PROMOTING NATURAL BIOLOGICAL CONTROL OF SOIL-BORNE PLANT PATHOGENS

MARK P. McQUILKEN

Plant Science Department, The Scottish Agricultural College, Auchincruive, Ayr, Scotland, KA6 5HW, UK

ABSTRACT

Despite a considerable research effort, there are very few commercially-available biological control agents of soil-borne plant pathogens. An alternative approach to biological control is to manipulate the existing population of microbial antagonists. Examples of both agricultural and horticultural practices which manipulate existing microbial antagonists and promote natural biological control of soil-borne plant pathogens are reviewed. The potential for the future use of these practices in different crop production systems is discussed.

INTRODUCTION

Soil-borne plant pathogens have been with us ever since agriculture began, and include about 50 genera of fungi as well as a few bacteria and viruses. They infect foliage, stems, seeds and actively growing roots. Effective control of fungal soil-borne plant pathogens has usually been achieved by the intensive application of fungicides. In recent years, however, there have been considerable changes in attitude towards their widespread use in disease control programmes. A major problem has been the development of pathogen resistance. Currently recommended programmes, involving the alternate use of fungicides with different modes of action, are not always effective. Moreover, increasing public awareness concerning the levels of fungicides, as well as other agrochemical residues in plants and the environment, has led to more stringent regulations on their use. It is also likely that a number of fungicides, which are currently on the market, will be withdrawn in the future. Consequently, the need for safer and more effective disease control methods that can be used as alternatives or supplements to conventional fungicides has become urgent.

Biological control, using introduced microbial inocula, is one strategy available. However, despite a considerable research effort by both academia and industry, very few biological control agents have been developed commercially (Rhodes, 1992). For example, in the UK, there are only three examples and these are confined to use in horticulture. Nevertheless, there are many forms of biological control that do not involve the direct application of commercially-produced inocula, but rely on manipulating the existing population of microbial antagonists. These include cultural practices such as crop rotations, tillage, the incorporation of organic amendments and composts, and the ploughing-in of green manures (Palti, 1981; Campbell, 1989; 1994). There is also the possibility of promoting biological control by the application of fertilisers, periodic flooding and solar heating the soil (Cook and Baker, 1983).

This paper reviews examples of both agricultural and horticultural practices which manipulate the existing population of microbial antagonists and promote natural biological control of soil-borne plant pathogens. It also discusses the potential for their future use in different crop production systems.

TILLAGE

Control of soil-borne plant pathogens can be achieved by certain tillage practices (Cook & Baker, 1983). For example, ploughing buries diseased crop residues and pathogen propagules such as sclerotia, and also leads to a more rapid breakdown of the pathogen's food base. The propagules eventually die and the inoculum potential decreases. Microbial antagonists in the soil are likely to be involved in decreasing the viability of the pathogen propagules.

ROTATIONS

Rotations have been used for many years to reduce the inoculum potential of plant pathogens (Campbell, 1989; 1994). Besides providing plant nutritional and other agricultural benefits, rotations deprive pathogens of their hosts so that they have to survive for long periods in the soil. During this survival period, the pathogens may die of starvation, or be parasitised and lysed by antagonistic microorganisms.

SUPPRESSIVE SOILS

There are some soils in which diseases fail to develop even though the pathogen is present. These disease-suppressive soils may be associated with abiotic factors, such as the pH or the clay and mineral content. However, there are soils in which suppression is caused by microorganisms. For example, Lumsden *et al.* (1987) described the suppressive soils of the traditional Mexican chinampa agroecosystem, which involves the incorporation of high levels of organic materials, including manures and crop wastes, and also mineral nutrients from aquatic sediments. The incidence of *Pythium* damping-off within these soils is low, and they are suppressive to introduced *Pythium*. This phenomenon is associated with high levels of microbial activity, particularly fluorescent pseudomonads and saprophytic *Fusarium* spp.. Similarly, soils in Hawaii suppressive to damping-off caused by *P. splendens* contain high calcium levels and a high population of soil microorganisms (Kao & Ko, 1986).

Soils suppressive to *Fusarium* wilt of muskmelon occur in the Chateaurenard region of France (Alabouvette, 1986). Suppression is due to competition between the natural saprophytic *Fusarium* spp. and the pathogen *Fusarium oxysporum* f. sp *melonis*. Transferring small amounts of this soil to pasteurised conducive soil will control *Fusarium* wilt from introduced inocula, but sterilisation of the suppressive soil removes this ability. This feature is characteristic of suppression caused by microorganisms. Transferring samples of suppressive soil to container media and disease-conducive soils may be of use in the future in controlling diseases in horticulture.

Soils may develop suppressive characteristics during prolonged monoculture. The classic example is take-all decline. This phenomenon has been extensively researched for many decades, but it is still not fully understood (Hornby, 1979; Rouxel, 1991). It is likely that disease suppression following continued cropping of wheat is caused by a change in the microbial population of the rhizosphere to one which is antagonistic to the take-all fungus, *Gaeumannomyces graminis* var. *tritici* (Hornby, 1979).

ORGANIC AMENDMENTS

The addition of organic amendments to soil is known to stimulate the activity of antagonistic microorganisms and to control a wide range of pathogens. For example, various partially degraded crop residues and manures have been shown to control *Fusarium* spp., *Rhizoctonia solani*, *Thielaviopsis basicola* and *Sclerotium* spp. (Lumsden *et al*., 1983). Control of such pathogens is mainly due to a reduction in inoculum potential, or suppression of germination and growth. This may involve the production and release of antibiotics, competition for nutrients or parasitism by resident antagonistic microorganisms.

The addition of chitin to soil is perhaps one of the best documented examples of using organic substances to control soil-borne plant pathogens. For example, wilt of peas, caused by *Fusarium oxysporum* f. sp. *pisi*, was reduced by up to 82% following the incorporation of chitin several weeks before planting (Khalifa, 1965). A general increase in the actinomycete population was correlated with a fall in the inoculum potential of *F. oxysporum* f. sp. *pisi* together with a reduction in pea wilt. Amendment of soil with chitin has also been shown to control *R. solani* and *Sclerotium rolfsii* (Sneh *et al*., 1971).

COMPOSTS

In China, Japan and other countries in Asia, composted organic waste materials have been used for many years as organic fertilisers and to control soil-borne plant pathogens. However, the potential of these materials to control plant pathogens in the West has only been recognised during the last three decades (Hoitink & Fahey, 1986). Composts prepared from sewage sludge, municipal solid wastes, tree barks as well as other materials have given control of a number of plant pathogens both in the field and under glass.

Amendment of soil with composted sewage sludge over a four year period reduced the incidence of lettuce drop caused by *Sclerotinia minor* (Lumsden *et al.*, 1986). Disease suppression was correlated with increased microbial activity, but also changes in N, P, Mg, Ca and total organic matter content of the soil. Similarly, incorporation of composted organic household waste gave a reduction in root rot of peas, beans and beetroot, caused by *P. ultimum* and *R. solani* (Schüler *et al.*, 1989). Unfortunately, these two types of composted materials have the potential of introducing heavy metal contamination. This factor must be carefully considered before widespread application is considered.

Composted tree barks incorporated into container growing media have been shown to control damping-off pathogens during seedling production (Stephens & Stebbins, 1985). Other composted materials which have shown potential for the control of damping-off in container media include hemlock (*Tsuga heterophila*) bark (Kai *et al.*, 1990), liquorice (*Glycyrrhiza glabra*) roots (Hadar & Mandelbaum, 1986) and grape marc (grape skin, seeds and stalks left over after wine processing) (Gorodecki & Hadar, 1990). Disease control has been suggested to result from the populations of antagonistic bacteria and fungi which colonise the composted materials.

Recently, foliar sprays of compost extracts produced from composted organic materials have shown some potential for controlling a number of diseases, including potato blight and Botrytis grey mould (Weltzien, 1992; McQuilken *et al.*, 1994). Antagonistic microorganisms within the extracts probably suppress the pathogens by direct inhibition of germination and growth. Before compost extracts can be widely used to suppress diseases on edible crops, it will be necessary to determine the possible environmental and toxicological hazards of extracts based on municipal waste or sewage sludge.

GREEN MANURES

Green manuring involves the incorporation into soil of fresh organic material, other than just plant residues, which has been grown either *in situ* or elsewhere (Campbell, 1989). The process is known to encourage general microbial activity in soil, and there are several examples where plant pathogens have been effectively controlled. One of the best examples is the control of common scab of potatoes caused by the actinomycete, *Streptomyces scabies*. Early work by Millard & Taylor (1927) indicated that incorporating green manures in the planting trench increased microbial activity which in turn anatagonised *S. scabies*. Ploughing-in *Medicago lupulina* as a green manure was shown to reduce take-all in wheat and to significantly increase the rhizosphere population of bacteria, particularly fluorescent pseodomonads (Lennartsson, 1988). Similar work has shown that actinomycetes antagonistic to the take-all pathogen increase in response to various green manure treatments (Campbell, 1994). Ploughing-in of green manures in cotton production in the USA has been shown to control the root pathogen, *Phymatotrichum omnivorum* (Cook & Baker 1993) An increase in microbial activity, particularly *Trichoderma* spp., was correlated with colonisisation and destruction of sclerotia of the pathogen.

Caution must be taken in using green manures as some can encourage disease development. For example, using *Sesbania* spp. (tropical woody legumes) as a green manure increased the incidence of damping-off caused by *Pythium* and *Rhizoctonia*. (R. Campbell, personal communication).

FERTILISERS

Fertilisers have been implicated in stimulating the indigenous soil population of microbial antagonists. For example, in Australia, application of sulphur to soil in order to maintain a low pH reduced root rot and heart rot of pineapple caused by *Phytophthora cinnamomi* (Cook & Baker, 1983). Control was attributed to a decrease in zoosporangium formation of *P. cinnamomi* and an increase in the antagonist *T. viride*. Take-all of cereals can be suppressed when crops are provided with ammonium rather than nitrate nitrogen (Cook & Baker, 1983). The ammonium nitrogen lowers the rhizosphere pH, which increases the availability of trace nutrients and stimulates the activity of antagonists.

FLOODING

Flooding has been shown to provide highly effective biological control of soil-borne pathogens. For example, Leggett & Rahe (1985) demonstrated that flooding weakened the sclerotia of the white rot pathogen (*Sclerotium cepivorum*) of onions in soils of British Columbia, thereby enabling microbial degradation of the sclerotia to occur. Similarly, flooding soil in Florida has been found to be effective in eliminating sclerotia of *Sclerotinia sclerotiorum*. Again, microbial colonisation and degradation of previously weakened sclerotia was thought to occur.

SOIL SOLARISATION

Heating soil can be accomplished by a process known as solarisation, in which heat from the sun penetrates a clear plastic sheeting placed on top of moist soil (Katan, 1981). Solarisation raises the soil temperature to kill pathogens by direct destruction, or it weakens the pathogens to such an extent that they are attacked by resident antagonists which survive the heating process. The process has been used successfully to control *Sclerotium rolfsii*, *Sclerotinia sclerotiorum* and *Fusarium* spp. in soil. In all cases, control was mainly due to microbial colonisation and degradation of pathogen propagules previously weakened by the sublethal temperatures produced by solarisation. Unfortunately, the use of solarisation for disease control is restricted to countries with a high insolation.

CONCLUSIONS & FUTURE PROSPECTS

Manipulating the existing population of microbial antagonists using a range of cultural practices is a form of biological disease control, which has obvious environmental benefits. Many of these practices which involve the application of large quantities of organic materials are labour intensive and expensive. Consequently, they are better suited to low technology agricultural systems, especially in developing countries where labour costs are relatively inexpensive and fungicides are either too expensive to buy or commercially unobtainable. In labour intensive China, the widespread and intensive use of organic materials has led to the absence of important root diseases (Kelman & Cook, 1977).

As labour costs are very expensive in Western agriculture, there are limits to the kinds of practices that can be used. However, as many of these practices as possible should be adopted and their increased use in integrated disease management systems, in combination with reduced fungicide applications, is likely to help in preventing or delaying the onset of pathogen resistance. Rotations and green manuring have been used to some extent in conventional, and more fully in organic agricultural systems. These merit further investigations as a means of reducing disease problems and over use of fungicides.

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A BRIEF REVIEW OF THE STATUS AND PROBLEMS OF BIOLOGICAL CONTROL OF WEEDS

D.H.K. DAVIES

Crop Systems, SAC, Bush Estate, Penicuik, EH26 0PH, Scotland, UK

ABSTRACT

Approaches to control of weeds by use of biological organisms are described. Rust fungi which have well developed and stable host specificity have been successfully developed as products that can be used through conventional farm equipment products. However, commercial and registration pressures are hindering their development. Arthropods have occasionally been used successfully, but maintaining populations has presented problems. There have been no useful breakthroughs in the development of specific prokaryotic and viral-based products, nor in the use of nematodes. If suitable mostly specific products can be produced that can be used through farm equipment, then there is no marketing barrier so long as the product is perceived as useful. However, it is considered that only highly valuable niche markets will be commercially worthwhile for the present. Genetic manipulation of organisms may provide most the promising approaches to improving bioherbicide performance, but such developments are still open to scientific and political debates.

INTRODUCTION

The use of a living organisms to affect a weed species to such an extent that its population falls below a damaging or threshold level is called biological control. Although we associate the concept of biological control with a modern approach to integrated pest management (IPM), there is in ancient literature comment on use of grazing animals, especially geese, amongst certain crops too large or indigestible for them to tackle. The use of chickens and pigs to clean land of weeds and their propagules is a commonly understood husbandry approach in some farming systems. However, the use of modern biological methods of weed control may date back to 1902, with the release of a range of exotic organisms to control *Lantana camara* in Hawaii (Tisdell, 1990), or even earlier when a Canadian farmer suggested Puccinia rust could be a method of control of *Cirsium arvense* (creeping thistle) (Greaves, 1992). This approach of releasing a specific organism, which then multiples and spreads so long as the host is present in sufficient quantity, is often known as the classical approach.

CLASSICAL APPROACH

Theoretically all kinds of plant pathogens and pests that adversely affect the growth of a weed could be considered for classical biological control, including fungi, prokaryotes, viruses, nematodes and arthropods.

To develop a biological control strategy one needs to understand the distribution of the weed host and its original habitat. It is to be presumed that it is in the original habitat of the species that most of its pathogens would have co-evolved. However, some authors have argued that newer host-parasite relationships may be more effective as the host will not have developed a high level of resistance (Hokannen, 1985 vide Cullen & Hasan, 1988). Nevertheless, in practice, highly co-evolved obligate parasites have been the most effective agents (Cullen & Hasan, 1988). It is probable that this approach is most effective, however, when weed species have spread well beyond their original habitat, and there is little or no competition with the potential parasite to reduce its effectiveness. The spread of weeds is well documented and Watson (1991) suggests that 13 of the top 15 most important in the USA are imports, which should facilitate the use of highly selective pathogens from their original habitat. The parasite from the original habitat of the weed must, obviously, be able to survive in the new climate/habitat, and as well, if not more importantly be able to demonstrate satisfactory specificity so that it does not attack other neutral or beneficial organisms in the new habitat. Efforts in this area are now largely limited to groups of fungi with records of well developed and stable host specificity. One of the best examples of this approach was the introduction of the European plant, *Chondrilla juncea* into Australia, which, in the absence of grazers spread rapidly as a weed. The introduction of the associated rust, *Puccinia chondrillina*, in 1975 has resulted in a reduction in the plant equivalent to European levels (Cullen, 1988 vide Cullen and Hasan, 1990). Rust species dominate the successful introductions (Watson, 1991) because as obligate parasites they tend more easily to fit specificity requirements. However, the pathogen often spreads slowly from such introductions. This is unsuitable for rapidly growing weeds in annual crops, and is probably more suited for perennial cropping situations and grassland where slower growing weeds are a problem.

AUGMENTATIVE APPROACH

Another approach is to encourage natural pathogen populations on native weeds by augmenting the pathogen through dispersing inoculum at disease conducive periods (Charudatta, 1985). For example, *Puccinia obtegens* has been augmented in Montana, USA, to assist in the control of *Cirsium arvense* (Dyer et al, 1982 vide Charudatta, 1985). The response time tends to be slow as in the case of Classical Approaches.

BIOHERBICIDE APPROACH

Microbial herbicides

All of the microbial weed control agents developed or in use in the USA in 1985 were fungal pathogens (Charuddaltan, 1985) or mycoherbicides. This is probably still the case. In the microbial herbicide strategy, an inoculum of the pathogen is mass cultured, standardised, formulated and deficiencies in speed of spread overcome by mass inocreation by conventional farm sprayer inoculation. To the present the products developed have been natural strains, and there would probably be ideological constraints to the development of genetically altered strains (M Greaves, 1995, personal communication).

Research in the 1960s and 1970s culminated in the registration of two mycoherbicide products with the United States Environmental Protection Agency (EPA): (a) DeVine® - *Phytophthora citophthora* for the control of *Morrenia odorata* (strangler-vine) in citrus orchards in Florida, and (b) Collego® - *Colletotrichum gloeosporoides* f.sp. *aeschynomene* for *Aeschynomeme virginica* (northern joint vetch) control in rice and soyabean in south-eastern USA. Since then another six products had been used, or were near marketing by 1992 (Greaves, 1992) (Table 1). Charudattan (1991) pointed out that a ratio of six or seven commercial products out of about 130 researched attempts over the period was very good compared with commercial herbicide discoveries.

TABLE 1. Mycoherbicide products in use and reported near to market in USA, 1985-91. (Adapted from Greaves, 1992)

Product	Agent	Target weed	Status
Devine®	*Phytophthora citrophthora*	*Morrenia odorata*	In use
Collego®	*Colletotrichum gloeosporoides* f. sp. *aeschynomene*	*Aeschnyomene virginica*	In use
	Cephalosporium dispyrii	*Dispyros virginiana*	
	Fusarium oxysporum	*Orobanche spp*	
Luboa II	*Colletotrichum gloeosporoides* f. sp. *cuscutae*	*Cuscuta spp.*	In use
	Colletotrichum gloeosporoides f. sp. *clidemiae*	*Clidemia hirta*	
Casst	*Alternaria cassiae*	*Cassia spp* *Crotolaria spectabilis*	Near market
Bromal	*Colletotrichum gloeosporoides* f. sp. *malva*	*Malva pusilla*	Registered
Velgo	*Colletotrichum coccodes*	*Abutilon threophrastis*	Near market
ABG5003	*Cerospora rodmanii*	*Eichhornia crassipes*	Near market
Doctor Biosedge®	*Puccinia canaliculata*	*Cyperus exculentus*	Near market

To date, rust fungi have dominated the microbial herbicide research area. There has been very limited research on the potential for prokaryotic and viral based products. Viral mechanisms often present major problems in the requirement for a carrier to transmit the pathogen. This is also true for many bacteria. Plant pathogenic bacteria also generally lack resistant structures that readily allow packaging, storing and application (Lacy, 1991).

It may be that increasing specificity in the vector is as important as improving the pathogenicity of the pathogen. However, these relatively simple organisms are more amenable to genetic manipulation with the potential to improve both specificity and pathogenicity. I have no information that weeds are being targetted in this way, and the area remains very much one for future research.

Nematodes

There has been much less work on the use of nematodes as potential biological weed control agents. In part this is due to a lack of understanding of host ranges with a consequent concern as regards their specificity - what work there is concentrates on foliar gall-forming types (Parker, 1991). There are no nematode - based products.

Use of Arthropods

Use of insects and other arthropods presents particular problems. Although arthropods have been used in classical and augmentative approaches, with Julien *et al* (1984) suggesting they comprised 488 out of 499 species of natural enemies released, these authors also suggest that they only account for 51 successful releases. The inability of agricultural habitats, particularly annual cropping, to maintain populations is suggested as a major reason for failure by Bernays (1985) and van Emden (1990). They suggest that an intermediate host, or the widespread presence of the host outside or around the cropping system, is needed to maintain a pod of colonising individuals. The problem is reduced in perennial cropping.

Bernays (1985) also suggests that finding grazers for grass weeds presents a particular problem; they are not attacked by many insects. Dicotyledonous weeds have many more pathogens. Specificity can also be a major problem, and Bernays (1985) indicates that artificial selection pressures may be needed to induce specificity in a potential pathogen.

An approach that is being considered is the conservation biological control of weeds by encouraging changes in the environment, particularly encouraging the growth of other host plants in the neighbourhood, perhaps by sowing, which allow breaks in cropping to be survived by the insect weed pest. However, a great deal more needs to be understood about the life-cycle of potential weed pests.

Bernays (1985) and other authors confirm that insect releases are likely to be most successful in range-weed situations where the potential host is more widespread. This fact encouraged an example of recent work in the UK: an attempt to control *Pteridium aquilinum* (bracken) with introduced South African moths (*Conservula cinisigna* and *Panotima* spp.) (Lawton et al, 1988). There is no tradition in the UK for such approaches to weed control, and there have been problems with survival. Nevertheless, evaluation of the potential for such an approach to overcome an intractable problem is still considered important.

However, it is evident that much more work must be done to define strategies for use of arthropods in biological weed control. Berhays (1985) gives the following suggestions (adapted):

- a reduced input on classical biological studies, no effort on graminaceous species.
- encouragement of research on plant competition in crops so that least harmful weeds may be identified.
- an integrated research effort between weed ecologists and entomologists to establish areas where arthropods can be used to alter weed balances in favour of crops.
- co-operation with plant pathologists.
- genetic improvement of selected species of the native fauna to increase their virulence against weeds.

These suggestions would indicate an acceptance that complete control of an individual weed is not required by the farmer. The balance between what is acceptable in terms of leaving weeds and the impact on crop quality and seed return to affect other crops in the rotation is still poorly understood, and is very species specific. Nevertheless, the reduced vigour of an infested weed may make it more susceptible to very low doses of conventional herbicides, mechanical weed control, or other biological control mechanisms. Such interactions are at the heart of understanding sustainability in farming.

Selective genetic improvement of potential biological agents is still open to debate and consideration as to their ethical and environmental impact. This is probably as true for genetic modification of arthropods as much as for any other organism. However, selection rather than modification may have greater social support. Nevertheless, such genetic engineering is at an early stage of technical development (Tauber, *et al*, 1985), and the potential is unpredictable.

DEVELOPMENT AND USE PROBLEMS

Watson (1991) describes six identifiable areas of research required in the development of a product based on a pathogen for biological control purposes:

- determination of the suitability of the target

- survey of suitable pathogens
- ecology of potential pathogens
- host specificity
- introduction and establishment into the new habitat
- evaluation of the effect on the target weed

To this should perhaps be added the impact on the crop. Complete weed control is not often needed to maximise crop yield response, so good suppression by a pathogen may be sufficient.

Once identified as a potential pathogen there are many practical barriers to development. Particularly where foreign species are imported, investigations may be required to be undertaken in quarantine, and the extent of its host specificity and impact on other natural enemies of the host, and related organisms, identified (Watson, 1991). Presenting the pathogen in a form that will maximise its effect and speed of spread is very important, as the competitive effect of weeds can occur over a comparatively short period; particularly in annual crops. Formulation of bioherbicide fungal pathogens in spore form is now well understood (Greaves, 1995, personal communication), and such materials can be applied, as in the case of Devine® and Collego®, through conventional farm sprayers. This is essential as the narrow weed control spectrum of such materials usually requires that other herbicides are also used, along with other inputs. So compatibility in tank-mixes and sequences of routine farm treatments may be required (Smith, 1991). This presents problems with the use of arthropods as biological control agents in arable crops unless the eggs can be disseminated in a similar manner to the spores of pathogens .

The narrow weed spectrum of such products may present a problem to some farmers, but single or limited weed spectra are not unknown amongst conventional herbicide products, for example fluroxypyr for control of *Galium aparine*, difenzoquat for control of *Avena* spp, and are accepted long as the need is perceived as greater than the inconvenience of tank-mixing separate treatments.

PRODUCTION, MARKETING AND THE FUTURE

From the list in Table 1, Devine® and Collego® were withdrawn in 1994 on commercial rather than technical grounds. There was considered to be a lack of market size (Greaves, 1995, personal communication), although farmers found no difficulty in using the products combined with other herbicides. Collego® may be produced by an American university. Doctor Biosedge is a *Cyperus* spp rust pathogen, but the USA EPA has asked for so much data that the market size, although substantial, may not be sufficient. These fates appear to be common to this market, and the only currently assured product may be Luboa, a Chinese government produced product for the rice market, sold very cheaply. Greaves (1995, personal communication suggests that there may be ideological limitations to the development of the technology within the large agrochemical industry, and they also may feel that the technology investment would be high. However, he points out that a fermentation system to produce microbial and fungal spores could cost 25% of that of a novel chemical plant; and that some of the companies already have such technology available for pesticide manufacture. Nevertheless, the uncertainty of the patenting status for such products must also be a major barrier.

Funding for research is this area is only likely to be through public bodies, and this is unlikely given limits in near-market spending in most countries.

Consequently the only markets likely to succeed are highly valuable niche markets such as American lawn-care followed by urban vegetation control and aquatic weed control where legislation may increasingly restrict the use of pesticides.

Where the agrochemical companies may have a greater interest is in more clearly patentable areas, such as modifiable toxins that can be identified from pathogens. If these however are then modified to improve activity as well as ensuring patentability, they are then no different from any other organic agrochemical molecule in the testing required, and perceived potential hazards.

The genetic manipulation of organisms for specific enzymes or toxin production within the pathogen is probably the most promising approach for improving mycoherbicide performance (Greaves, *et al* 1989). This may also be true for other forms of pathogen. Such manipulation may also elucidate greater specificity. The potential for such developments will have to await clarification as to patenting rights to protect such investment, and for the scientific and philosophical debates to come to a reasonable conclusion.

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