Directions for bioherbicide research in Australia

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Summary

One of society's responses to chemical pesticides has been to increasingly demand more environmentally acceptable methods of pest control. Biological control of weeds is perceived as an appealing option in this regard, but the predominantly used classical approach cannot be applied to many weeds. Furthermore, classical biocontrol has a history of targeting subjects on an opportunistic or fortuitous basis, and often as a last line of attack; a pattern which appears to have been mimicked by the inundative bioherbicide approach in its infant years.

In Australia, the major crops are winter cereals and the important weeds are exotic annuals. Many of the weeds are genetically closely related to crops (e.g., crucifers, composites and grasses) so, in most of these cases, opportunities to import exotic biocontrol agents will be denied because of quarantine restrictions. Such species, along with ones which are not being effectively controlled by existing technology, or others that have developed resistance to chemical herbicides are obvious targets for bioherbicides. These and other aspects of weed management in cropping systems are considered in order to identify the opportunities and suggest directions for bioherbicide research in Australia.

Introduction

As with chemical herbicides, bioherbicide technology is supplied to markets by enterprises seeking to make a profit (Auld 1991). Consequently, provided there is a demand, commercial opportunities exist for using microorganisms as biological control agents. Notionally, bioherbicides could be preferentially marketed because of their environmentally benign characteristics, low development and registration costs and the ability to control some weeds more efficiently and economically compared with conventional chemical herbicides (Wilson 1990).

Although the tactic of manipulating plant pathogens to control weeds is firmly established, private enterprise has shown only a reluctant or token interest in the technology, with organisms from a range of countries and target weeds failing to be commercialized (Templeton 1992a,b). Most of these organisms appear to have been "orphaned" because of the minor international importance of the targets and their consequent small market potential. In part, this stems from the fortuitous or opportunistic choice of obviously virulent organisms, rather than a pragmatic selection of economic candidates.

Because the bioherbicide tactic primarily uses endemic organisms, the market size for any venture in Australia would initially be limited to onshore demand. Exportation would only be possible after satisfying foreign quarantine and registration requirements. The question considered in this paper then is: do viable markets for bioherbicides exist within Australia that would warrant allocation of scarce resources for research and development? If so, these should be identified so that research can be logically directed to gain public and private sector support.

Opportunities for bioherbicides

Classical biological control has been cast either as an alternative to other forms of control, or considered as a last line of attack when the alternatives fail. It is unfortunate that bioherbicides have also been tarnished with this image for they should be considered not only as offering an alternative or unique means of control, but more as adjuncts to integrate with existing technology.

One of the opportunities for marketing bioherbicides is undoubtedly as alternatives to chemical herbicides since society is increasingly demanding more environmentally acceptable methods of weed control (Greaves and MacQueen 1988). But the demand should not wholly be framed as one of supplanting chemical herbicides. Particular problem species which are currently being inadequately controlled, cannot be economically controlled, or are tolerant or resistant to chemical herbicides also warrant consideration as economic targets. There are also lucrative opportunities to synergistically combine biological and chemical ingredients (Wilson 1990).

Foundations to the bioherbicide tactic have been unequivocally established, forged largely by universities and public sector research. This research continues to escalate; in 1982 some 54 pathogens were under study whereas by 1989 there were 109 (Charudattan 1991), and there is ample opportunity for further exploration since many diseases of weeds have yet to be examined.

Commercialization of agents has largely relied on involvement from the private sector for product development and marketing. Multi-national chemical companies in particular have been courted because of their fermentation, production, formulation, and marketing expertise. Commercial adoption has been limited, however, with only three registered products entering the market since the tactic was initially illustrated by Daniel *et al.* (1973). Measured against growth in the chemical herbicide industry, at the same stage of development, commercial progress in bioherbicide technology has been slow. Although there are many technical obstacles to be overcome with bioherbicides, just as there still are with chemical pesticides after fifty years of industry, the major constraint is commercial adoption, not technological development. Commerce has simply not invested the necessary capital into bioherbicide development. No matter how efficacious, it thus appears that microorganisms are unlikely to be developed as bioherbicides if the market size is inadequate. For this reason alone, further exploration of pathogens in Australia should logically be directed towards major weeds of the major crops. Since there is a broad spectrum of weeds in most cropping systems (Medd 1987), products having compatibility with chemical herbicides will be required to expand marketing opportunities and overcome the typically narrow spectrum of bioherbicides (e.g., Grant *et al.* 1990).

Cropping systems, because they lack diversity, are vulnerable to pest and disease invasions, and integrated pest and disease control actions have to be maintained (Groves 1989). Compared with other ecosystems, crops are better suited to the bioherbicide tactic because they are more likely to provide a stable environmental platform for disease development. Whilst this also favours some crop diseases, it is rarely economic to use fungicides in winter crops in Australia; thus eliminating a potentially antagonistic conflict when applying bioherbicides. A critical limitation of the biocontrol approach, however, is that the majority of weeds of cropping are exotic introductions and many are closely related to crops. From the standpoint of classical biocontrol, this limits options for importing microorganisms because of quarantine restrictions in place to safeguard crops. Thus the only hope for controlling this important subset of weeds by biological means is to exploit endemic pathogens. However, Wapshere (1987) argued that for bioherbicides to succeed, virulent organisms selected from the centre of origin of particular target weeds would need to be imported. This conflict casts doubt on the relevance of the bioherbicide tactic for crop relatives, but does not condemn it. The argument ignores the possibility that virulent organisms could have already been introduced or that virulent new host/disease associations could form between endemic pathogens and exotic weeds. The anthracnose disease caused by *Colletotrichum orbiculare* on Bathurst burr (*Xanthium spinosum* L.) (Auld *et al.* 1988) would appear to illustrate such a new association as it is confined to Australia (Walker *et al.* 1991). Also ignored by Wapshere's stand is the opportunity to enhance the virulence of endemic pathogens by genetic manipulation.

Perceived markets for bioherbicides in Australia

Identification of major markets

The Australian herbicide market is of the order of $400 million annually. Almost 85% of herbicides are used in pasture and, predominantly, crop production (Table 1). Disregarding those used for minimum tillage and vegetables, more than two thirds of the herbicides are used for pre- or post-emergence weed control in cereals with an annual market size of around $145 million. The importance of the winter cereals can also be appreciated from Table 2 in that wheat, barley and oats represent 84% of the total area sown to crops and produce 73% of the total income derived from the major grain and cropping enterprises.

Table 1. Crop and pasture herbicide sales in Australia in 1990.

Herbicide class	$(Million)
Cereal pre-emergence	59.5
Cereal post-emergence (grass)	52.7
Cereal post-emergence (broadleaf)	32.4
Triazines	22.9
Substituted ureas/uracils	14.7
Phenoxy acid derivatives	32.3
Minimum tillage	70.7
Vegetables	50.1
Total crop and pasture	**335.3**
Non-crop herbicides (Industrial, etc.)	63.0
Total herbicides	**398.3**

Clearly, the winter cereal crops represent a major market for weed control in Australia. In addition there are other sizeable untapped markets for bioherbicides if products could be marketed at low cost for use in low input rangeland situations. For instance, vegetable fault in wool, primarily caused by fruits of *Xanthium* species, costs the industry an estimated $185 million annually (Anon. 1988). In this case the burrs go unchecked because farmers view the existing technology as being either unsuitable or uneconomic. Galvanized burr (*Sclerolaena birchii* (F. Muell.) Domin) and spiny emex (*Emex australis* Steinh.), for example, similarly represent untapped rangeland markets.

Table 2. Commodity statistics for the major agricultural grain and fibre crops in Australia (1989–90). Source: Australian Bureau of Statistics, Cat. Nos. 7330 and 7503.

Crop	Area (million ha)	Value ($ million)
Wheat	9.00	2775.1
Barley	2.31	708.8
Cotton	0.24	629.7
Grain legumes	1.29	294.5
Oats	1.09	178.0
Oilseed	0.20	85.0
Other grain and fibre crops	0.71	360.7
Total	**14.84**	**5031.8**

Important weeds of the major crops

Of the 430 species nominated as weeds of arable lands in Australia, more than two thirds belong to dicotyledonous genera (P.W. Michael, unpublished working checklist). Less than one quarter of these are of major importance (Wilding *et al.* 1986), and as discussed by Medd (1987), the composition of the weed flora varies according to regions, crops and fields. Furthermore, the spectrum of species within a field is influenced over time by farming practices and changes in technology.

Among those species or species complexes listed by Gilbey (undated), Wilding *et al.* (1986) and Mullens and Dellow (1992) there are three prominent groups of potential targets: some annual grass weeds, composites and crucifers, most of which are exotic introductions. A range of cheap herbicides is available for treatment of broadleaf weeds but there are specific problems and potential openings for bioherbicides.

The grasses in particular meet several important criteria for bioherbicide targeting, although host specificity is a critical issue (Wapshere 1990). The annual grasses have sizeable markets, e.g., >$25 million for *Avena* spp. (Medd and Pandey 1990), and treatment costs with chemical herbicides is high compared with the broadleaf weeds (Table 3). Some taxa, e.g., *Vulpia* and *Bromus*, are tolerant of all the aryloxyphenoxypropionate and cyclohexanedione herbicides and so cannot be controlled with chemicals within winter cereals. Biotypes of *Avena* and *Hordeum* have developed resistance to specific herbicides and annual ryegrass (*Lolium rigidum* Gaudin) exhibits cross resistance to several herbicide groups (Powles and Howat 1990).

A feature common to these annual grasses is their short cycle habit which makes them ideally adapted to the continuous cropping systems extensively practised in Australia (Martin and Pannell 1990). They are characterized by their low level of seed dormancy, rapidly declining seed banks in the absence of seed production and rapid build-up if uncontrolled. Medd and Ridings (1990) and Pandey *et al.* (1992) have demonstrated that control of seed production in such weeds has a far greater impact on population control than can be realistically achieved through the control of biomass or plant numbers.

Table 3. Major weed taxa of winter cereal crops in Australia with susceptibility to, and cost of treating with herbicides registered for winter cereals.

Weed	Susceptibility[1]	Cost of control[2] ($ ha^{-1})
Poaceae		
Avena spp.	R	39.10
Bromus spp.	T	–
Hordeum spp.	R	24.37
Lolium spp.	R	32.85
Phalaris spp.	T	39.10
Vulpia spp.	T	–
Asteraceae		
Arctotheca calendula (L.) Levyns	R	16.15
Carthamus lanatus L.	S	16.15
Chondrilla juncea L.	S	28.41
Sonchus spp.	R	18.00
Brassicaceae		
Brassica tournefortii Gouan	S	6.50–17.49
Raphanus raphanistrum L.	R	6.50–17.49
Rapistrum rugosum (L.) All.	S	6.50–17.49
Sinapis arvensis L.	S	6.50–17.49
Sisymbrium spp.	S	6.50–17.49

[1] R = some biotypes resistant to some chemical herbicides;
T = some species tolerant of chemical herbicides;
S = susceptible to chemical herbicides.

[2] Cost of preferred recommended herbicide (excluding application cost) (Mullens and Dellow 1992).

Consequently, any bioherbicide development venture for these species would do well to concentrate on preventing seed production as opposed to killing plants.

Conclusion

Potentially rewarding commercial opportunities for bioherbicides exist within Australian broadacre winter cropping industries and possibly for several weeds of rangelands if products could be marketed for low cost. In the interest of providing farmers with more efficient and sustainable, and society with more acceptable weed management options, funding should be made available for public sector research to systematically survey and screen pathogenic organisms of major weeds of cropping systems. The emphasis should be on weeds with potentially large markets such as the annual grasses and broadleaf weeds of winter cereals, especially those which are tolerant of, or have developed biotypes resistant to chemical herbicides.

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