Alternatives to Herbicides

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Summary

Recent public opinion about the use of herbicides has highlighted the need to re-assess our methods of weed control, in particular, to eliminate or reduce the use of chemicals. There are a number of alternatives to herbicides which are outlined and discussed in terms of their advantages and disadvantages and practicalities. Whilst examples exist of each of the alternative methods of weed control they are few and usually weed specific. The need to develop weed management strategies using all available alternatives is recommended whilst recognizing that there is still a need for efficient chemical weed control.

Introduction

Increased public concern about the use, and alleged misuse, of chemicals in agriculture causing health and environmental problems, and the importance of zero chemical residues to ensure unrestricted entry of agricultural products to world markets, has re-enforced the need to develop techniques to eliminate or reduce the current level of chemical inputs in agriculture. As well, some farmers are interested in reducing chemical inputs both for the above reasons but mainly for economic reasons.

In Australia in 1988, $550 million was spent on agricultural chemicals (excluding veterinary products and fertilizers) of which approximately 70% were herbicides (this does not include the cost of applying them). Although chemicals for weed control have been used for well over 2000 years (Smith and Secoy 1976) it is only since the 1950s that modern herbicides have been used extensively. I suggest their wide adoption was because of the dramatic increase in yield and the cost benefits that resulted with their use and their relative ease of handling. Because of these spectacular results other considerations such as their possible future environmental impact and problems of herbicide resistance e.g. paraquat resistance in barley grass (Powles 1986) were not considered.

The rapid and wide adoption of pesticides placed too much reliance on them with the result that some sound cultural practices such as, crop rotation and mixed crop farming were abandoned. Farmers became specialists and concentrated on monocultures with resultant increases in weed, insect and disease problems which in turn required continued and increased use of chemicals for their control - a vicious circle.

There are two alternatives to present chemical weed control strategies. The first is to eliminate the use of synthetic herbicides altogether and the second is to reduce the number of applications and/or amount (in terms of area of application rather than rate) of herbicides used. This paper will examine the first of these options and draw some conclusions.

Alternative control options

There are a number of options for non chemical weed control:

* no control - co-exist with weeds
* cultivation or mechanical control
* physical barriers
* physical energy
* biological weed control (classical control, mycoherbicides, companion planting)
* natural chemical compounds (allelochemicals, microtoxins)
* weed management

1. No control

Weeds reduce crop yield, for example blackberry nightshade *Solanum nigrum*, L.) in processing tomatoes: one nightshade between each tomato plant reduced yields by 70-90% (two seasons) and one nightshade to six tomatoes by 36% (Morgan, unpublished data). As well weeds often reduce crop quality e.g. *S. nigrum* seed are hard to separate from a harvested crop of processing peas, and often stain and discolour the peas.

Assuming, that weed control is desirable a less drastic option to zero control is to have some weed control - this might include mowing weeds where possible such as in an orchard between trees, and in row crops on the shoulders of the land. However, it has been well established that it is the weeds closest to the crop plant that are the most competitive. Hence inter-row weed control only is not an ideal option.

2. Mechanical Control - Cultivation

Cultivation or tillage is the traditional means of weed control and in many row crops hand hoeing, the oldest and simplest form of cultivation is still practiced. In processing tomatoes for example, teams of hand hoers are employed throughout the season. With the advent of machinery, tillage systems were developed as a means of weed control, particularly for cropping. Usually ground is cultivated a number of times prior to sowing. The effectiveness of cultivation for weed control can be enhanced if rain falls or irrigation is applied between cultivations to stimulate premature germination of weed seeds. This is particularly successful with weeds which germinate in a 'flush'. A final cultivation before or with sowing can remove these weed seedlings.

In row crops inter-row cultivation ranging from extreme (rotavation) to minimal soil disturbance (chain harrows, knives, scarifiers and brush weeders) can be extremely effective. However, intra-row cultivation is not achieved with these techniques.

Further, cultivation may: incur high costs, not be completely effective, stimulate a further germination of weeds, lead to soil erosion and/or compaction (Pratley 1987), cause root and foliar damage or totally destroy some of the crop or spread disease. Some of these problems could be overcome with the use of modified machinery (Brown and Huzzey 1987, Tisdall and Adem 1988).

3. Physical barriers

The use of physical barriers (mulches) to prevent seedling establishment by excluding sunlight is very effective and particularly suitable for row crop production. Artificial barriers such as black plastic (sheeting or woven), paper and paper-like products (mixture of peat moss and cellulose fibre) and woven cloth have been adopted to varying degrees. Machinery is available which will lay black plastic and punch holes in it for transplanting. Problems encountered with the use of artificial mulches include application, tearing, application of nutrients and overhead water and disposal after harvest.

Natural barriers or mulches include plant materials such as straw, rice hulls, lawn clippings, animal manures or other organic products such as brown coal, sawdust and composted combinations of these. Natural mulches have other beneficial effects by adding organic matter and nutrients to the soil. However, they are awkward and time consuming to apply, and in some they cases may introduce weed seeds, or, if not composted prior to use may burn the crop.

4. Physical Energy

This form of control includes the use of many different energy forms: thermic, electromagnetic, electricity, laser, very high frequency (VHF) and sunlight.

Thermic, or heat radiation or flameweeding has been used: for non-selective weed control usually after a pre- sowing irrigation, as inter-row controlled band flaming (Sanwald and Koch 1978) or for post emergence weed control in direct drilled crops such as carrots and onions (Desvaux and Ott 1988). Post-emergence weed control radiation is timed to occur either just after crop germination but before crop emergence e.g in carrots, or at a specific leaf stage e.g. in onions (LN4) with the flame applied at an angle to the crop. Flame weeding relies on heat (60°C) denaturing the leaf protein structure. Monocotyledons are not as susceptible to heat as dicotyledons as their growing points are generally at or below ground level and new leaves arise internally whereas dicotyledons have exposed growing points. Flame weeders are reasonably common in Europe and Scandinavia but the use of high energy sources is not common in Australia. Heat has also been used to stimulate germination of some weed seed e.g. boneseed (*Crysanthemoides monilifera*) (Lane and Shaw 1978).

Similar evaluations of laser, VHF and electrical (Knievel and McKee 1977) energy have been made with promising results. With all forms of energy control, efficacy is dependant on voltage and exposure time, which requires speeds as slow as 2km/hour (Desvaux and Ott 1988) and that the weeds have an adequate moisture content. In addition, consistent crop management practices (seed bed preparation, evenness of seed bed and furrows, minimal spread of germination) are critical.

Soil solarization uses clear or opaque polyethylene sheeting to increase the soil temperature for control of soil borne pathogens but is also effective for weed control (Egley 1983). This technique is most effective during periods of high air temperature and intense solar radiation and requires a moist seed bed (Bell *et al.* 1988) as weed seeds can tolerate extremely high temperatures in dry soil.

Emergence of *Solanum nigrum* seed was unaffected after 18 days of exposure to 80°C for 8 hours in every 24 hours in dry soil, but no emergence occurred from moist soil under similar conditions (Morgan and Newton 1986). In Victoria, soil solarization has only been successful in the north of the state (Porter 1985) because of the requirement for prolonged solar radiation.

Weed control using this technique can be very effective, and the polyethylene sheeting can be re-used but the main disadvantages of soil solarization are the cost, lost production time and the fact that beneficial soil micro organisms are also killed. It is probably a technique to use only in extreme situations, and not regularly.

5. Biological Control

a. Classical biological control

Biological pest control is, in the public image at least, the ideal form of pest control. However this is a contentious conclusion. The very specific relationship between the pest and the biological control agent has disadvantages in the development and application of biological control:

(i) the long term research effort required studying the life cycle of the weed and the potential biological control agents to ensure specificity and immunity of crop plants.

(ii) the cost of these research programs (Combellack 1989)

(iii)the lag phase required for build up of the predator/pathogen population to effective levels

(iv) complications if there are more than one biotype or race of a weed.

Successful control of the dominant biotype can lead to an increase in the population, and hence seriousness, of other biotypes. A well documented example of this problem occurred with the attempted control of skeleton weed, (*Chondrilla juncea* L), by the release of a rust fungus, gall mite and a gall midge. Successful control of the narrow leaf form has been achieved (Cullen and Groves 1977) but there has been a subsequent ecological replacement of it by the broadleaf and intermediate-leaf forms. While strains of a fungus which will attack the intermediate leaf form have been released (Davidson 1983) there is still no specific biological control for the broadleaf form.

(v) problems when the control agent escapes and becomes a pest e.g. cane toad. This situation has not occured in any biological weed control programmes.

Cullen (1981) when reviewing the progress of biological control of weeds concluded that although research activity is increasing and necessary and is often successful, the impact of a new organism introduced into a new environment must be understood. This conclusion still holds today and is particularly important if biological control is to be part of an integrated system of weed management.

b) Mycoherbicides

A more recent development in biological control has been the development, registration and marketing of plant pathogens as herbicides (mycoherbicides). Their use is more specific or controlled than the more conventional biological control agents in that they are applied as a herbicide when and where the weed problem exists. They do not require time for build up and spread and are applied to the weed at a specific rate. The specificity of mycoherbicides can be a disadvantage when compared to some chemical herbicides that control a wide spectrum of weeds (Klerk *et al.* 1985) but they can be used in combination with different mycoherbicides (Boyette *et al.* 1979) or some chemical pesticides (Klerk *et al.* 1985) in integrated pest management programs. They can also be applied pre-emergence as granular formulations (Walker 1981b). Pre-emergence use of spore mixtures is attractive because lowered rates are required for emerging weed seedlings and band applications in the drill row can be used reducing the quantity of spores required per land unit.

The use of fungal plant pathogens remains a relatively untapped source of technology for selective weed control. Successes include the use of *Colletotrichum gleosporiodies* fsp *aeschynomene* for control of northern jointvetch (*Aeschynomene virginica*) in rice (*Oryza sativa* L.) (Daniel *et al.* 1973). More recently Walker (1980, 1981a, 1982) has developed techniques for producing spores of several fungi that are highly selective in controlling velvetleaf (*Abutilon theophrasti*, Medic.), spurred anoda (*Anoda cristata* (L.) Schlecht.), sicklepod (*Cassia obtusifolia*) and prickly sida (*Sida spinosa* L.) (McWhorter 1984). Mycoherbicides are needed for cropping systems in Australia both for broad acre and row crops.

c) Companion plants

Companion planting with legumes and/or grasses has been used as a means of weed control in slower growing crops such as sweet corn (Werner 1988). Similarly, low growing companion plants of a second crop for example lettuce or spinach can be used to control weeds on shoulders of raised beds when the main crop is slow growing e.g. corn or leeks (Blake 1987). Living mulch or green manures are also used to smother weeds and are usually most successful if established before the crop. To avoid competition for nutrients and moisture they must be carefully managed possibly by mulching or flaming.

Weed species react differently to companion planting e.g cress (*Lepidium sativum*, L.) eliminated all weeds present, grasses reduced fat hen (*Chenopodium album* L.) and white clovers reduced *Veronica* spp (Werner 1988). Allelopathy may also be involved.

6. Natural Chemicals

Many natural products have potential to form the basis for commercially successful herbicides because of their relative environmental safety and good target species selectivity. Phytotoxic natural products are usually of plant or micro organism origin (Duke and Lydon 1987).

(a) Allelopathic compounds

Many plants have the potential to produce and release allelochemicals into their environment which inhibit other plants and offer varying degrees of protection against pathogenic micro organisms and insects (Duke and Lydon 1987). In this paper the term allelopathy will be used to describe the harmful effect, either direct or indirect, of one plant species on the germination and growth of another through the production of allelochemicals (Rice 1974). It is thought that allelochemicals have unintentionally been bred out of modern crop plants in favour of agronomic characteristics giving weed species a chemically competitive advantage (Lovett 1982). Comprehensive reviews of the plant parts capable of production of allelochemicals, the factors influencing the quantity produced, a classification of compounds involved and a list of known and most common allelochemicals have been undertaken by Rice (1974, 1979).

The effectiveness of allelochemicals depends on the season, soil type and conditions including fertility and microbial activity and their interaction. Phytotoxicity is higher in soils of low fertility due to nutrient stress and/or reduced microbial activity.

Examples of allelopathy in Australia have been extensively reviewed by Lovett (1986, 1987). Of particular interest for this paper are his sections on introduced weed, crop and pasture species and in the 1987 paper he summarized in a table eighteen studies on the interactions between weed and crop and/or pasture species. It is disappointing that only one of these Australian studies involved the effect of crops on subsequent weed germination and growth (Purvis *et al.* 1985). Most allelopathy studies in the literature give examples of the effect of weeds on crop growth, crops on crops (autoallelopathy) which is obviously a serious problem with continuous cropping, and often weeds on weeds (Lockerman and Putnam 1979). However, it is the ability of crops to suppress weeds which is of interest and of economic potential. Lockerman and Putnam (1979) found that allelopathy and competition can interact on weed populations.

Selected cucumber accessions can reduce the number and inhibit the growth of several weed species including proso millet (*Panicum miliceum* L) (Putman and Duke 1974). Stubble residues of matured crops of sorghum (*Sorghum bicolour* Muench) sunflower (*Helianthus annuus* L.), rape (*Brassica napus* L.), wheat (*Triticum aestivum* L.) and pea (*Pisum sativum* L.) inhibited development of monocotyledons except wild oats (*Avena fatua* L.) (Purvis *et al.* 1985). Germination and development of wild oats was actually stimulated by all crop residues particularly wheat and pea stubble which reduced numbers of competitive broad leaved weeds (Purvis *et al.* 1985). Hence, a number of options for wild oat management are available. Similarly, portulaca or pigweed (*Portulaca oleracea* L.) and smooth summer grass (*Digitaria ischaemum*, (Schreb.)Muhl.) were reduced by 70% and 98% respectively by sorghum residues whilst larger seeded vegetables grew normally and smaller seeded vegetables were severely injured (Putnam and De Frank 1983). Spackman (1987) has considered the role of allelopathy for weed management in field crops and provides examples of overseas work on the effect of the crops, sunflower, grain sorghum, soybeans, wheat, rye oats and barley on weed growth.

Cover crops are an important component of organic farming and reduced tillage systems, where they contribute to soil organic matter, enhance water penetration and prevent soil erosion. Crop residue effects also need consideration when planning reduced tillage systems as they can effect subsequent crops as well as weeds.

Allelopathy has potential for weed management immediately and in the future. Weed management by the use of crop rotations, companion planting, use of crop and weed residues as mulches or incorporated (as organic matter) into the soil is already being practised in a limited way. In the future, new crop cultivars should be screened for allelopathic properties and allelochemicals could be used in the development of new herbicides (Lockerman and Putnam 1979, Spackman 1987, Lind 1987).

However there are still a number of areas which require further research;

(i) the isolation and identification of the mode of action of allelochemicals which could be the products of either a reaction between two or more exudates or, microbial action upon exudates (Lind 1987),
(ii) how environmental factors e.g heavy rain, alter the effectiveness of allelochemicals,
(iii)identification of the factors which influence their production: e.g. nutrient deficiencies or moisture stress,
(iv)whether production can be induced as required in the field,
(v) identification of the site of action of the chemical on the recipient plant, and
(vi)testing of the safety of allelochemicals

(b) Other plant chemicals

Many chemicals from plants are highly phytotoxic e.g phototoxins and coumarins and hence are not specific enough for herbicide use. However, Duke and Lydon (1987) recognized the enormous potential for new herbicides from plant chemicals. The amino acid -amino-levulinic acid (ALA) known as the 'laser' herbicide has been patented but its potential use is limited by its cost and some environmental limitations on efficacy.

(c) Microbial phytotoxins (Microtoxins)

Microtoxins are microbial products (phytotoxins) which have several advantages over living biological control micro-organisms. They are easier to store and apply and are more compatible with other formulations, are less affected by environmental factors and cannot spread disease to non-target species. They also have advantages compared with allelochemicals from green plants which are generally not very selective and are often auto-toxic. Microtoxins are highly selective for weed control and can be used at very low rates.

There are two types: (i) Host specific toxins - all produced by fungi and (ii) Non host specific toxins - produced by bacteria and fungi. Commercial examples of microtoxins include Bialophos and glufosimate. There are a number of other microtoxins under consideration for development as herbicides. Several Japanese, European and American companies are carrying out research into this field (Duke and Lydon 1987).

7. *Weed management*

Weed management must be included in all crop management strategies and should consider ways of preventing soil weed seed reservoir build up, preventing or decreasing weed seedling establishment, decreasing the soil weed seed reservoir and eliminating the weeds which grow with the crop. Weed management requires an understanding of how factors such as crop phenotype and genotype, crop density and spacing, crop rotation, fertilizer input, cultivation and seasonal conditions effects the spectrum of weed species on a property (Medd 1987). Changing any of these factors does not eliminate weeds but rather favours development of different groups or species of weeds.

In Australia since the 1920s the trend has been for total number of weed species to increase on arable land even with the advent of herbicides (Amor and De Jong 1983). This phenomenon has been well documented by Haas and Streibig (1982) and Medd (1987).

(a) Preventing the soil weed seed reservoir from increasing.

An understanding of the biology of the weed species helps to define the critical time to prevent weed seed reservoir increases. In the case of blackberry nightshade seed from green or 'immature' berries is capable of germination and emergence. Green berries contain at least 50% viable seed (Morgan 1983). One blackberry nightshade plant is capable of producing 13,000 and 160,000 seeds in 9 and 20 weeks, respectively, from emergence (Morgan and Newton 1983). There are an average of 40 seeds per berry making even one berry left on the ground important. Farmers previously thought it was enough to hoe weeds at the green berry stage and leave the plants on the ground. Now it is suggested that hoeing occurs at first flowering and that older plants with berries are removed from the field.

It is also important to prevent weeds seeding between crops in fallows (Medd 1987) or in cover crops. Similarly, control of weeds along fence lines and access areas is important since seeds from these areas can be spread by birds and very effectively by laser grading.

(b) Preventing or decreasing weed establishment.

Use of vigourous crop varieties which emerge earlier and grow quicker than weeds (Blake 1987) or other techniques to increase the speed of crop emergence relative to weeds such as seed priming and pre-germination, shallow sowing, moist seed beds, and anti crustants may all have a place in weed management. Delayed sowing is a useful tactic for control of weeds which have a flush of germination after cultivation and/or rain.

Cultivation and pre-sowing irrigation can be used to encourage weeds which would normally emerge with the crop (Morgan *et al.* 1987). These can be destroyed by light cultivation e.g bean knives, with minimum soil disturbance prior to sowing the crop. Grazing is also an option at this stage. Conversely, for weeds with prolonged emergence, early sowing (Reeves 1976) and higher sowing rates can provide greater competition with weed species in some grain cropping systems.

Timing of fertiliser application can also be used to give crops a competitive advantage. Peters (1984) demonstrated this for suppression of wild oats in spring barley crops but, it is uncommon for broadleaf crops to be repressed by the addition of nitrogen (Medd 1987). This is further complicated by the fact that allelochemical activity is often greater in soils of low fertility (Spackman 1987).

(c) Decreasing the soil weed seed reservoir.

To deplete the soil reservoir, strategies which synchronise germination (McWhorter 1984, Medd 1987) break dormancy or inhibit germination (Medd 1987) are needed. Cultivation (or aeration and light) and moisture provide limited options at this stage. Some examples of allelochemicals from crop residues, stimulating weed germination have been discussed previously.

(d) Eliminating weeds in the crop.

Strategies as described in (b) above, plus the use of all the alternatives discussed previously (especially physical barriers, energy and cultivation) are important in row cropping with the degree of selectivity depending on operator skill.

Weed management as a technique does not offer a simple recipe or method for weed control. It is a complex and poorly understood option but one which has potential to significantly reduce the use of herbicides.

Conclusions

Non chemical weed control will require a planned, integrated approach using most of the above techniques. No single alternative will eliminate the range of weeds a farmer faces. At present, with the exception of the physical control methods, which are non specific, there are no alternatives to modern chemicals which are grass or broadleaf weed specific.

Weed management, utilizing an understanding of all the alternatives outlined above, plus a knowledge of the individual farm and its seasonal weed problems, could be used and based on a predicted outcome. The available information to predict outcomes and plan management strategies is limited and there is a need, indeed I would suggest a high priority need, to collate all known options into an information base for each of the major farming systems: broadacre and irrigated cropping, pasture, and row cropping as well as for public lands. These options could be tested and expanded by research workers and farmer groups.

It can be argued that one hundred percent weed control is not only unattainable it is also undesirable. Some weeds are beneficial, attracting and harbouring insect predators, and providing food for bees and butterflies e.g fathen (*Chenopodium album* L.) attracts hoverflies which eat aphids. Hence in an ecological system of farming such as organic growing there may be an acceptance of a certain level of weeds. This in turn presents the difficulty of controlling undesirable weeds and leaving the beneficial. Beneficial weeds would also need to be carefully managed to prevent excessive build up of soil seed reservoirs. A number of recent papers have discussed the need for weed management (Pratley 1987, Medd 1985) and research priorities for future weed control science (McWhorter 1984, McWhorter and Barrentine 1988).

McWhorter and Barrentine (1988) reported on the Weed Science Society of America's 1986 ballot of research priorities for weed science. The 'need to devise more efficient and less costly weed control technology for conservation - tillage crop - production systems' and to 'discover new ecological, biological and non-chemical methods of weed control' were ranked first in the USA and Canada respectively.

In a recent investigation of resource allocation for future weed control activities Combellack (1989) estimated that a no synthetic chemical option would lead to a reduction in Australian revenue of between $1.8-2.3 billion after 5 years even with a $1.5 million research program to facilitate the option. I am not suggesting an immediate change to a no herbicide option but rather the collation and use of all known viable options whilst continuing to expand our knowledge in this area.

In reality there are still many situations where herbicides are required at present and will be in the future. We can however use these herbicides more effectively by increasing application efficiency, the use of adjuvants, careful timing of applications and directing herbicides where required. At the same time this should not deter us from considering eliminating herbicide use wherever possible.

Discussion for the future will not be about the need for weed control but rather the need for alternatives to chemical weed control.

I conclude with a recent quote from McWhorter (1988) 'Each of us has a challenge during the next decade to be original and imaginative in our research programs'.

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