC Delémont, Switzerland, 5–6 October 1995 (40 participants).
- 2nd COST-816 Workshop on application and formulation of biological herbicides; IACR – Long Ashton Research Station, Bristol, United Kingdom, 17–22 September 1996.
- 3rd COST-816 Workshop on Integrating biological weed control into pest management strategies; University of Agriculture, Nitra, Slovak Republik, 30 June and 1 July 1997. Field visits: 2 July. Working Group meetings: 3 July.
- 4th COST-816 Workshop on risk assessment and registration; as part of the annual meeting of the British Mycological Society, Southampton University, United Kingdom, 5–9 April 1998.
- 5th COST-816 Workshop on biological weed control applied in the field as part of IPM; Basel, Switzerland, 29 June 1999.

Where to go from here?

It was clear from the beginning that such a complex topic as biological control would not lead to practical solutions during the lifetime of COST-816. To sustain the research potential for biological weed control, a new action with European dimensions is envisaged that builds on the bases provided by COST-816. The next major challenge is to apply these findings in the development of practical control solutions. The leading objective of a potential new action would be to stabilise or even promote biodiversity in different ecosystems by integrating biological weed control in the management of these systems. Such a new co-ordinated, European research programme is presently being elaborated.

It follows a system-centred, and addresses weed control in, initially, four principal habitats/systems. The systems were selected on the basis of importance in Europe, the need for control of key weeds in the systems, the need to promote biodiversity in the systems, and ongoing projects. These systems are (1) arable farming, (2) lowland grasslands, (3) montane grasslands, and (4) semi-natural and urban habitats. Together they consist of more then 500 million hectares. A special support group will be organised around molecular biology themes such as evolution, taxonomy, toxicology, resistance and risk assessment, but not on transgenic organisms. Current vegetation management practices in these systems make use of broad-spectrum, preventive chemical and mechanical control methods. They are highly efficient to reach primary management goals (e.g. crop yield), but allow little opportunities for biodiversity and may have a negative impact on the physical environment as well. The opportunities for the new action and its different participants are:

- biodiversity in rural landscapes will increase;
- herbicide use and dependency thereof in integrated farming systems will be reduced;
- opportunities for lower input and organic farming systems will be improved;
- the recreational value of rural and urban landscapes will increase;
- the benefits of biological weed control, although obvious for society, is not easily made profitable for an individual enterprise. The action will increase the possibilities for enterprises to make a profit by developing and marketing environmentally-friendly bioherbicides.

Some details of these systems regarding their (desired) level of biodiversity, current pesticide use and current knowledge on biological control of particular key weeds are given below for each of the systems.

Arable ecosystems

Arable farming is the most important agricultural system in Europe, both in area and in economic terms. Arable land area in 1996 was about 135 million hectares. All non-crop plant species are regarded as weeds on arable fields and mechanical, coupled with chemical control, are currently the most common weed control practices. Operations that preclude soil tillage increase herbicide use. Both tillage and herbicides negatively influence biodiversity. The amount of herbicides used is a major concern for all the European countries.

Weed problems in arable crops are rarely caused by a single weed species, so biological control, clearly, has to be considered as an integrated component of a well designed weed management strategy. The general aim is to develop control strategies that make arable farming less dependent on chemical herbicides and tillage. These changes in arable farming practices will greatly influence the quality of the crop land, but also of adjacent waterways and lakes by reducing leaching of fertilisers and herbicides into the environment. Biocontrol, because it can allow the biodiverse weed ecosystems to remain (vs. bare soil) will be a beneficial barrier to fertiliser movement. They may not have much impact on plant biodiversity in the arable fields, but biological control of invasive weed species in deliberate refuges like fertilizer and pesticide-free strips, or natural refuges like field margins, ditches and hedges that also belong to the arable landscapes will significantly promote biodiversity both of flora and fauna.

Annual weeds inhabit most arable land. Some key weeds are especially dominant or cannot be controlled with existing weed control measures. Biological control of these species can be a part of an integrated strategy together with reduced levels of chemical herbicide or mechanical weed control. Perennial weeds in arable farming are ideal targets for biological control. There are only a limited number of notorious species and their control often requires an extra treatment with a high dose rate of a herbicide. Biological control could replace one or more herbicide treatments. In organic farming systems, biological control of perennials, especially *Cirsium arvense* (L.) Scop. would reduce the number of mechanical treatments.

The selected key weeds are the same as in COST-816 but with *C. arvense* being included. The inundative approach is the method of choice for most species and situations, but the system management approach may also be feasible, particularly in perennial crops.

Lowland grasslands

Lowland grasslands form the second most important agricultural land use in Europe with some 90 million ha under permanent meadows and pasture. For example, almost three-quarters of the agricultural land in the UK is grassland. The intensity of lowland grassland utilisation varies greatly from intensive dairying through to semi-intensive and extensive grazing, mainly on permanent pastures. This influences the biodiversity of grasslands, from the *Lolium*-dominated, low biodiversity temporary swards of intensive grassland farming through to the high-diversity permanent grassland and hay meadows of much of Europe. Also, there are many habitats, such as chalk and limestone grassland, in which the high biodiversity of the site is dependent on grazing by farm animals. Indeed, grasslands are the only agricultural production system, which are compatible with, and which can utilise, richly biodiverse habitats.

The major problem weeds in grasslands are native biennial or perennial dicotyledonous herbs such as *Cirsium* spp, *Rumex* spp., *Senecio* spp., and *Pteridium aquilinum*. Many of these species not only out-compete the grass sward, but are also poisonous to livestock. This weed problem is exacerbated by inappropriate management, e.g. overstocking, poaching of the ground, excessive fertiliser input.

Control is difficult at present: herbicides or mechanical methods are often too costly to use in such a low-input low-return system, need repeated applications and are often ineffective on well-established plants (Hatcher, 1996).

Also, the weeds are often patchy and clumped, making large-scale spraying inefficient. Broad-spectrum herbicides would also be inappropriate to use in the forb-rich extensive lowland grasslands and, here, weed control is still often by manual removal. It is envisaged that biocontrol could have a major impact on weed control in these habitats (c.f. Cavers & Harper, 1964; Donald, 1990).

The selected key weeds are *Rumex obusifolius* L., *Cirsium arvense*, *Senecio jacobaea* L. and *Pteridium aquilinum* (L.) Kuhn. Many of the successful programmes of weed biocontrol throughout the world have taken place in extensive grasslands. However, most of these have involved introduced weed species. The problem in Europe is with indigenous species, and little progress here has, so far, been made with these. At present, there are many separate groups throughout Europe working on the biocontrol of these key species and this gives opportunities to try to exploit all three biocontrol strategies, : the classical, inundative and the systems management approach. One of the main goals will be to try to decide on the most appropriate approach.

Montane grasslands

Montane grasslands – grasslands in areas with a mean annual temperature $\leqslant 8\,^{\circ}\mathrm{C}$ – are considered one of the most important European biomes with regard to biodiversity (cf. Schaffner et al., 2001, and references therein). In contrast to many lowland grasslands, the focus on montane grasslands is primarily to conserve biodiversity, rather than to restore it. In the Alps, for instance, many species which have disappeared already in lowland regions still occur in montane grasslands. However, changing farming practices (intensification on productive land or withdrawal of cattle from marginal areas) has started, and will continue to exacerbate weed problems in the system. These problems are caused by only a few weed species; those that profit from the higher fertilisation levels in the productive areas or from the withdrawal of grazing animals from the marginal areas. Hence, there is an obvious demand for novel montane grassland management practices that selectively control the weed species that have become dominant (Ammon and Müller-Schärer, 1999; Schaffner et al., submitted).

Key weeds are: *Veratrum album* L. (due to abandonment), *Rumex* spp., *Senecio* spp. (due to high fertilisation). In montane grasslands the system management approach and inoculative (classical) biological control could be the approaches of choice. *Rumex obtusifolius* and *Senecio jacobaea* have a lready been successful targets for biocontrol in North America and/or Australia. The inundative approach could be applied in situations where system management and inoculative biological weed control are not feasible or do not have the desired effect on the weed.

Amenity and urban habitats

Amenity and urban habitats include parks, private gardens and playing grounds, road verges, ponds and waterways, as well as railroad tracks and other civil-technical constructions. The vegetation of amenity and urban areas often brings intensive contact with the general public. In view of the functions of these areas, the use of herbicides should be limited. Apart from regular plant or biomass removal by mowing, raking or hoeing, specific, and often very expensive measures, are needed to control certain weed species because they are allergenic, cause other human health hazards, or are just a nuisance. Some of the worst weeds are dispersed in such a way that selective chemical control is problematic.

The number and variety of key weeds mentioned by colleagues is much larger than with the other landscapes. Breaking the dominance of a key weed may restore much of the original biodiversity, particularly in amenity areas and recreational landscapes.

Selected key weeds are *Ambrosia artemisiifolia* L., *Cirsium arvense*, *Fallopia* spp., *Senecio* spp., *Heracleum montegazzianum* Somm. et Lev., *Hydrocotyle ranunculoïdes* L.f. The target environments are ecologically “open”, i.e. prone to successful invasion by alien species. Hence, inoculative biological weed control may be the approach of choice for several targets but the inundative or system management approaches may be justified, especially with allergenic weeds.

Conclusion

Though the opportunities for biological weed control are good, R&D efforts in this field during the past 25 years have yielded only a few successful biological weed control programmes in Europe. Only the bioherbicide Biochon, based on mycelium of the fungus *Chondrostereum purpureum*, is actually on the market (DeJong, 2000). Successes have been constrained by several factors. The narrow host range of biocontrol products limits their market size. Further, their variable capacity to damage and control weeds under prevailing weather conditions, and the lack of a registration procedure that ensures the safe and cost-effective use, are also limitations that deter investment in R&D.

The agenda of R&D on biological weed control for the coming ten years should be focused on the issues that have been identified as critical. International cooperation is essential to direct the limited funding available towards realistic goals. A systems-centred approach is needed in which experts from various disciplines work together to address the challenges and to make more biological weed control agents available for the end-user. Financial support from government bodies is needed for the next decades because commercial organisations foresee limited opportunities for themselves under the present conditions. As many of the weed problems are rans-national within Europe, even more can be expected from international funding bodies.

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