An appraisal of opportunities to reduce herbicide use

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Summary

Public concern about herbicide use is reflected in direct government intervention by the imposition of strict registration requirements. As the concerns have not been alleviated by this approach it is argued that a more rational stance needs to be adopted particularly as the advantages of herbicide use outweigh the disadvantages. The implementation of a policy, with a strong extension, research and education focus, to reduce herbicide use rates by 15% in five years and 50% in ten is considered to be the most appropriate way to overcome the public's concerns. Ways of achieving these goals are identified, the most significant being whole farm planning, manipulating the weed flora, development of an "expert" advisory system and developing more efficient application systems. It is suggested that funding for the project be generated through a 1% levy on herbicide prices at the farm gate. To achieve the objectives the policy should be implemented by a management team which must include consumer and conservation representatives.

Introduction

Ideally herbicides should be used when necessary, at the minimum rate to achieve a level of weed control that optimizes economic returns to the user and have minimal adverse effects on the environment. This ideal is not being achieved because herbicides are often applied at the wrong time, mostly with a greater than optimal dose rate, with equipment that gives uneven distribution and inappropriate droplet spectrum and under unfavourable weather conditions (Combellack 1990). That herbicides work in spite of these inadequacies reflects the robustness of the recommended dose rates. This has led users to adopt an indifferent attitude toward herbicide use particularly farmers producing high yielding or high value crops. This seems a reasonable attitude when neither government nor industry in most countries appears willing to tackle the issue in a realistic manner. Denmark is an exception (Haas 1989). It seems legitimate to expect industry to adopt a more responsible stance by ensuring that recommended dose rates reflect the "better" rather than the "worst" user. Governments should ensure that the most cost-effective and environmentally sensitive dose rates are used.

This paper will consider key factors involved in achieving this objective and suggests ways of financing, planning and implementing a policy which aims to reduce herbicide use.

1. Managing the weed flora

Weed control should be considered before, for example, planting a crop in a field or the garden, designating the status of a park or defining the required vegetation quality along roads or rail. This is necessary to anticipate whether it is possible to effectively and selectively remove the existing or anticipated weeds. Frequently land managers overlook the consequences of the existing weeds let alone anticipate those that may arise. In their defence the lack of data on long term changes in weed flora means that most weed control practitioners are only able to predict for one or possibly two seasons.

Studies of the long term changes of the weed flora are rare. Those of Denmark's agricultural system are unique (Haas and Streibig 1982). These studies, taken over a 70 year span, show that there is only a small change in the number of weed species, but those that dominate, change with the imposed management system, e.g., cropping or pasture, and weed control method used, e.g., tillage practices or herbicide (Haas and Streibig 1982). A recent study in Australia has shown that annual rainfall pattern is important in determining the weed flora present in cereal crops (Streibig *et al.* 1989a). However crop type and soil clay content had the greatest influence on the weed flora in Danish crops (Andreasen and Streibig 1990) while in flood-irrigated Australian rice crops it is a reflection of cropping intensity (McIntyre *et al.* 1991). These few studies support the need for regular weed surveys. They also demonstrate the value of including information on soils, cropping history and climate in an analysis of the data. By doing this it is possible to provide a better insight into the reasons for a change in weed flora. Such information is increasingly important as herbicides have already demonstrated their ability to impose dramatic changes to the weed flora. For example the dominant broad-leaved flora in Victorian cereal crops before 1950 was changed to one of annual grasses by the late 60s. From personal observations the annual grasses are increasingly being replaced by perennials, both monocotyledons and dicotyledons, or plants resistant to herbicides. These are typically more difficult and expensive to control.

If we are to reduce herbicide inputs it will be essential to predict changes by committing resources to weed surveys and interpretation. This information should be integrated with weed spread, and economic consequences, to provide information on weed impact (Combellack 1990). The derived information would enable better control strategies to be developed and ensure a reduction in herbicide use by preventing the build up of more intractable species and by manipulating the flora toward "easy" to control and relatively non-competitive species in the long term. It is difficult to assess herbicide savings from such a project but they are conservatively estimated at five percent per annum after ten years (Combellack 1989b).

2. Whole farm planning

To enable reductions in herbicide inputs through whole farm planning it is necessary to integrate an array of control options, including rotations and grazing management, to reduce the ability of weeds to reproduce.

(a) Biological control

This can be achieved in pasture, in part by strategic grazing with sheep, which are able to reduce seed production of ryegrass (*Lolium rigidum*) and ragwort (*Senecio jacobeae*) and goats which reduce seed production of blackberry (*Rubus fruticosus* agg.), variegated thistle (*Silybum marianum*) and St. John's wort (*Hypericum perforatum*) (Combellack 1989). Other studies have shown that grazing intensity changes the dominance of pasture species with low grazing pressure, for example, increasing the dominance of grasses (Leys 1990). The value of grazing management has been poorly researched and deserves greater recognition as a major contributor to weed management.

The introduction of "classical" biological control agents such as *Cochylis atriapitana* to reduce the production of flowering stalks, and hence seed production of ragwort (*S. jacobeae*) or the *Chrysolina* beetle to defoliate and reduce seed set of St. John's wort and the two weevils, *Lixus cribricollis* and *Perapion antiquum*, for the control of spiny emex (*Emex australis*) have unfortunately not been particularly successful. However seed production of skeleton weed (*Chondrilla juncea*) was severely reduced following the introduction of the rust *Puccinia chondrillina* in the early 1970s (Hasan 1974). But thirty years on, one of the three original forms of skeleton weed that was resistant to the introduced rust strains is now growing in densities approaching those before the release of the rust (Shepherd, personal communication). Another rust fungus *Phragmidium violaceum*, which reportedly reduces the seed production of blackberry has recently been released in Victoria (Bruzzese, personal communication).

In reality "classical" biological control offers limited scope for the reduction of herbicide use in Australia as it has proven to be of limited value for the control of weeds in crops where approximately 70% of the herbicide is used. Also it is likely that research on strategic grazing by ruminants will be more successful than "classical" biological control in reducing weed infestations in crops.

(b) Mechanical control

Cultivation remains one of the most widely used weed control techniques. It can change the flora by burying seeds, thus reducing emergence, and preventing seed set by controlling emerged plants. The type of cultivation and its frequency affect the resultant flora (Cussans 1987). In cropping areas frequent cultivation in the fallow, particularly over the summer, has been widely employed to control pernicious deep rooted perennials such as skeleton weed, silver-leaf nightshade (*Solanum eleaegnifolium*) and creeping knapweed (*Acroptilon repens*). This practice generally provides only temporary suppression and limited benefits to productivity (Wells 1970). It is emphasized that cultivation is one of the major contributors to the degradation of old fragile soils such as exist in Australia (Pratley and Rowell 1987). There has been, and will continue to be, pressure to minimize soil cultivation and reduce aggressive cultivation as a means of weed control. This will be achieved in part by using less aggressive implements and or increased herbicide use in the fallow.

As cultivation will remain an important component of most whole farm management programmes, research should be directed toward defining weed control effectiveness, relative energy and economic inputs compared with other weed control options and the relative effect of various weed control options on soil degradation. Prevention of seeding is also possible by mowing, slashing or burning. As these are also neglected areas of research their value in reducing propagule viability cannot be accurately gauged.

(c) Natural chemicals

The use of allelopathy offers some opportunities. The inclusion of rye (*Secale cereale*), oats (*Avena sativa*) or sorghum (*Sorghum bicolor*) in the rotation may reduce the incidence of weeds such as pigweed (*Portulaca oleracea*) or smooth crabgrass (*Digitaria ischaemum*) (Putnam 1987).

(d) Other considerations

These include the physical control by flameweeding or soil solarization (Morgan 1989). Mulches can be considered in horticulture and the home garden (Morgan 1989). The density of weed seedlings that emerge in the year after harvesting, and which follow the path of the harvester, suggests that it is worthwhile collecting the seeds for subsequent disposal. Finally the breeding and sowing of crop varieties that are more competitive through growth habit or allelopathy is worth considering (Chancellor and Peters 1976).

There seems little doubt that an integration of some, or all, of these would enable a reduction in the quantity of herbicide used. As the implementation of such strategies is complex it is suggested that "best bet" options be initially developed for major crops. This would also enable deficiencies in the knowledge base to be identified. It is estimated that reductions in herbicide use of 5 to 10% could be achieved within five to ten years. Further, if linked with weed impact even greater savings are envisaged because the weed flora would be manipulated toward herbicide "sensitive" and less competitive species. However it is realised that as the emphasis on continuous cropping increases in the developed nations designing and implementing effective strategies will become an increasingly difficult challenge.

3. Timing of weed removal

Studies have shown that the early removal of weeds in crops ensures the use of a lower dose of herbicide and invariably the best yield from the crop. It is therefore regrettable that the user frequently does not heed this simple fact. Experienced users are concerned that further weed seeds may germinate and thus will not treat until they believe all have emerged. As a benefit 25 to 30% in reduced herbicide dosage is possible from early treatment, (e.g., Edmund and York 1987). This is an opportunity that needs to be exploited.

To encourage the majority of users to change their current practices it will be necessary to demonstrate that early treatment is prudent both for efficacy and economic reasons. Further it will be necessary to show that under most circumstances late emerging weeds are few in number and not as deleterious as those emerging earlier. Much of the relevant data is held by herbicide manufacturers. As this is an essential element when determining optimal herbicide rates it is disappointing that so little is reported in the literature. If companies cannot be persuaded to release their data this must be regarded as a high research priority. For a community concerned about herbicide use this is particularly important as savings in herbicide rates of up to 25% appear possible.

4. Application efficiency

(a) Sprayer calibration

Application equipment is frequently not accurately calibrated and inappropriate droplet sizes are used. Rider and Dickey (1980) for example reported that only 40% of users were applying within 10% of the desired dose and even more alarming are the studies of Cupery (1987) who found only 19% of applicators within the same limits. These reports only reflect poor calibration and mixing. These are exacerbated during application by, for example, boom instability which is reported to account for variations in the dose applied of up to 100% across and 30% along the swathe (Maybank *et al*. 1974). They concluded that if the distribution was improved the dose could be halved. Further, Combellack and Richardson (1987) have reported that a reasonably stable boom having a static coefficient of variation of spray deposit of less than 12% could be used with 12.5% less herbicide. Even greater savings are likely if appropriate droplet size and droplet trajectory are used (Combellack 1987). This hypothesis needs field testing and, if verified, extended to users.

(b) Use of adjuvants

The addition of adjuvants to the spray mix brings about enhanced activity by modifying surface behaviour such as spreading, dissolution or disruption of epicuticular waxes, modifying the resultant residue on the plant surface, expediting dissolution by solubilization, offering increased humectant properties and modifying cuticular and stomatal penetration. As the improvement in efficacy has typically been within the 5 to 15% range it is necessary to employ careful experimental procedures such as a comparison of relative potency (Kudsk *et al*. 1987). Recent studies with paraffinic oils show that dose rates of certain herbicides used to control johnson grass (*Sorghum halepense*) could be reduced by up to 50% when applied at very low volume using the twin fluid atomizers (Barrentine and McWhorter 1988).

In view of these results a project has been initiated in Australia to develop a new spraying system. This project integrates the resources of nozzle manufacturers with those who manufacture sprayers. Concurrently manufacturers of adjuvants (mostly oils) are co-operating with herbicide producers to produce modified formulations. Researchers at Monash University and at Keith Turnbull Research Institute provide a coordinating role and technical input. The "Spray

Smart" project currently involves over twenty organizations and is governed by a board of management comprising representatives from government, industry, universities and users. To date effective nozzles have been selected, operating parameters determined for their use, a suitable small plot sprayer designed, a laboratory sprayer developed which is capable of applying herbicides at 2.5 L ha^{-1} when operated at 20 km h^{-1} and a rainfall simulator has been constructed to assess possible enhancement in rainfastness. The initial efficacy trials have been very promising.

This area of research offers great promise, particularly for the grass herbicides within the groups aryloxyphenoxypropionates ("Fops") and cyclohexanediones ("Dims"). The objective of the "Spray Smart" project is to reduce herbicide dose rates by 5 to 10% per unit area. Initial trials suggests that this is achievable providing a sufficient range of appropriately formulated herbicides are marketed to warrant the user purchasing an very low volume sprayer.

(c) Patch spraying

Weeds typically occur in patches across a field. However herbicides are applied to the whole field, often in mixtures, so that adequate control of the species range is possible. It has been suggested that herbicide savings of 70 to 80% are possible if the appropriate herbicide is only applied to those species against which it is effective and only where it occurs (Combellack and Richardson 1987). There is considerable scepticism about this concept as data on weed demography within a field is limited and the technology to carry out the spraying is thought not to exist. The limited studies on spatial weed distribution within a field (Thornton *et al.* 1990) confirmed the patchiness of weeds and their limited distribution. Also, in-line injection sprayers are available which enable two herbicides to be separately injected, each at a different rate. Therefore to make patch spraying reality, all that remains to do is to develop a digitised pad upon which the field, and weeds within it, can be mapped. This must then be linked to a controller which activates the appropriate herbicide pump as the sprayer approaches a weed patch.

It is realised that this is not an easy project and that the resultant sprayer may well be expensive. However if the community is serious about reducing herbicide inputs implementation of this concept offers the possibility of reducing doses by at least 25 to 33%. It is also possible to treat individual weeds, or patches of weeds, by using red and infra-red reflectance to discriminate green vegetation from soil or litter (Felton *et al.* 1987). Such a sprayer has been commercialized and is a valuable tool in minimum till or no till cropping systems.

5. Expert systems

These are still in the development stage in most countries including Australia. They should offer users the opportunity to assess the relative merit of the range of treatments available. Central to these systems should be an estimate of economic return. This should be based on six inputs :-

i) the density of each species,
ii) the relative competitiveness of the species,
iii) the estimated weed free yield,
iv) the level of weed control expected from the treatment selected by the data base
v) the anticipated net value per unit for the crop and
vi) the cost of the treatment selected.

The value of such a system has been demonstrated by Streibig *et al.* (1989) who used the rectangular hyperbolic yield-density model (Cousens 1987) to determine thresholds for a number of weeds of wheat. By reworking published data they showed that for a given species the anticipated weed-free yield was important in predicting net returns. For example with annual ryegrass (*Lolium rigidum*) the economic break even density was approximately 80 m^{-2} for an estimated weed-free wheat yield of 2.4 tonne ha^{-1} in New South Wales but 220 m^{-2} for a weed-free yield of 2.2 tonne ha^{-1} in Western Australia. These differences reflect changes in the competitiveness of individual ryegrass plants in different regions and the maximum effect an infestation would have at infinite density which were estimated to be a 61% reduction for the Western Australian trial and 95% for New South Wales.

It will be realised that this information is not reflected on herbicide labels nor in sales literature. The author found little acceptable data when generating this paper. While the ideal model should predict the treatment that maximizes economic returns this is not possible for most crops in most countries of the world as the availability of sound weed threshold data is very limited. If reductions in herbicide rates per unit area is desired then the development of a suitable "expert" model is essential. It should be recognized that users currently attempt to make sound economic decisions but these are, through necessity, based on intuition rather than factual knowledge.

6. Herbicide savings

Estimates of achievable herbicide savings for each of these categories are :- managing the weed flora, 5 to 10%; whole farm planning, 5 to 10%; timing of weed removal, 20 to 25%; application efficiency, 25 to 30% and expert systems, 20 to 25%. Obviously the savings are not additive. However as previously stated (Combellack 1989a, b 1990) a reduction in herbicide use of 15% in 5 years and 50% in ten is achievable if appropriate research and extension was implemented.

7. Proposal structure and objectives

In most developed nations senior administrators have accepted the assumption that herbicides are a threat to human health. This concern has been reflected in direct government intervention by the imposition of stricter registration requirements particularly in relation to toxicology and environmental data and or the implementation of strategies aimed at reducing herbicide use (Haas 1987). Reviews on this topic have concluded that the advantages of herbicide use outweigh the disadvantages (Combellack 1989a, b 1990). Further the need to persuade politicians, administrators and the public to adopt a more rational stance on herbicide use have been emphasized (Combellack 1989a). This is difficult to foster when it can be theoretically shown that herbicide dose rates could be reduced by 15% per unit area in five years and up to 50% in ten (Combellack 1989a, b). As the direct main beneficiaries of continued herbicide use are the users and herbicide manufacturers, it is my view that a levy of 1% be generated against herbicide sales at the farm gate to implement a strategy to achieve these goals. The collected revenue should be used to implement an extensive extension campaign to achieve the first goal, 15% reduction in five years. This could be achieved by users implementing available information.

The programme should not only be directed toward users but also the consumers (i.e., the public). The public must be alerted if herbicides are found in unwanted places, for example, they must also be advised on the resultant risks together with reasons why they are being used. One of the key targets should be those most concerned about herbicide use.

The monies should also be used to underwrite research needs, such as sound threshold data, more efficient application methods, weed surveys to monitor changes in the weed flora, development of best-bet whole farm management plans and the development of an expert system that includes economic considerations.

The monies should be controlled by a management team comprising representatives of users, consumers, government, research, extension and education. The management team should be paid, as should the leaders of research, extension and education projects. The management team must set measurable goals and implement an annual review process to ensure these are met. A pro-active strategy such as this will be more beneficial than the current way governments reflect public concern, for example, by increasing the amount of data required for registration. The wisdom of this existing policy is questioned for it is has apparently not satisfied those who are concerned and it has made labels increasingly complex. This latter aspect is increasing the difficulties faced by users because technical support for products by manufacturers and government is declining. The need for a rational strategy on herbicide use outlined above, is in my view the best approach for the future.

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