# SESSION 5B

## HORTICULTURAL AND MINOR ARABLE CROPS

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# THE FUTURE OF WEED CONTROL IN UK HORTICULTURE : A GROWERS VIEW

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ABSTRACT

The various factors which have led to specific weed control problems in UK horticulture are examined. Recent changes in grower practice have created novel problems for which the manufacturing industry, partly as a consequence of tighter legislation and regulatory requirements, has not provided solutions. Future trends in horticultural production, the process of pesticide registration and funding of research and development are only likely to exacerbate the problem. The horticultural industry itself is unable to compensate for the shortfall in government and manufacturer research and development into weed control. A radical reappraisal is needed of the contribution of government towards crop protection in horticulture if horticultural production in the UK is to remain competitive.

## INTRODUCTION

In horticulture, the problems of pest, weed and disease control faced by the rest of agriculture are magnified. Operating in the free market, economic constraints on growers differ from those in agriculture and often fluctuate rapidly. The outdoor horticultural area in the UK has fallen from 311,000 ha in 1970 to 204,000 ha in 1990, representing less than 4.5 per cent of land used for cropping. Horticultural crops are therefore very much minor crops as far as agrochemical manufacturers are concerned, leading to more severe problems in availability of control measures. Quality specifications for horticultural produce are particularly strict - and may vary seasonally - so that there is often less room for manoeuvre in adopting crop protection techniques. Perhaps because of this, growers have a reputation for a readiness to adopt and develop new techniques, and to exploit new technologies. This is certainly true in modern approaches to crop protection in horticulture, but there is a limit to the extent to which growers, individually or as a body, can sustain the necessary new technology alone.

In many respects, problems of weed control present a less severe constraint on horticulture than do pest and disease control. With some notable exceptions, weed problems tend not to be crop specific so that crop safety, rather than availability of an effective herbicide, becomes a limiting factor. Crop rotations are frequent, allowing cultural control to a degree not practised in present day agriculture. Herbicides in general leave fewer residues in produce than do insecticides and fungicides, so have tended to be of lesser concern to retailers and processors. Although resistance cannot be ignored, it has tended to be in pest and disease control where pesticide resistance has had its major impact on horticulture. Nevertheless, severe weed control problems do exist for horticulture, and these are likely to develop alarmingly in the future. The purpose of this paper is to examine approaches to dealing with current problems, illustrated by personal experience on a range of crops, and then to look ahead to future difficulties in weed control and how growers may prepare to tackle them.

CURRENT WEED CONTROL PROBLEMS

Weed control problems peculiar to horticulture have arisen as a result of recent changes in legislation leading to loss of approved products, changes in cultivation practice which have resulted in the development of novel control problems, development of resistance within weed species, and customer requirements particularly relevant where fresh produce is sold direct to the consumer.

Many of our most serious weed problems arise as a result of the previous crop, either through the development of volunteers or by the creation of a weed population that is difficult to control in the following crop. A major weed problem in horticulture is thus volunteer potatoes. Potatoes are often grown as part of the rotation in a horticultural enterprise due to the suitability of soils, similarity of techniques and availability of labour, as well as their profitability, especially when produced for a specialist market. Chemical control is possible (though not always effective) in crops such as many brassicas and carrots, but due to restrictions on herbicide use, problems exist in iceberg lettuce, salad onions and spring greens. Currently the problem is tackled by appropriate husbandry, especially the use of long rotations between successive potato crops, and by following potatoes with a cereal crop which is subsequently cleaned-up pre-harvest. Such an approach is only possible where horticultural crops are "extensively" grown; more intensive systems will have less room for variation in husbandry. Oilseed crops can cause carry-over problems, and indeed such crops are not grown in many rotations partly for this reason. The potential carry-over from an oilseed rape crop can be serious - the huge seed bank limits the ability to direct-drill following crops, and absence of an adequate selective herbicide restricts control to hand-roguing, costing of the order of £375 per hectare. Additionally oilseed rape carries the risk of transfer of brassica pests and diseases, so is avoided for that reason. Other minor oilseed crops - linseed and poppy for example, shed immense amounts of viable seed and have caused problems in the past, so are now often avoided altogether.

Certain weed species are encouraged in previous horticultural crops, and become problems in subsequent crops where fewer herbicide options are available. Summer brassicas encourage the build up of weeds such as charlock (*Sinapis arvensis*) and field pennycress (*Thlaspi arvense*), whilst winter brassicas create conditions for treacle mustard (*Erythemum cheiranthoides*), annual mercury (*Mercurialis annua*) and shepherds purse (*Capsella bursa-pastoris*), in subsequent crops of lettuce and calabrese where they can become a serious and uncontrolled problem. In soft fruit it has become practicable and economic to tackle such problems with methyl bromide fumigation and plastic or straw mulch.

### Weed control and cultivation practice

Direct-drilled crops, such as many brassicas, have traditionally created a build-up of perennial weeds such as common couch (*Elymus repens*). Although effective herbicides are now available, the problem of perennial weeds in

Brussels sprouts has been partially overcome by moving from direct-drilling to modular transplants, thus shortening the interval between planting and harvesting, but with a significant increase in labour costs. Seed-bed preparation may place conflicting requirements for optimum herbicide use and seedling germination and survival. Horticultural crops may be planted throughout the year, and on a readily capping soil an uneven seed-bed creates better conditions for germination and seedling establishment, but is clearly less than ideal for herbicide performance, thereby restricting the ability to gain maximum performance from residual grass weed herbicides.

Undoubtedly the most striking recent development in husbandry practice has been the widespread use of plastic film covers for early season production and to extend harvest periods (Greenfield, 1989). Many crops are produced in this way and on our own farm of 75 hectares, over 20% of the area is started under plastic, including salad onions, iceberg lettuce, spring greens, calabrese, and potatoes. Some early trial work is yielding results, but there are still very few herbicide products with label recommendations for use on crops grown under plastic sheeting. Earlier indications were that crop susceptibility to herbicides may be increased, and that residues of herbicides would remain longer in the soil. In practice, reports of damage have been fewer than expected, e.g. in onions and runner beans (Greenfield 1989). Problems of reduced efficacy have, however, been more significant. For example, lack of moisture under the film has reduced the efficacy of chlorthal-dimethyl and propachlor for salad onions. Other desirable products for example, trifluralin cannot be used to maximum effect due to the difficulties of incorporation into a wet, clay soil sufficiently early pre-planting to ensure crop safety.

Resistant weeds

The outstanding weed resistance problem in horticulture is triazine resistance by groundsel (*Senecio vulgaris*), a weed which causes problems not only because of its competitive effect, but also due to direct contamination of produce with seeds, resulting in cosmetic losses. This weed problem has been difficult to overcome, but, ironically, the withdrawal of dinoseb for spawn control in raspberries has made alternative groundsel control measures in the crop more acceptable, since spawn control by frequent mowing gives a measure of control. Mechanical weed control and plastic mulchings have also become more important in strawberries, but there is increasing reliance on methyl bromide fumigation to deal with a wide range of soil borne problems in this crop.

Customer requirements

Demands by retailers and processors have not yet had a major impact on herbicide use since the concern has mainly been with those pesticides which leave residues in food. General requirements for record keeping and for residues analysis are now a regular feature of contracts between produce marketing companies and their suppliers. The absence of any UK Maximum Residue Level (MRL) has resulted in retailers setting their own standards for, e.g. chlorpropham tecnazene, methyl bromide, and the ban on the use of maleic hydrazide by certain marketing organisations has certainly exacerbated the need for alternative means for controlling potato volunteers.

However, a more far-reaching impact is likely if the general restrictions and protocols for pesticide use already announced by the

Cooperative Wholesale Society and more recently by the Campaign for the Reduction of Pesticides (CROP) become more widely implemented. These call for a prohibition on the use of certain pesticides by suppliers, and, in the case of the CROP programme, set an arbitrary target of 50% reduction in pesticide use. Growers will face severe difficulties in crop protection if this trend increases, and at least one county council is investigating the potential for similar control over pesticide use on farms under its authority. Very often such pesticide reduction schemes are at best loosely based on scientific principles, and set reduction targets which have more to do with appealing to popular credulity than with practical reality. Herbicides 'at risk' under such schemes would be those included on the UK red list, such as the triazines, or in the 'dirty dozen', for example paraquat. In recognising and responding to public pressure to minimise the use of pesticides, and in particular to reduce residue levels in food, growers would support a rational means of pesticide reduction, based on planned integrated crop protection systems. We greatly fear the consequences if the authority of the Advisory Committee on Pesticides is undermined by well -meaning but less well-informed independent organisations.

## FUTURE TRENDS FOR WEED CONTROL

Modifications to current practice have allowed us to overcome many of the present shortcomings in weed control in horticulture, often at greater cost, and with a less satisfactory outcome. However, more serious difficulties lie ahead, as herbicide availability is certain to become more restricted as a result of both legislative and economic pressures. Growers must also respond to pressures to reduce herbicide usage, as well as adopting control measures to match future developments in husbandry practice.

### Lack of availability of herbicides

The problems of shortage of suitable herbicides for UK horticulture will increase, partly as a direct consequence of recent UK pesticide legislation, and partly due to a more general increase in the costs of development and registration of pesticides worldwide. Following the introduction of the Control of Pesticides Regulations, safety data requirements for pesticides were upgraded, and the Ministry of Agriculture, Fisheries and Food (MAFF) introduced a programme of pesticide reviews to update safety packages of older pesticides. In addition, there was a requirement for provisional approvals to be supported by full efficacy data, whilst in order to overcome the immediate loss of on-label approval for many minor crops, the off-label approval system was introduced, allowing growers to apply for registration of minor uses not already covered by the product label. Each of these has created its own problems, especially for the horticulture sector.

With the exception of the review of the sulphonylurea herbicides, the only reviews completed to date have concerned active ingredients over which there was some human safety concern, largely relating to operator safety. Herbicides affected have been the HBN herbicides and dinoseb. Restrictions on the application timing, and especially the long harvest interval for ioxynil, have seriously limited its usefulness to onion growers. Dinoseb was withdrawn completely, leading initially to problems for pea and bean growers, and still creating difficulties for hop and raspberry growers. Active ingredients are now subject to routine review. Further data requirements in support of such pesticides may be extensive, extending to further toxicity studies, and to residue and metabolism studies in a wide range of potential crops. Clearly, potential returns on investment for less widely grown crops are likely to be limited, so again horticulture will be the first victim of such reviews. Of those herbicides currently under review, simazine is of major significance to horticulture, with crop safety to ornamentals, and control of a broad spectrum of "difficult" weeds for soft fruit being key attributes. The increasing practice of multi-row cropping for top fruit production will face severe problems if such residual herbicides are withdrawn. Adequate replacements for linuron on crops such as celery would be difficult to find, either due to phytotoxicity or poor spectrum of control by alternative herbicides, and there is a similar reliance on monolinuron, also currently under review, by potato producers. Mecoprop, under review due to problems of water contamination, has important horticultural uses especially in orchards even if, as in the ADAS Integrated Fruit Production programme, this is restricted to localised applications only. Of those herbicides awaiting review in the "priority" list, diquat, paraquat, MCPA and MCPB all have significant horticultural uses. In conclusion, over the period of the review programme many horticultural herbicide uses are likely to be lost. The absence of replacements is clearly of major concern.

Of other changes to the approvals process which will affect horticulture, the 'up-grading' of provisional approvals, requiring further efficacy data, has potentially a major impact. In practice, the initial effect of this on herbicide availability has been slight. Manufacturers have responded to the call for further data so that relatively few uses have gone by default. However, the likelihood is that as resubmitted data packages are evaluated, many individual uses will be lost due to lack of manufacturer support for minor horticultural uses. To meet specific requirements, where such uses are no longer supported by manufacturers, the off-label scheme has been devised, and this is now an essential element for almost all branches of horticulture. In this case efficacy requirements are waived, and use is at the grower's risk. However as with all other registration procedures, stringent data requirements and the need for rapid initial implementation have led to queues in this system also. Table 1 indicates how the off-label system has now virtually ground to a halt, with only emergency requirements now receiving any attention.

TABLE 1. Off-label approvals granted per year, 1988-1991

| Year | Approvals issued |
|---|---|
| 1988 | 270 |
| 1989 | 208 |
| 1990 | 86 |
| 1991 (to 1 Aug) | 10 |

Herbicides form a significant proportion of the off-label queue, approximately 171 of off-labels issued are herbicides, and 98 herbicide off-label applications remain in the queue. However, as the off-label system is the only potential grower solution to the problem of herbicide availability, the pressure on this system is certain to increase in the future as the review programme and the increased efficacy requirements begin to take effect.

The prospects for new product development specifically for horticulture offer little cause for optimism. Of the handful of novel compounds receiving approval over the past two years, a high proportion has been herbicides. Cycloxydim has a useful range of horticultural (vegetable) uses, however this is very much the exception, with most new herbicides having few or no horticultural applications. Generally, manufacturers' interests both in defending existing horticultural products, or in developing new uses for horticulture, are declining due to the high development and registration costs, especially 'crop-specific' trials for efficacy and residues. Horticultural crops are of high value to the grower, but high risk to manufacturers. The declining interest in developing new horticultural uses is reflected equally abroad. The eight major crops (wheat, barley, beet, rape, maize, rye, vines and potatoes) account for 84% of German pesticide sales (Anon 1991 a.), and manufacturers are unwilling to allocate the necessary expense for the thirty other crops which account for the remaining 16% of the market. Similarly, there is alarm among horticulturalists in the United States, where a high proportion of the registrations for fruit and vegetable uses have been cancelled, again due to the cost of data generation, and a scheme akin to the off-label system has been introduced in an attempt to ensure that pesticides remain available, but this is clearly under-funded (Anon 1991 b.).

This shortfall in industry involvement in 'minor use' registration has been exacerbated by the lack of current government support for 'near-market' research. Out of a total MAFF (Pesticide Safety Division) R&D budget of £20 million, the total currently allocated to weed control in horticultural crops (largely geared towards reducing or optimising herbicide use) is under £600,000. The extent to which the growers themselves can compensate is strictly limited. At present, the Horticultural Development Council (HDC) levy of 0.38% of turnover raises some £1.8 million from about 3200 growers. Of this, some £1.2-1.4 million is available for all research contracted by HDC - currently of the 82 projects funded on outdoor crops only ten tackle problems of weed control, using some 1% of the funds available for research. Even if HDC was able to raise the levy from the full turnover of the horticultural industry (£1700 million), clearly growers themselves would be able to make little contribution towards the cost of product registration for all minor crops, and will be hard-pressed even to maintain the present level of off-label approval registrations. In short, neither manufacturers nor government are putting adequate investment into horticultural weed control, and the industry itself is unable to make up the shortfall. The solution must lie in a radical reappraisal of the potential contribution other sources, especially government, can make towards "near market" crop protection in horticulture; otherwise we face a progressive loss of the UK market to ever more competitive foreign imports.

## Future trends in horticultural practice

Technological changes in growing practice create a changing scene of horticulture, to which crop protection must adapt. Whilst Integrated Crop Protection has a major future potential for pest and disease control, the potential reduction in herbicide use, through monitoring and use of thresholds at present shows less scope in horticulture than in arable crops. To a large extent, growers' weed control programmes are based on their knowledge of individual field characteristics and associated historic problems for weed development. The cosmetic requirements for vegetable crops often result in a zero weed tolerance, even when the competitive weed effect is low. Thus, for example, contamination of iceberg lettuce with groundsel seed has to be avoided. In perennial horticultural crops, the absence of rotations reduces the flexibility for control using herbicides. Hence, for example, there is little emphasis on use of weed monitoring or use of thresholds in the ADAS Integrated Fruit Production guidelines (Cross et al., 1990) for apple and pear production, although the emphasis on localised treatments using residual herbicides such as oxadiazon and pendimethalin would lead to a reduction in their overall use. Many apple growers are, however, successfully reducing dose rates of herbicides and there is, indeed, scope for wider use in horticulture of herbicides at reduced dose rates, often in combination with adjuvants. The use of reduced dose rates is not driven purely by economic considerations, one of the chief objectives in vegetable production is to allow safe use of herbicides on sensitive crops. Reduced dose rates permit earlier treatment, especially important in direct-drilled crops where early weed control is necessary and when the full herbicide rate may check growth of the young crop. Such practice is widespread in the use of chloridazon/ chlorbufam bentazone on onions, cyanazine on brassicas, metribuzin on potatoes, and simazine and propyzamide on strawberries.

Changes in cultivation practice will create further challenges for weed control. The practice of injecting fertilizer beneath seed is likely to increase; this can create cloddy conditions and so reduce herbicide performance as well as stimulating weed-germination. In contrast, the increased frequency of using stale seed-beds, together with a continuing trend towards shallow cultivation in vegetable cropping, reduces soil disturbance and so may give greater opportunities for optimal herbicide performance. Use of clay split pills, in which seed is encased in a split coating to allow more rapid germination, is also becoming more frequent and may lead to problems of crop safety, for example in unusually wet conditions an increased susceptibility of calabrese to propachlor has been experienced.

Biotechnology will create its own problems, as well as being the source of future solutions. The availability and use of crops such as potatoes or sugar beet resistant to sulphonylurea herbicides or glyphosate may well create further problems for these already difficult volunteer weeds when followed by horticultural crops and it is unlikely that manufacturers will see commercial advantages in engineering such resistance into horticultural crops. The potential impact of biological control is also difficult to assess at this stage. Mycoherbicides have evident potential for arable crops but, facing the same registration difficulties as conventional pesticides, are unlikely to attract significant commercial interest for horticultural crops. Indeed the initial concern of the horticulturalists will be to ensure that adequate screening of novel agents takes place to ensure crop safety.

There have recently been a number of developments in mechanical cultivation aids for weed control in horticulture. All such developments require skilled operators; however the trend within the UK has been towards increased reliance on casual labour and fewer skilled contractors are found. If UK horticulture is to remain competitive, the response is likely to be a move towards increased intensification, with growers putting heavy investment into smaller areas, possibly as part of a larger, arable unit. Under such conditions rotations will be more frequent and soil sterilisation may become a more regular feature for both disease and weed control. Already methyl bromide fumigation is economic for white rot control in salad onions and in strawberry production, whilst partial sterilisation by flaming is now practised under glass. In this context, the imminent prospect of greater restrictions on fumigant use is of serious concern to horticulturalists.

The continued pressure from imports of horticultural crops is likely to create an alternative scenario of increased specialisation in production. Here, novel weed control methods will become paramount and, for example, on suitable ground wide beds with gantry systems may become feasible for brassica crops. This would permit mechanical cultivation for weed control without recourse to expensive skilled labour. One consequence of such production for the niche market, however, is the still further marginalisation of UK horticulture, rendering it yet less attractive to the pesticide manufacturer. An inevitable consequence of this is an increasing reliance on the off-label approval system, whose significance seems certain to increase.

## CONCLUSION

A serious shortfall in government and manufacturer research and development into weed control in horticulture has already taken place, for which the industry itself cannot hope to compensate. The pesticide reviews, and increased data requirements for approval will certainly exacerbate this. Growers have in the past shown ingenuity in developing their own approach to weed control problems, and must, in co-operation with manufacturers and government, find means of ensuring that the tools remain available for them to continue to exploit that ingenuity.

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# HORTICULTURAL WEED CONTROL IN THE UNITED STATES IN THE NINETIES

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## ABSTRACT

Due to pesticide reregistration requirements, producers of vegetables, fruits and amenity crops in the US are facing the possibility of significant herbicide losses during the 1990s. Coping with this, as well as with increased regulation of pesticide use for food and environmental safety reasons, will increase production difficulties, promote use of alternative weed control strategies, and likely decrease profitability. Cultivation and the use of weed thresholds are not acceptable 'alternatives' for herbicides at this time. Cultivation currently complements herbicide use, and with few exceptions, weeds at any level can cause unacceptable reductions in quality. Alternatives to current weed control strategies that are being considered include: post-emergence, as-needed applications of selective herbicides; banding herbicide applications; use of newer, low-dose herbicides; living and dead mulches to suppress weeds and prevent pesticide runoff; and increased planting densities.

## INTRODUCTION

Herbicides have become the predominant method of controlling weeds in agricultural production systems in the United States, accounting for more than 50% of all pesticide sales. However, changes in weed control methods are expected in the 1990s as herbicide registrations are being cancelled faster than new compounds become available. Additionally, concern about potential pesticide residues in fruits and vegetables may force processors to restrict pesticide use by their suppliers. Concurrent with concern for the safety of the food supply, increased testing of ground water in agricultural areas has revealed detectable levels of several herbicides, making further usage restrictions likely.

The pesticide regulatory system in the US is multi-layered and complex, with the Environmental Protection Agency being at the top, administered by Congress. Federal pesticide registrations are controlled by this body. However, each state has a pesticide regulatory body as well, housed either in a state department of agriculture or an environmental protection office. These state offices can make changes in pesticide registrations that are more strict than, but not more lenient than the federal laws, and many (e.g., California, New York) do so. Additionally, a recent Supreme Court ruling will allow local government to enact legislation controlling pesticide use. This means that there are marked differences in pesticide usage in the 50 states. This, coupled with the tremendous edaphic and climatic differences across the US, makes generalizations about horticultural weed control trends in the 1990s difficult, if not impossible, within the framework of this paper. Keeping in mind the size and complexity of US horticulture and the plethora of pesticide regulation possibilities, it is our objective to present, on a commodity basis, subjective assessments of current grower awareness of the need for and/or willingness to adopt alternative, non-herbicidal or reduced input strategies for weed control, as well as the direction in which these strategies are expected to go.

VEGETABLE CROPS

Today, a general statement about growers' awareness of potential regulatory problems may be that the level of concern is directly proportional to the degree of local regulation and/or impending loss of an important herbicide. Growers in states having little state-directed pesticide involvement had fewer concerns, whereas the opposite was true in states where local regulatory efforts were common. These state regulatory efforts appear to be driven largely by concerns with groundwater contamination.

Concerns for pesticide residues in produce occur primarily in states where vegetables are grown mainly for processing, not for fresh market. This difference is explained by the fact that consumers, when allowed to choose between pesticide-treated and non-treated produce in the supermarkets, overwhelmingly select treated produce due to its lower price and greater visual appeal. In this case, risk is self-assumed. When the product is in a can or frozen, the right to choose the risk is removed and consumers are likely to avoid products rumoured to contain pesticide residues. Consequently, US processors have begun to dictate which herbicides they will allow as well as quantities and application times. Their goals are for zero pesticide residues in the finished products. This control exhibited by the processors has only begun to have an impact on production. It is expected to continue and increase.

The emphasis on pesticide reduction, particularly herbicides in vegetables concerns researchers, extension personnel and growers alike. Efforts to reduce herbicide rates have been going on for many years. Akobundu et al., (1975) recommended a significant reduction in atrazine rates to facilitate crop rotation for small, multiple-crop vegetable producers. Lower-than-labelled rates (0.14-0.28 kg. a.i. ha) of metribuzin applied post-emergence in potatoes and tomatoes have long been used in many states, and work has recently been completed extending these low doses to carrots in New York (Wallace and Bellinder, 1991). Herbicide registrations for vegetables usually occur as extensions of registrations on related field crops. However, vegetables exhibit less tolerance and considerable research is required to arrive at appropriate lower dosages. These lower dosages are often much closer to the efficacy window, and further dose-reduction could result in loss of efficacy.

Dependent upon the degree of awareness or the impending threat of herbicide loss, vegetable growers are differentially responsive to alternative weed control options. Using fewer herbicides or lesser quantities and accepting weed thresholds has been suggested as a way to reduce herbicide use. Acceptance of thresholds is nil across the country because even when it can be shown that there are no direct yield losses, weeds in any quantity are thought to cause non-uniform maturation (important in both hand- and machine-harvested crops), decrease quality, increase mechanical harvesting losses, and increase costs (i.e. penalties at the factory). In only three situations are weeds allowable: 1. where weeds emerge shortly before blossoming in short-season crops (e.g., green peas, snap beans); 2. where they emerge early in crops where post-emergence herbicides are registered (sethoxydim, metribuzin); and 3. where weeds emerge late in the cropping season and will not form viable seeds.

Reducing herbicide use,in most crops, has as its corollary increasing mechanical control via cultivation. In vegetable production, cultivation, except where no-tillage systems are used, is common practice, particularly for fresh market vegetables, where the number of available herbicides is small. In many cases, herbicides are reducing or suppressing weed populations and total control is achieved only by supplementing with cultivation and handweeding. With a desire for zero weeds and cultivation already being practised, most growers do not feel that a 'return to cultivation' will suffice in the event that important herbicides are lost.

It is only recently that post-emergence, highly selective graminicides have been registered for use in most vegetables. Growers are beginning to adjust to their uses. Carefully managed, these herbicides could supplant the older, soil-applied residual grass herbicides. The newer ones are more environmentally 'soft', can be used in low doses, and can be applied on an as-needed basis. The post-emergence, as-needed approach to broadleaved weed control is more difficult, as selectivity is usually quite narrow. The use of multiple low-rate (0.14-0.28 kg a.i. ha) applications of metribuzin has come close to replacing the 0.86-1.1 kg a.i. ha rates of trifluralin in tomatoes in New York. It is, however, apparent that while this as-needed approach will reduce the chemical load on the environment, it will require increased management skills.

When the low-dose sulfonylurea and imidazolinone herbicides, both acetolactate synthase (ALS) inhibitors, are registered in sweet corn, beans, peas and potatoes, there will be a shift away from many of the older herbicides that are applied in higher doses. While this shift to lower-dose, more environmentally safe compounds will reduce the environmental impact, it also increases the likelihood of herbicide resistance (LeBaron, 1990). Currently, vegetable growers across the US are having only minor problems with herbicide resistance, largely by triazine-resistant species. However, resistance problems are expected to increase in the next ten years.

Reduced tillage systems have been recommended for soil conservation, water conservation, and/or wind protection in various parts of the US since the 1930s. Within the last ten years it has been reported that with some crop residues, particularly grain rye, early-season weed suppression is significant (Barnes and Putnam, 1983; Bellinder et. al., 1991; Wallace and Bellinder, 1990; Weston, 1990; Weston, et. al., 1991). Consequently, interest in utilizing this four to six week period to reduce herbicide input is increasing. However, reduced tillage systems require experience and increased management to be successful.

Growers who produce both vegetables and field crops and participate in government subsidy programs for the latter, are now required to keep the soil covered for three out of four years. This is equivalent to growing a row crop one year in four. By moving to no-till systems growers can continue to produce row crops in all four years. This has occurred on large areas of processing snap beans, peas and sweet corn in Wisconsin (Dr. L. Binning, personal communication). No-till vegetable production may increase during the 1990s, but it is expected to occur first with smaller, fresh market growers, 'niche' market growers, and growers of crops having few labelled herbicides, e.g., cucurbits.

In summary, although today's vegetable growers in the US, taken as a group, are more concerned about the impact of the free trade agreements with Canada and particularly, Mexico, the loss of critical herbicides (dinoseb, chlorpropham, chloramben) has attracted their attention. American farmers in general and especially vegetable growers, are strongly independent and have difficulty forming groups. They are now, however, becoming more pro-active, even political, in commodity, state, and national associations. Their impact on agricultural and public policy will increase in the 1990s.

## SMALL FRUITS

Currently, small fruit growers, in general, show little concern for issues involving pesticide residues in either groundwater or fruit. On a per hectare basis, pesticide usage is small. Growers do not view themselves as large users of chemicals, but are particularly vocal when pesticides are lost. Raspberries and strawberries are especially vulnerable to the loss of registered herbicides because of their extremely high value per hectare, and low numbers of planted hectares. As an example, there are only two pre-emergence herbicides presently labelled for use in strawberries throughout the US. Due to the small number of pesticides registered for use on small fruit crops, growers are usually willing to try alternatives, on a small scale, but only if the alternative is simple to implement. When alternatives are complex or require a higher level of management, willingness decreases. Growers are using the following approaches to control weeds with a minimum of herbicide inputs.

1. Pre-plant Weed Control. Growers are putting more effort into site preparation because the choice of post-plant treatments is limited and not always effective. In addition to assessing nutrient levels and biological factors affecting replanting, growers are using glyphosate, and occasionally fumigation, to eliminate weeds and reduce viable weed seeds prior to planting. Researchers are evaluating pre-plant cover crops that will aid in weed reduction and pest exclusion, since soil fumigants are also being reduced because of environmental concerns. Certain crops, such as marigold (*Calendula arvensis*) and sudangrass (*Sorghum sudanense*), show promise in reducing weeds and nematode-related causes of replant problems in perennial crops.

2. Cultivation. Growers are well aware of the problems caused by soil compaction and cultivation. They avoid driving tractors through their fields; many apply pesticides through irrigation systems. To grow perennial berry crops, cultivation would be required in early spring and fall when soils tend to be wet, and subject to compaction. Additionally, all of the berry crops have extremely shallow root systems that are easily damaged with regular cultivation. Strawberries (runners) and raspberries (suckers) reproduce in such a way that cultivation in, or close to, the plant rows is impossible.

3. Post-emergence herbicides in the planted row. Growers are giving more consideration to managing weeds with timely applications of post-emergence herbicides rather than using pre-emergence materials to prevent weed establishment. Researchers are developing thresholds so that growers will know when to treat weeds before detrimental competition occurs. This

strategy lessens concerns about soil residues and leaching, and is more compatible with the IPM approach or use on an as-needed basis. However, grower acceptance of weed thresholds is minimal, largely for aesthetic and marketing reasons. Many small fruits, particularly strawberries, are marketed as pick-your-own and weedy fields are unacceptable to the public.

4. Choice of planting system. In most fruit crops there is a move toward planting smaller plants at higher densities. Although there are many factors influencing this trend, one consequence is a reduction in herbicide use. Many perennial strawberry growers are planting at high densities in narrow rows. With this system, not only are yields higher, but weed control costs are reduced because fewer weeds establish within the rows. Also, since plant numbers are determined at planting, fields can be heavily mulched immediately after planting, further contributing to weed control. Strawberries in annual production systems (California, Florida, North Carolina, and day-neutral producers) are grown at high densities in plastic-mulched beds. Fumigation is commonly used with this production system.

5. Use of mulches. Mulches have been used for hundreds of years to control weeds and conserve moisture in fruit crops. However, mulches can interfere with the availability of nitrogen, so excess or deficient levels can occur within a season, resulting in winter injury, low yields, or poor fruit quality. With the advent of herbicides and drip irrigation, reliance on mulches decreased.

Growers are showing a renewed interest in the use of mulches for weed control as a better understanding of fruit crop nutrition management and mulch technology is developing. In some western states, the cost of water has been subsidized so that growers practised minimal weed control and compensated with increased nitrogen and irrigation. With the prolonged drought in that region, growers are again considering mulches for weed control and moisture conservation. Blueberry and strawberry growers rely on mulch for much of their weed control needs. Recent research at Cornell has found that newly planted, micropropagated, primocane-fruiting raspberries are injured by herbicides and cultivation, but cane production increased dramatically in response to mulches in the planting year.

By establishing a sod cover, killing it, then planting through the residue, growers have found that weeds can be controlled for a period of time after planting. Ryegrass (Lolium sp.), with its allelopathic tendencies, is often the sod of choice in this situation. When growing perennial crops on raised beds, the killed sod also helps improve the integrity of the bed. Growers have significantly reduced the total amount of herbicide applied per unit area by establishing permanent cover crops in alleys between rows and chemically treating only the planting strip. The permanent cover crops are specifically selected to form a dense stand that will exclude weeds, yet not grow into the planted row and compete with the crop. Mixtures of fine-leaved fescues and dwarf perennial rye grasses (Festuca sp., Lolium perenne) are commonly used. Sod alleys also reduce off-site surface run-off of pesticides. 'Living' mulch cover crops that have low vigour and are less competitive for water and nitrogen are being investigated. In some fruit production systems, cultivation is used to control weeds early in the season, then seasonal cover crops are seeded later to displace germinating weeds. This allows the grower to better control nitrogen and moisture availability. In strawberries, this strategy is showing some promise, especially when seeding occurs after renovation and cover crop growth is regulated with low rates of selective, post-emergence herbicides.

In summary, with the additional losses of herbicides, the cost of producing fruit will continue to increase. In many cases, this increase will be passed along to consumers. With raspberries and strawberries, the cost is already so high than many cannot afford to purchase them. Although these crops will continue to be grown, the market may soon be limited to expensive restaurants and wealthy consumers who can afford to pay the price that will be required to grow these fruits.

## TREE FRUITS

Until the present century, orchard weed control or ground cover management was a low priority for growers. Grazing livestock provided the mower and the fertilizer under the tall trees of bygone eras. Modern growers cannot afford the losses in fruit production caused by livestock grazing or weeds competing with trees for light, water and nutrients. Routine weed control has become an essential part of good horticultural management.

Research and extension staff in the northeastern US and elsewhere have worked for several decades to get growers to abandon older production systems involving clean cultivation or totally grass-sodded orchard floors, and to maintain weed-free strips in the tree row. Currently, fruit growers rely on tillage and/or herbicides to suppress ground cover vegetation within the tree row, while sodgrass alleys are maintained to facilitate orchard access and minimize soil compaction and erosion. This management system has proved to be the most economical, efficient, and productive weed-control system under current production conditions. Thus, both growers and extension researchers are reluctant to move into alternative systems, many of which are actually traditional methods from the pre-herbicide era. However, following the recent public alarm about daminozide (Alar) and dithiocarbamate (EBDC) fungicide residues on apples, there is concern in the industry that increasing regulatory and environmental pressures will force the adoption of non-herbicidal weed control methods. Therefore, there is significant interest in both research and production sectors that such alternative systems be evaluated now, in preparation for that eventuality.

Pesticide inputs per hectare of apple orchard in the Northeast (estimated at 85 kg/ha/yr) are among the highest of any food crop. The stringent edaphic and climatic requirements of tree fruits have caused concentrations of production on hilly, coarse-textured soils near large bodies of water, making runoff and leaching of orchard pesticides and/or fertilizers particularly problematic. Until fairly recently, fruit growers in the northeastern US have not been especially concerned about potential groundwater contamination. However, it is now evident that the widespread use of agrochemicals has increased this risk, prompting public concern and making future regulatory strictures likely (Logan, 1987). Research and extension efforts, and the widespread adoption of IPM tactics, have substantially reduced the amount of agrochemicals applied in orchards. Additionally, close attention to sprayer technology and application methods has minimized off-site aerial drift. Despite this, there is continued demand on the part of both growers and funding agencies for information about the potential for minimizing agrochemical contamination through the proper selection and timing of orchard weed control practices.

Many growers in irrigated, arid regions of the country continue to utilize cultivation as part of their year-round orchard weed control programmes. Often this involves turning under winter-grown or early spring cover crops that contribute significantly to soil organic matter residues. In fruit-growing regions that typically have significant rainfall during the growing and harvest seasons, there are several problems with mechanical weed control. Cultivation increases soil erosion and compaction, reduces access to the orchard during periods of rain and mud, and injures shallow roots of the crops. The increasing proportion of high-density fruit plantings on dwarfing rootstocks has also made cultivation a less satisfactory weed control practice.

There is extensive literature documenting the benefits of vegetative groundcovers for conserving and improving the structural integrity and fertility of topsoil (Russell, 1973; Hogue and Neilsen, 1987). These benefits must be weighed against the known detriments of weed competition. The critical importance of sustaining long-term soil fertility can not be overlooked indefinitely in preference for short-term gains in crop production. This constitutes an argument in favour of orchard weed thresholds that would allow the retention of acceptable amounts of surface vegetation in order to protect the soil surface from weathering, compaction and erosion.

Among the more promising alternative strategies for orchard weed control, one involves the integration of and rotations among different orchard floor management systems in order to exploit fully the benefits of each. For example, pre-emergence herbicides could be used during the critical first three years in orchard establishment. This would be followed by low-vigour, minimally competitive sodgrass species such as fine-leaf fescues, seeded to restore the soil surface aggregates, improve water infiltration and retention, and minimize soil compaction during early fruit production and the development of mature tree structure. Another alternative strategy involves partial suppression for regulation of weed growth with low rates of herbicides (e.g., glyphosate) or growth regulators (e.g., maleic hydrazide). Such tactics might allow precise and timely reduction of weed competition during critical periods such as flower initiation, fruit set or sizing, while maintaining enough ground cover to promote good soil physical conditions.

Also, a number of mulching materials are being evaluated for weed control. Durable, affordable synthetic mulches or "landscape fabrics" are being compared with herbicides and traditional organic mulches in US Department of Agriculture Low Input Sustainable Agriculture trials in New York's Hudson River Valley. The increased emphasis on recycling rather than landfill disposal of industrial and community wastes may substantially reduce the costs of organic mulch materials such as wood chips and recycled fibres. Finally, a number of non-traditional grasses and herbaceous ground covers that may be minimally competitive for soil nutrients and water, resistant or suppressive to soilborne pests such as nematodes, or attractive to beneficial predatory insects are being studied in several programs around the US.

This increased emphasis on integrating weed control strategies more fully into overall pest management programs appears likely to continue in the future. However, high crop values and costs of orchard establishment, consumer insistence upon larger, blemish-free fruit, and the broad spectrum of weeds, insects and diseases which affect fruit trees, are all likely to require growers to continue applying substantial quantities of fertilizers, herbicides and other pesticides.

## TURFGRASS AND NURSERY INDUSTRIES

In the United States, there are an estimated 1.7 million ha of commercially maintained turfgrass (Roberts and Roberts, 1990; personal communication, National Golf Foundation) receiving an estimated 170,000 metric tonnes of herbicide active ingredients annually. As these treatments are in highly populated areas, the turfgrass and landscape industries are on the "front line" of legislative restrictions and public pressure to reduce or eliminate the use of synthetic pesticides. The turfgrass and landscape industries are very concerned and are attempting to negotiate with federal and state authorities to develop helpful and workable guidelines for urban pesticide utilization.

Government regulations which are now affecting herbicide use include posting, right-to-know, ground water protection, surface run-off management, and inconsistent local ordinances. In urban areas, a sign displaying the product(s) used and the date of application, must be posted at all entrances to the property before treatment and removed 24 hours after treatment. In some states, prior notification of landowners and tenants, including full disclosure of the toxicological data, are required before pesticide applications to the landscape. To protect ground and surface water and to eliminate the possibility of off-target pesticide movement, some nurseries and golf courses have installed systems to capture all runoff water. The water is then used for irrigation and the net result is a recirculating system that must be monitored for build-up of fertilizer salts and pesticides, particularly herbicides. A recent US Supreme Court Ruling which will allow local governments to enact and enforce pesticide-use ordinances will increase the number of regulations and is expected to dramatically affect the pest management programmes of the lawn, landscape, and golf course maintenance industries in the 1990s.

Integrated Pest Management (IPM) is at the core of how growers and turfgrass managers hope to decrease the environmental loads and non-target effects of pesticides. Through the implementation of IPM programs, turfgrass and nursery professionals are hoping to reduce pesticide inputs. While scouting, the use of thresholds, and biological control strategies have been successfully utilized for insect and disease management, such concepts have not been applied to weed management. As was the case in your pick own strawberries, the nursery, landscape, and turfgrass industries are based on the aesthetic appeal of the commodity. The presence of just a few weeds detracts from this appeal. Therefore, the threshold for weeds is generally approaching zero.

Some changes are under-way. Research has shown that vegetative strips between nursery crop rows do not interfere with crop growth (Neal and Senesac, 1990; Warren and Skroch, 1987). Consequently, innovative nurserymen who once maintained 100% bare ground in their fields are now maintaining permanent sod between rows of nursery crops and planting winter annual cover crops, such as oats or rye, to further prevent erosion. They rely on residual herbicides to maintain weed-free crop rows. While supplemental cultivation is an accepted practice, shortages of trained labour and cost necessitate that cultivation be minimized.

The use of newer, lower-dose herbicides could significantly reduce the environmental load of herbicides. For example, as little as 0.28 kg a.i. ha of isoxaben can be as effective as 0.8 kg a.i. ha (the manufacturer's suggested rate) or simazine at 1.6 kg a.i. ha for broadleaved weed control in nursery stock (Neal and Senesac, 1990). Several older herbicides, have been lost due to reregistration expenses, with minimal impact on the nursery and turfgrass industries. However, 2,4-D and simazine, the most widely used herbicides in turf and nurseries, respectively, are in danger of being lost due to toxicological and/or environmental concerns. Alternatives are available in most states but the costs will be considerably higher.

While there are currently no biological control agents for turfgrass or nursery weeds, significant research is under-way in this area. A.K. Watson et al. have investigated several promising pathogens, including isolates of Sclerotinia spp., for broadleaved weed control in turf (Ciotola, et al. 1991). Mycogen Corp. is developing an isolate of Xanthomonas campestris for selective control of Poa annua (Savage, 1991). Other researchers are investigating possible biological control agents for spurge (Euphorbia spp.)., nutsedge (Cyperus spp.) and other weeds. The acceptance of non-chemical approaches to disease and insect suppression has been phenomenal. We would expect a similarly enthusiastic response to effective non-chemical approaches to weed control.

In summary, the single most important factor expected to influence weed management practices in turfgrass and nursery crops in the 1990s is public policy. The legislative issues which will affect pest management practices in nurseries and turf areas include ground and surface water protection, right-to-know legislation, and inconsistent local ordinances. Additionally, the loss of older, broad-spectrum herbicides due to reregistration expences or public (and political) pressure could impact several segments of this industry. Nursery, landscape and turfgrass management professionals are very concerned about these issues and are supporting research, educational programs, and legislation to address these concerns.

## CONCLUSIONS

The 1988 amendments to the Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA) require that all pesticides registered before 1984 be reregistered, i.e., go through new testing, by 1997. It is expected that many herbicide uses for horticultural crops will be lost during this period. US horticultural producers will be affected more by the loss of herbicides through reregistration costs and/or increased costs for developing toxicology packages for new compounds than by environmental concerns. Unlike many western European countries, where significant efforts to reduce herbicide use in field crops have been in process for several years, these discussions have only just begun in the US.

Due to the expected decrease in herbicides for horticultural crops, research into alternative methods of weed control is on-going across the country. Funding for research comes from numerous sources, often in small amounts. The Interregional Project 4 (IR-4) is a federally funded group with a mandate to facilitate pesticide registrations for minor crops. Prior to the 1988 FIFRA amendments, IR-4 was modestly successful in procuring herbicide registrations. Following the amendments, despite additional federal funding, the agency is swamped and is not expected to be able to save many of the endangered herbicide uses for minor crops. There is additional federal funding for 'sustainable agriculture', but the research needs far exceed the budgeted funds. There is considerable controversy within the granting agencies as to what constitutes sustainability. Across the country, grower and industry groups are being created (many have been active for years) and there is an awareness that old funding sources have disappeared. These groups will become major sources of funds in the future.

Despite the expected loss of important weed control tools, we can say with confidence, that American horticultural producers are alive and well, and becoming increasingly adept at dealing with regulatory adversity.

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# CROP LOSSES DUE TO WEEDS IN FIELD VEGETABLES, AND THE IMPLICATIONS FOR REDUCED LEVELS OF WEED CONTROL

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## ABSTRACT

The effects of weed interference on the yield of vegetable crops in field trials made over a 20 year period are described. The results demonstrate that, despite the impression that marketable yield increases as weed density decreases, on many occasions even low weed populations cause considerable crop losses. If sparse weed stands can compete as effectively as dense ones in certain situations, it is very difficult to define an economic level of weed control. In addition to affecting yield, weeds may spoil the appearance of the crop making it less acceptable to processors and consumers. Harvesting can be hindered and any weed seed returned to the soil will increase subsequent weed populations. Whatever form weed management takes in the future it is vital that a high level of weed control is maintained. If the term reduced inputs becomes synonymous with reduced weed control then growers will find it difficult to produce high quality vegetables consistently.

## INTRODUCTION

Before the introduction of herbicides, weeds were considered to be a major problem in vegetable growing. Salter (1972) stressed that weed control was the key to efficient systems of vegetable production based on optimum plant densities and row spacings. The success of herbicides in controlling weeds is reflected in the many changes made possible in crop production. However, there is now increasing pressure to reduce pesticide use and it seems timely to re-examine the extent of crop losses that can result from weed interference and consider the implications of reduced levels of weed control.

The effect of weed competition on the growth of field vegetables has been examined using a variety of methods (Zimdahl, 1980). Often investigations only continue for two to three years and although they provide useful information, such studies alone do not allow robust generalisations to be made on crop losses due to weeds. Different crops have different growth habits, with some better able to withstand weed competition than others. Weed species differ in their morphology and growth rate therefore the composition of the weed flora will influence the level of competition. Nutrient status of the soil, time of year, prevailing weather conditions as well as other factors are likely to affect the extent of crop losses due to weeds. To establish if a general relationship exists between weed growth and reductions in the yield of particular crops the results need to be compared from weedy and weed free plots over several years, with consequent variations in sowing time, weed populations, weather conditions and crop growth as well as other factors.

Herbicide evaluation and competition trials with field grown vegetables and natural weed populations have been made for many years at HRI - Wellesbourne. The experiments often included unweeded and hand-weeded control plots to allow crop losses due to herbicide injury or weeding treatment to be assessed. In this paper the results from such plots have been used to compare the response of different crops to weed interference and, based on the yield reduction that occurred, to determine the consequences of reduced levels of weed control.

## MATERIALS AND METHODS

The experiments were made on fields at HRI - Wellesbourne during the period 1971 to 1990. The soils were sandy loams or sandy clay loams with approximately 2% organic matter and pH between 6 and 7. The land was ploughed in autumn or late winter and allowed to weather before being power harrowed to produce a seedbed shortly before drilling. Fertilizer was applied at rates appropriate for the individual crops. The weed-free plots were hoed or hand-weeded at frequent intervals to prevent weed competition. Weed seedlings on the unweeded plots were counted and identified on whole plots or in a number of random quadrats per plot and/or the weed fresh weight at harvest was recorded. There were 3 to 5 replicate plots of each treatment. The crops were harvested, apart from any guard rows, and the yield of the unweeded plots expressed as a percentage reduction from that of the hand-weeded control.

### Lettuce

Lettuce was drilled in four rows 30 cm apart and thinned to a spacing of 30 cm in the row. Hearted lettuce (marketable) were cut and weighed during a three to four week period and after the final harvest the remaining unhearted plants (unmarketable) were cut and weighed.

### Carrot

Carrot was drilled in four rows 30 cm apart with around 40 plants per metre of row. At harvest the number and weight of carrots from the centre two rows was recorded. The carrots were not graded and the marketable yields are based on the total weight of roots.

### Summer cabbage

Cabbage was drilled in three or four rows 45 cm apart and thinned to 45 cm apart in the row. Cabbage were cut as they matured (marketable) over a three to four week period. After this time any remaining unhearted plants (unmarketable) were recorded.

### Runner bean

Runner bean was hand-sown in three rows 45 cm apart with 45 cm between stations. The runners were pinched out when about 45 cm long and plants formed small bushes that did not require support. Mature pods (marketable) were harvested at weekly intervals over a three or four week period. At the final harvest the remaining haulm was cut at ground level and weighed following pod removal.

### Dwarf bean

Dwarf bean was drilled in three rows 45 cm apart. A single harvest was made when pods had filled out. Pod yield (marketable) and haulm weight were recorded from the centre row.

Broad bean

Broad bean was hand-sown in three rows 45 cm apart with 15 cm between plants within the row. At harvest the weight of mature pods (marketable) and the weight of haulm from the centre row were recorded.

## RESULTS AND DISCUSSION

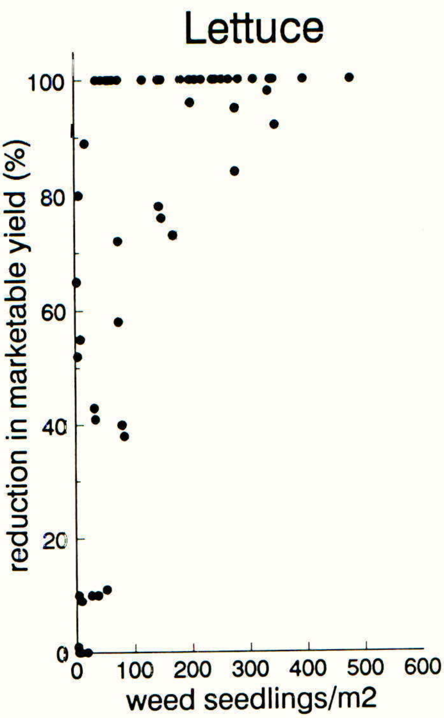
The reduction in marketable yield of each of the different crops as a function of weed density is shown in Figures 1 and 2. No attempt has been made to fit lines to the data. The points by themselves serve to illustrate the extent to which weed density can influence crop yield. The results also demonstrate the variation in response within crops to similar weed densities.

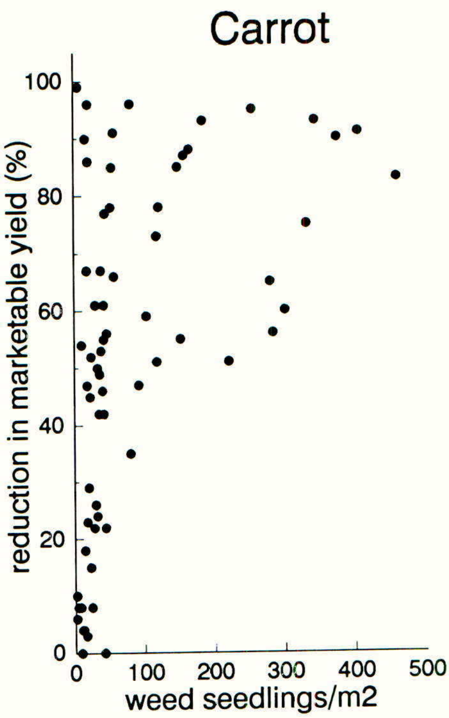
Lettuce, carrot and cabbage invariably suffered severe loss of yield at weed densities greater than 100 weeds/m$^2$ (Figure 1). However, with lower weed numbers there was considerable variation in crop response and similar weed densities caused both minimal and severe reductions in marketable yield. Comparable variations in response occurred at low and high weed densities with runner and dwarf beans (Figure 2). Among the crops studied, only broad bean appeared able to tolerate low weed densities without occasionally suffering severe yield loss (Figure 2).

Less data were available to illustrate the effect of weed fresh weight at harvest on marketable yield and only the results for cabbage, carrot and runner bean are presented (Figure 3). There was considerable variation in the response of cabbage and carrot to weed fresh weight. Similar weed weights on different occasions caused both large and small reductions in crop yield. In runner bean the data were somewhat scattered but yield loss appeared to be more closely related to weed fresh weight than to weed density.

The results demonstrate that a small or reduced weed population is no guarantee of a lack of competition with the crop and sparse weed stands can cause a similar loss of marketable yield as much denser ones. The results agree with those of Shadbolt & Holm (1956) who found that a reduction in weed number to as low as 15% of the original population still inflicted serious damage to vegetable crops. A few robust weeds can have a severe effect on yield. Hewson (1971) reported that fat-hen (*Chenopodium album*) at densities of 2.3 and 4.6/m$^2$ reduced the yield of drilled lettuce by 55 and 89% respectively. It is therefore difficult with vegetable crops to set an economic level of weed control in the same way as has been done for cereals unless perhaps a single weed species can be identified as being solely responsible for the yield loss (Lawson & Wiseman, 1978). Rather than accepting a lower standard of control, in vegetable crops it is necessary to develop crop and weed management systems that make optimum use of weed control inputs.

There are several techniques available to manipulate weed and crop growth in favour of the crop. Stale seedbeds can be used to kill the main flush of weed seedlings before drilling or planting takes place. The effectiveness and reliability of this technique can be improved by encouraging prompt weed emergence; the presence of adequate soil moisture is an important factor in preventing undue delays in seedling emergence (Bond & Baker, 1990). Studies to enhance weed seedling emergence in the period between seedbed preparation and weed destruction prior to drilling are continuing at HRI - Wellesbourne.



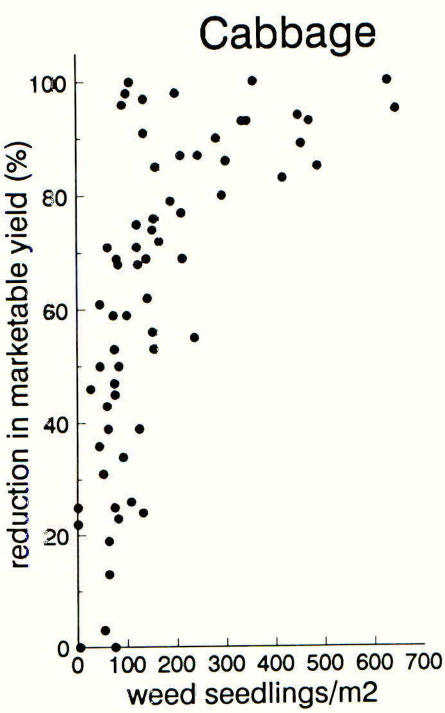
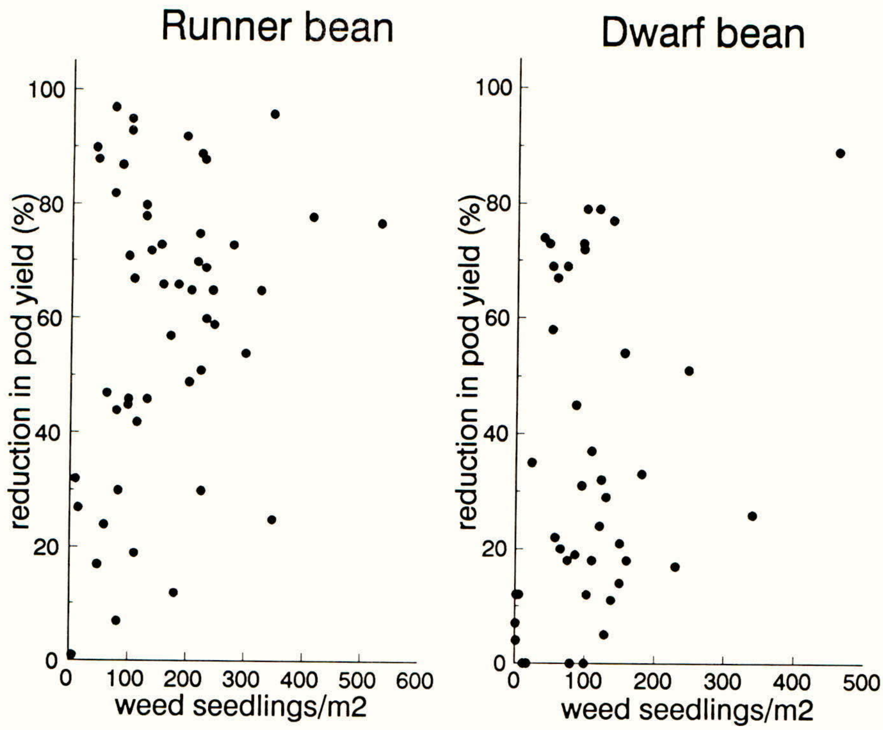




FIGURE 1. Reduction (%) in marketable yield of lettuce, carrot and cabbage plotted against weed density.



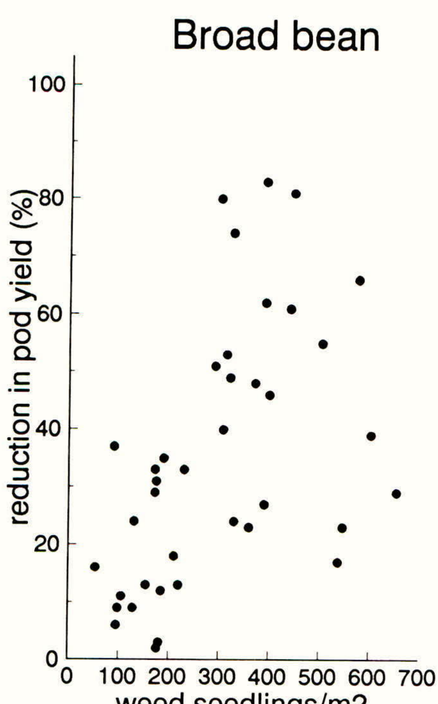




FIGURE 2. Reduction (%) in marketable pod yield of runner, dwarf and broad bean plotted against weed density.

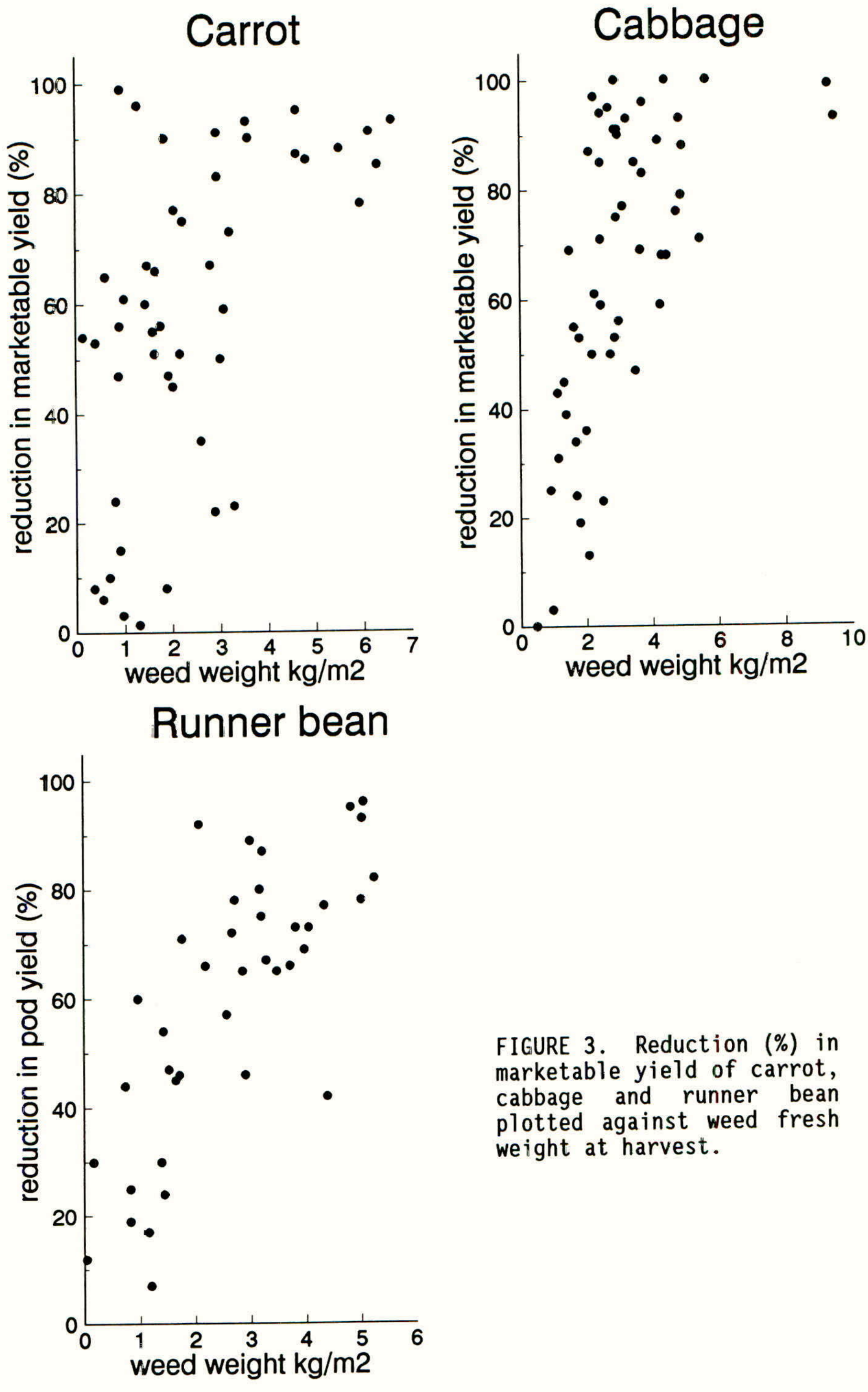



FIGURE 3. Reduction (%) in marketable yield of carrot, cabbage and runner bean plotted against weed fresh weight at harvest.

Raising transplants in modules gives the crop an immense advantage over the weeds if establishment can be achieved without a check to crop growth. In drilled crops the use of primed or pre-germinated seed and starter fertilisers also gives the crops an advantage over the weeds. Crop plant spacing can be used to influence the balance of competitiveness in favour of the crop but this approach may be limited by the specifications of the desired crop product and by the need to facilitate cultural weed control.

Although weeds that are present from crop emergence through until harvest can affect final yield, workers have shown that vegetable crops do not need to be weed free for the whole of that time to prevent losses occurring (Roberts, 1976). Early weed growth does not generally affect crop yield if the crop is subsequently kept weed free, and similarly, as weed emergence declines and the crop becomes more competitive, weeds allowed to develop later do not reduce yield. Studies have identified the necessary weed free period for several vegetable crops but the time interval may vary with season, weed population etc. Physical removal of weeds at the optimum time may also prove difficult. Studies are currently being made at Wellesbourne to assess the consistency of optimum weeding periods in crops grown at different times of the year and on different sites.

While yield is the main consideration, other factors are also important. Poor appearance will reduces the value of a crop whether due to weed seed shedding on to hearted lettuce, or berries and seed heads contaminating crops for processing. Late-emerging weeds may not affect yield but harvesting can be hindered. Spring-germinating knotgrass (*Polygonum aviculare*) will make mechanical harvesting of overwintered onions difficult as well as affecting bulb ripening, while small nettle (*Urtica urens*) can make hand harvesting of any crop very painful. Weeds remaining in the crop until harvest may return large numbers of fresh seeds to the soil and thereby increase the weed seed bank from which future weed populations will be recruited.

It is inevitable that herbicide use in the future will decrease as a result of environmental and public pressure. For commercial reasons too, it may be uneconomic to maintain production and approvals of some herbicides solely for use in horticulture. As with any other change in crop management the effects of reducing herbicide inputs will take some time to manifest themselves fully. In the short term, problems will obviously be encountered in those production systems that depend upon weed-free conditions. In the longer term we may find that weed populations increase, possibly in favour of late-germinating or ephemeral species. Research already in progress to improve established non-chemical weed control methods and develop novel techniques, will need to be consolidated if the industry is to succeed in reducing herbicide inputs while maintaining high standards of weed control.

## CONCLUSIONS

The results from field experiments over many years demonstrate that good weed control, whether chemical, cultural or a mixture of the two, is essential if a consistent supply of high quality vegetables is to be maintained. It is important that reduced inputs do not lead to reduced weed control otherwise methods of vegetable production that were devised on the basis of weed-free crops may have to be revised.

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# COVER PLANTS IN FIELD GROWN VEGETABLES: PROSPECTS AND LIMITATIONS

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## ABSTRACT

Integrated production aims predominantly at reducing pesticide application, such as regulating weeds with non-chemical methods. One such method for weed control in field grown vegetables is the deliberate use of cover plants (living mulch). The effect of inter-row plant cover in increasing habitat diversity has also been extensively studied by applied entomologists in order to reduce pest numbers. Advantages of using cover plants and their ideal attributes are discussed from the point of view of a weed scientist, an entomologist and a soil scientist. An ongoing project in field-planted leek (*Allium porrum*) is briefly described. Cultural control methods such as the use of cover plants constitute complex ecological experiments demanding an interdisciplinary approach. Detailed cost/benefit analysis involving both economic and ecological aspects are also needed to offer realistic suggestions to farmers.

## INTRODUCTION

Cultural control includes some of the oldest control practices known for weed and pest control, such as crop rotation, choice of crop, manipulation of the sowing date or mixed cropping (Coaker, 1987). The concept of integrated pest management has generated renewed interest in cultural control methods and these have been extended to include ecosystem management. Ecologically-based direct payments to farmers using environmentally compatible culture methods are presently at a final stage of discussion in Switzerland. Such govermental subsidies are thought to encourage farmers to produce more ecologically.

The production of field vegetables is, compared with other crops, a highly pesticide-intensive system. Integrated production aims predominantly at reducing pesticide application, such as regulating weeds with non-chemical methods (Ammon et al., 1986). One such cultural method for weed control in field grown vegetables is the deliberate use of cover plants (living mulch). The use of interrow plant cover, however, has also received much attention by applied entomologists aiming at reducing pest numbers (reviews by Coaker, 1987, 1988; Altieri, 1988). Finally, when using cover plants it has to be taken into account, that they will also influence soil structure and the nutritional status of the crop . In this paper, we discuss conditions that have to be met for the use of cover plants and briefly describe an experiment that has been set up to evaluate its potential application in field-planted leek.

WHY COVER PLANTS ?

Cover plants in field vegetables may decrease weed infestations, insect pest pressure, soil erosion and soil compaction, while enhancing organic matter, water infiltration, and water and nutrient retention (see Wiles et al., 1989, and references therein) (Table 1). Altogether, this may result in reduced fertilizer and pesticide requirements.

TABLE 1. Advantages of intercrop diversity

1) potential to reduce weed infestations
2) soil cover prevention of erosion, mud or other structural damage of the soil
3) prevention of washing out of nitrates, especially during autumn and winter
4) effects on pests and pathogens of the crop
   - reduced host recognition by specialists
   - repellant effect
   - attractant effect (catch crops)
   - enemy hypothesis (leading to higher populations of antagonists)
     - increased food resources for adults (pollen, nectar)
     - alternative hosts for antagonists
     - soil cover as hiding-place for predatory beetles

Effects of polycultures (cover plants, multicropping, living mulch, trap crops) as a tool in integrated pest management has been extensively evaluated by entomologists (Coaker, 1987). It is long known that plants growing at high densities and low diversity are more susceptible to insect infestations when compared to plants growing in complex natural communities (Pimentel 1961a, 1961b). The influence of diversity on crop pest control was discussed extensively by Cromartie (1986). In this context, Coaker (1987) suggested the following strategies for reducing insect pests, on which cultural practices can be based : " a) to make the crop or habitat unacceptable to pests by interfering with their oviposition preferences, host-plant discrimination or location for both adults and larvae; b) to make the crop unavailable to the pest in space and time by utilizing knowledge of its life history, especially of migration and overwintering patterns; c) to reduce survival on the crop by enhancing natural enemies or by altering crop suitability." Hence, when weed scientists select a cover plant species for a given crop species, items a) and c) should be considered.

WHEN TO SOW THE COVER PLANTS? THE CONCEPT OF THE PERIOD THRESHOLD

It is quite evident that by competing for nutrients, water and light, weeds affect vegetables adversely (Bond, 1991). Farmers know that this can vary greatly and easily result in a 100% loss, depending mainly on the crop species, the weed species present and the growing conditions of the crop. Two particularly relevant questions in this context are: a) for how long can weeds be allowed to remain before irreversible effects on final yield do occur? b) for how long must the crop be kept clean in order that weeds establishing afterwards shall not affect yield (Roberts, 1976)? To answer these, experiments have to be carried out with contrasting crops in which weeds are allowed to remain for different times, while other plots have to be kept clean for different initial periods before weeds are allowed to establish (Dawson, 1986).

Such experiments have been carried out at the Swiss Federal Research Institute at Wädenswil during the last 10 years for the following crops: carrot (Nantaise), scorzonera, cauliflower, fennel (Potter, unpublished results), dwarf bean (Potter 1990) and red beet (Potter, 1991a). As a rule of thumb, it could be concluded that weed control can be restricted to the first half of the vegetation period, while weeds can be tolerated later without yield losses or formation of viable weed seeds (Potter, 1991b). This does not apply for crops with an open canopy such as leek and onion, or for cutting vegetables such as lettuce, chives, parsley or spinach. Although weeds may be tolerated at the very beginning of the growing season without negatively affecting crop yield (Hewson & Roberts, 1973a, b; Hewson et al. 1973; Roberts, 1976), we recommend keeping the crop weed-free during the first half of the vegetation period. Weed control can then be done at the optimal time with regard to weed and crop development, either mechanically or by low dosage of herbicides. Pre-emergence herbicides may have to be applied in crops with a long emergence period, while post- emergence herbicides (if available) or mechanical control can be used at the appropriate developmental stage.

In most living mulch systems, competition is also often identified as the most important mechanism of interference. Attempts to reduce competition in these systems have focused on mechanical or chemical suppression of mulch growth (see below), screening for less competitive mulches, and variation of mulch planting dates (see below) (Wiles et al. and references therein). The time period during which weeds negatively affect crop yield and the amount of yield reduction was generally found to be only slightly affected by weed density within the range of 150-850/m$^2$ (Roberts, 1976). Together with the results of our period-threshold experiments, we suggest that cover plants should generally be seeded in order that they emerge only at the beginning of the second half of the vegetation period. Mechanical or chemical weed control can therefore be restricted to the first half of the vegetation period. If this is met, crop yield should not be reduced (Potter, 1991b).

## WHICH SPECIES TO USE AS COVER PLANTS?

Taking the above-mentioned considerations into account, an ideal cover plant should have the attributes listed in Table 2. The type of cover plant will vary among crop species depending mainly on its competitive ability, height, density and associated pest species.

TABLE 2. Attributes of an ideal cover plant

1) to suppress weeds without stressing the crop
   - quick emergence
   - fast soil coverage
   - short height
2) to lower insect pest pressure on the crop
   - plants interfering (attracting, repelling) with the crop pests
   - plants favouring antagonists of the crop pests
      - pollen and nectar for adult parasitoids or predators
      - alternative host for parasitoids and predator
      - cover for predatory beetles
3) to favour nitrogen availability in the soil for the crop
   - species with low nitrogen demands
   - leguminous plants with nitrogen-fixing bacteria

Up to now, we have used clover and grass species - singly or in various mixtures - in asparagus, savoy cabbage (Potter, unpublished results) and sweet corn (Potter & Niggli, 1989). By considering the critical time period for weed (cover plant)-crop interaction, no adverse effects were found on yield. Several weed species such as gallant soldier (*Galinsoga ciliata*) or *Amaranthus* species, which are especially vigorous and can grow through the established undersown vegetation, may cause serious problems, as they can no longer be removed mechanically.

We therefore tested various herbicides to find chemicals that do not harm the specific crop-cover plant combinations. For leek undersown with a clover/grass mixture, we found that ioxynil or MCPB were quite efficient against broad leaved weeds and had no adverse effect on the crop or cover plant, when used in split application.

## WHICH CROP SPECIES ARE SUITED FOR UNDERSOWING?

Field vegetables are often relatively sensitive to competition during early development. Undersowing is best suited in perennial crops (berries, rhubarb) or planted annual field crops with a relatively long vegetation period (leek, onion, cabbage), especially autumn and winter crops with no subsequent culture, so that the vegetation can be left until spring. At the present time, a series of experiments in field-planted leek and cabbage, using various compositions and densities of cover plants, is being carried out at our Institute.

## EXPERIMENTS WITH FIELD PLANTED LEEK

An interdisciplinary approach has been chosen to evaluate the impact of cover plants in field planted leek. The field experiments were initiated in early spring (planting date: May, 29) and lasted until mid-September (date of harvest). The strategy involves:

a) a field experiment to determine the time period for weed-crop competition, during which weeds (cover plants) do not cause economic losses,

b) a field experiment to evaluate the impact of the seeding date of the cover plant on the yield of leek, its insect pests and pathogens, and soil quality. Standard cultural practices such as planting density and fertilizer application were varied to be adapted by using cover crops. A clover (*Trifoliom repens* var. Tahora)/grass (*Lolium perenne* var. Elka) mixture was used as cover vegetation and seeded at three different sowing dates

c) Laboratory experiments planned to study effects of plant compounds on oviposition behaviour of the leek moth (*Acrolepia assectella*) (specialist) and *Thrips tabaci* (generalist). Selected compounds will then later be tested either as constituents of the companion plants or sprayed on the cover plants.

In a similar experiment with winter leek, Matthäus & Jampen (1991) found greatly reduced nitrogen levels in the plots undersown with ryegrass (*L. perenne* ) two months after planting, when the grass was sown at the time of planting. Subsequent fertilizer application could not prevent significant yield losses in spring. Our experiments, however, indicate a significant negative correlation between the length of the time period during which grass was present and the infestation level by thrips, i.e. plants in cover plant-free plots showed the highest attack rates by thrips. The behaviour of the leek moth, on the other hand, seems to be indifferent to the presence of grass (B. Hurni, personal communication).

## DISCUSSION

Present knowledge suggests that the mulch seeding date seems to be most important in determining final crop yield. Follow-up studies will show how the cover plants will affect nitrogen retention during winter. A complication from using cover plants will arise from interference with mechanical harvesting. Our experiments with leek, however, showed that interference will be minimal, if cover plants are only used in the second half of the vegetation period. This will also prevent the cover plants from seeding. In a further step, a detailed cost /benefit analysis of intercropping will have to be worked out in order to offer realistic suggestions to farmers. Both economic (crop yield, pesticide and fertilizer) and ecological aspects (long term benefits) will have to be taken into account.

To conclude, cultural control methods such as the use of cover plants constitute complex ecological experiments. It is needless to say, therefore, that the study of effects of cover plants on crop yield urgently needs an interdisciplinary approach, including vegetable agronomists, weed scientists, entomologists, plant pathologists and soil scientists.

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# THE UTILIZATION OF NITROGEN FERTILIZER SOLUTIONS FOR SELECTIVE WEED CONTROL IN CRUCIFER CROPS

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## ABSTRACT

Field experiments were conducted on broccoli, cauliflower and cabbage over 4 years to evaluate crop selectivity and weed efficacy. Nitrogen fertilizer formulations were liquid ammonium nitrate (20-0-0) and ammonium thiosulphate (12-0-0-24). Directed spray applications of undiluted fertilizer solutions at 495 to 858 litres/ha were applied to direct-sown crucifers at the 2 - 4 true leaf stage of growth. The nitrogen solutions killed or suppressed several broadleaf species which are resistant to soil applied herbicides. Effective control was obtained on Capsella bursa-pastoris, Senecio vulgaris, Solanum sarrachoides, Urtica urens and Malva parviflora. Several critical factors for crucifer selectivity are discussed.

## INTRODUCTION

Crucifers are a major vegetable crop with approximately 61,000 ha grown in California, of which two-thirds are direct sown, and the remaining transplanted (Anon., 1990). Although weeds in the transplanted crop are more easily controlled with pre-emergence herbicides and mechanical means, the direct sown plantings lack effective weed control measures. Several weeds which have assumed increasing concern in recent years due to their tolerance to chlorthal-dimethyl and trifluralin (Anon., 1989) are Senecio vulgaris, Malva parviflora and Capsella bursa-pastoris. Weed interference with seedling development, and cost of hand weeding and the lack of new herbicides have stimulated alternative control measures. Experiments have been conducted at the Extension field station and growers' fields in the Salinas Valley (Agamalian, 1988) to evaluate treatments in broccoli and cauliflower for effective post emergence weed control. In this report the possible use of nitrogen solutions and the factors for crop selectivity are considered.

## METHOD AND MATERIALS

The experiments were of randomized complete block design with four replications. The plot size for the initial experiments was 30 $m^2$. Experiments established in grower fields were 0.25 ha in area with three replications. The two formulations of nitrogen fertilizers evaluated were ammonium nitrate (20-0-0) and ammonium thiosulphate (12-0-0-24) (Hawkes, et al., 1985). Initial experiments compared topical applications (spray solution applied over the entire plant), and directed sprays. The undiluted broadcast rates used in these experiments were 495 and 858 l/ha. Directed applications were made using low pressure nozzles (8002 LP) which afforded minimal leaf exposure and allowed for a 12 and 15 cm band on either side of the crop plant. All control treatments received a sidedress application at the 4 to 5 leaf stage of growth. Weeds were removed from the control treatments 10 - 14 days following the nitrogen spray applications. Subsequent weeding was conducted to remove escaped weeds from all treatments. Crop weed competition was maintained up to the 6th leaf stage of the broccoli and cauliflower.

One experiment was established with 7 broccoli varieties to evaluate varietal responses to ammonium nitrate with the two methods of application. Data was obtained on percentage stand, plant dry weight and harvested spears.

The effects on weeds were assessed by visual scoring for weed kill on 1 metre$^2$ quadrats in each replication. Percentage weed control was determined from the unsprayed control population. Weed evaluation from grower experiments as determined by visual scoring on a scale of 0 (no effect) to 100 (complete kill). Two additional experiments were conducted to compare environmental influences on crop selectivity with ammonium nitrate. Field tests were conducted in a winter period of temperatures of 2° - 12° C, and a summer period 5 - 23° C low-high range. Evaluations of plant population and seedling dry weights were used to assess temperature influence on broccoli tolerance.

The influence of predisposing factors such as plant protection chemicals was evaluated by applying a wetting agent (X-77) followed by ammonium nitrate treatments. Intervals of 24, 48 and 72 hours were used to establish the effect on broccoli tolerance of subsequent nitrogen applications.

## RESULTS

### Effect on weed control

Weed evaluations are summarized (TABLE 1), indicating that effective weed control was obtained on several difficult-to-control broadleaved plants with existing pre-emergence herbicides. In this summary of 13 experiments, weeds were indigenous to the respective sites. Effective control of Senecio vulgaris, Solanum sarrachoides, Malva parviflora, Capsella bursa was consistent. The results demonstrated two critical factors which influenced percentage control. These are the size of the weed and apparent cuticular (waxy) barriers to the ammonium nitrate.

Weed size greatly influenced control at the rates of nitrogen solution used in these experiments. Once weeds were greater than the 5 leaf stage, susceptibility decreased. Often, the older weeds would show evidence of severe necrosis, but would recover from the nitrogen sprays. Weed suppression was obtained, but not absolute kill, when compared with weeds of 1 - 4 leaves.

Specific weeds tolerant to these levels of ammonium nitrate sprays included Portulaca oleracea, Chenopodium murales, and Chenopodium album. These weeds appear to have the ability to shed the spray solutions in the same way as the crucifer crops. Grassy weeds, limited to Poa annua and Echinochloa crus-galli, were quite tolerant of the nitrogen solutions. Although leaf necrosis was evident, these weeds were able to survive. The susceptibility of Sonchus oleracea appears to be size-related. Consistent control was only evident in the cotyledon leaf stage and once true leaves were developed, control was severely reduced.

### Effects on the crucifer crop

Tests compared broccoli and cauliflower tolerance (TABLE 2) to directed sprays and topical applications. In this experiment the undiluted ammonium nitrate was applied at 495 and 858 l/ha. Cauliflower was more sensitive than broccoli. Cauliflower yields were significantly reduced with the topical application when compared with the directed spray.

Seven broccoli varieties were evaluated to determine their tolerance to ammonium nitrate applied as a directed or topical spray (TABLE 3). The ammonium nitrate treatments were compared with a hand weeded control. Stands of cv. Futura were significantly reduced by both direct and topical sprays. Plant dry weights 14 days after topical treatments showed significant differences except for cv. Green Duke. Cvs. Excalibur, Futura, Premium Crop and Shogun showed reduced plant weights with the directed spray. This may result from lower crop leaf desiccation. Following ammonium nitrate application spear weights of all varieties except cv. Green Duke were significantly lower at harvest in the topical spray treatments.

Crop-environment

Environmental influence on crucifer tolerance to liquid ammonium nitrate is not completely understood. A summary of four experiments shows the seasonal effect on crop selectivity (TABLE 4). Broccoli tolerance was significantly reduced when ammonium nitrate was applied as a directed spray during January and February. During this period, maximum temperatures ranged from 12° C to lows of 2° C. Crop injury symptoms were bleaching of the treated leaves and stand mortality. In midsummer experiments conducted in the Salinas Valley, with maximum daytime temperatures of 23° C and lows of 5° C, crop tolerance of broccoli was greatly improved. Leaf symptoms of marginal burning were sometimes evident, but crop stand was not affected.

Another factor influencing crop selectivity is the preceding pesticide application. Using a wetting agent at various intervals before ammonium nitrate application reduced broccoli tolerance (TABLE 5). Ammonium nitrate treatment within 24 hours of applying a wetting agent solution resulted in a 69% loss in dry weight. Treatment 48 hours after a wetting agent application reduced broccoli dry weight by 48%. Delaying the ammonium nitrate spray for 72 hours gave results similar to those in control plots (no wetting agent). For optimum selectivity, a 72-hour interval should thus be allowed between applications of insecticides or fungicides and the nitrogen fertilizer solution. The wetting agent in these sprays apparently alters the crop's leaf surface so that the differential wetting selectivity is reduced.

DISCUSSION

The effect of ammonium nitrate spray solution on crucifer crops is related to several factors, including the number and size of the leaves, the plant height, variety, absence of dew on the leaves, and application method. Other factors that appear to be related to selectivity, but are not documented, include the level of waxiness of the leaf and the stress condition of the crucifer plant at the time of application.

Susceptibility of broadleaved weeds is related to species and size. Several weeds with waxy leaf surfaces tolerated liquid ammonium nitrate at a rate of 495 litres/ha in these tests. Chenopodium murales, Chenopodium album, Portulaca oleracea and Sonchus oleracea were resistant. The optimum size for control of susceptible weeds is one to three leaves. Once weeds such as Capsella bursa-pastoris reach a six-to-eight leaf stage, leaf burning is evident but regrowth will occur. Grassy weeds such as Poa annua are not affected by the ammonium nitrate solution.

Changing from sidedressing nitrogen fertilization to directed spray banding of undiluted 20% ammonium nitrate at 495 l/ha per acre resulted in significant weed control in these tests. The conventional sidedress applications afford no weed control benefits. This application is shanked into the soil with no contact to the weeds other than the physical disruption by the shank. The application of surface banded nitrogen has altered the grower's fertilization management system. Standard preplant fertilizer applications of 12-12-12 have been reduced to compensate for the early post emergence applications. Broccoli and cauliflower growth responses to the method of application indicate excellent root uptake from this practice. Subsequent sidedressing is used at the mid-growth cycle to provide the required nitrogen for maximum yields. This procedure reduces the leaching potential of soil applied nitrogen. Surface banding of nitrogen solutions may be subject to volatilization, but under temperate climates this is less of a concern. Under irrigated agricultual practices the leaching potential of surface banding nitrogen is controlled by the amount of water applied.

The utilization of nitrogen banding for weed control in crucifer crops has led to an integrated system using limited pre-emergence herbicides and mechanical methods.

Although the fertilizer is not registered as a herbicide, its weed control characteristics, in addition to its fertilization value, have resulted in cost savings.

TABLE 1. Summary of weed susceptibility to liquid ammonum nitrate at two stages of growth in 13 field experiments.

| Weeds | Percentage Control* 1 to 4 leaf | 5 to 7 leaf |
|---|---|---|
| Poa annua L. | 0 | 0 |
| Echinochloa crus-galli (L) | 0 | 0 |
| Brassica nigra (1.) Koch | 92 | 47 |
| Urtica urens L. | 95 | 65 |
| Stellaria media (L) Vill. | 97 | 51 |
| Senecio vulgaris L. | 98 | 68 |
| Solanum sarrachoides Sendt. | 96 | 72 |
| Chenopodium album L. | 0 | 0 |
| Malva parviflora L. | 99 | 77 |
| Sisymbrium irio L. | 95 | 54 |
| Chenopodium murales L. | 0 | 0 |
| Matricaria matricarioides (Less) | 98 | 62 |
| Portulaca oleracea L. | 0 | 0 |
| Amaranthus retroflexus L. | 96 | 58 |
| Capsella bursa-pastoris (L.) | 95 | 41 |
| Sonchus oleraceus L. | 32 | 0 |

*Determined from weed counts per 60 $cm^2$

TABLE 2. Broccoli and cauliflower yield response comparing two methods of spray application with 20% ammonium nitrate.

| | | Broccoli | | | Cauliflower | | |
|---|---|---|---|---|---|---|---|
| Treatment | l/ha | % harvest | Mean Yield kg/30 m of row | Mean Spear wt g | % harvest | Mean Yield kg/30 m of row | Mean Head wt g |
| Control | 0 | 82 a+ | 33.3 a | 136 a | 94 a | 58 a | 790 a |
| AN-20 directed | 495 | 92 b | 40.0 b | 186 b | 96 a | 60 a | 817 a |
| AN-20 directed | 858 | 95 b | 45.0 c | 178 b | 94 a | 57 a | 835 a |
| AN-20 topical | 495 | 90 b | 45.0 c | 172 b | 85 b | 47 b | 804 a |
| AN-20 topical | 858 | 96 b | 46.4 c | 181 b | 82 b | 41 b | 685 b |

TABLE 3. The response of hybrid broccoli varieties to foliar applied liquid ammonium nitrate.

| Method of Application | Emperor | Excalibur | Futura | Green Duke | Green Valient | Premium Crop | Shogun |
|---|---|---|---|---|---|---|---|
| | | | | % Stand* | | | |
| Control | 98 a+ | 96 a | 99 a | 99 a | 98 a | 98 a | 97 a |
| Directed | 98 a | 99 a | 91 b | 93 a | 97 a | 98 a | 99 a |
| Topical | 96 a | 98 a | 89 b | 91 a | 96 a | 96 a | 98 a |
| | | | | Dried weight g per plant# | | | |
| Control | 21.1 a | 39.3 a | 27.7 a | 19.7 a | 26.4 a | 29.9 a | 25.0 a |
| Directed | 21.3 a | 31.9 b | 24.3 b | 20.7 a | 25.4 a | 24.1 b | 20.0 b |
| Topical | 15.2 b | 26.8 c | 20.6 c | 91.2 a | 20.4 b | 23.1 b | 18.4 b |
| | | | | Mean spear weight (g) | | | |
| Control | 132 a | 136 a | 128 a | 125 a | 133 a | 130 a | 133 a |
| Directed | 128 a | 131 a | 104 b | 123 a | 128 a | 126 a | 128 a |
| Topical | 118 b | 121 b | 86 c | 121 a | 113 b | 118 b | 120 b |

* Based on stand evaluations made before and after ammonium nitrate sprays and weeding

\# Plants sampled 14 days after treatment

\+ Values followed by the same letter are not significantly different at the 5% level by Duncan's multiple range test.

TABLE 4. Seasonal influence on the selectivity of broccoli cv. Futura to 20% ammonium nitrate spray.

| Treatment | l/ha | January - February Dried wt. g* | Stand/ 10 $m^2$ | July - August Dried wt. g | Stand/ 10 $m^2$ |
|---|---|---|---|---|---|
| Control | 0 | 36 a+ | 111 a | 45 a | 122 a |
| AN-20 | 495 | 22 b | 81 b | 40 a | 116 a |
| AN-20 | 858 | 15 c | 65 c | 35 b | 109 a |

TABLE 5. Tolerance of broccoli to ammonium nitrate applied to the leaves at specific times after treatment with a wetting agent.

| Wetting Agent++ | Delay** Hours | Avg. dry wt./plant g | Phytotoxicity % |
|---|---|---|---|
| None | | 44 a | 16 a |
| X-77 | 72 | 40 a | 15 a |
| X-77 | 48 | 23 b | 58 b |
| X-77 | 24 | 14 c | 92 c |

*Crop evaluations taken 14 days after treatment

**Delay between wetting agent and ammonium nitrate application. Both applied at broccoli two-to-three-leaf stage. (Ammonium nitrate applied at 495 l/ha.)

+Values followed by the same letter are not significantly different at the 5% level, Duncan's multiple range test.

++Applied at 0.5% v/v.

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# GLUFOSINATE-AMMONIUM - A NEW TOTAL HERBICIDE FOR USE IN ORCHARDS.

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## ABSTRACT

Glufosinate-ammonium is a new total contact herbicide, highly suitable for use in orchards. In a series of trials carried out in Eastern England, good control of annual and perennial grass and broad-leaved weeds was obtained with the product used alone. Although not translocated, sequential applications gave long-term control of some perennial weeds comparable to that achieved with glyphosate. Good results were also achieved when glufosinate-ammonium was tank-mixed with residual herbicides.

## INTRODUCTION

Glufosinate-ammonium is a new total herbicide and desiccant. (Hewson & Black, 1991; Read & Hewson, 1991).

It was developed by Hoechst AG under the code number Hoe 39866 (Schwerdtle et al., 1981). Glufosinate-ammonium blocks the activity of an enzyme, glutamine synthetase, in higher plants and this leads to a build-up of ammonia which kills plant cells (Wild & Manderscheid, 1983).

It is a contact herbicide with no residual action and breaks down rapidly in the soil to carbon dioxide, methane, ammonia and phosphate (Goetz et al., 1983).

In this paper results are presented on the control of a range of annual and perennial weed species in trials in orchards.

## MATERIALS AND METHODS

All trials were carried out in commercial top fruit orchards in Eastern England. Trial design had to be flexible in order to fit into the varied constraints of individual sites, but in general the trials were fully randomised incorporating three or four replicates. Plot size was either 10 or 15 $m^2$. Plots were spaced in the strips between trees. Applications were made using a Van der Weij 'AZO' precision plot sprayer at a pressure of 250 kPa and a water volume of 400 l/ha. Initial applications were made in early to mid-May when weeds were up to 30 cm high/across. In a number of the trials two applications were made 6-8 weeks apart.

The following products were used either alone or in mixtures at the rate given below:-

glufosinate-ammonium (Challenge 150 and 200 g AI/l Soluble concentrate) at 5 l/ha
paraquat (Gramoxone 200 g AI/l Soluble concentrate) at 5 l/ha

simazine + paraquat (Terraklene 400 g AI/l + 100 g AI/l Soluble concentrate) at 9 l/ha
simazine (Gesatop 50% w/w WP) at 5 l/ha
diuron (Hoechst Diuron 80% w/w WP) at 4.5 kg/ha
diuron + aminotriazole (Hoechst Orchard Herbicide 48% + 40% w/w WP) at 11.3 kg/ha
MCPA (Hoechst MCPA 500 g AI/l Soluble concentrate) at 4 l/ha
glyphosate (Roundup 360 g AI/l Soluble concentrate) at 5 l/ha

## RESULTS

Results are presented as means for the major weed species from the trials over a number of seasons (TABLE 1). In addition, results from sequential applications in orchards in two seasons on a range of perennial species are given in TABLES 2 and 3.

Finally, data on the control of a range of annual and perennial species with glufosinate-ammonium tank-mixed with residual herbicides is given in TABLE 4.

Overall, glufosinate-ammonium gave excellent control of a range of perennial species when assessed after 2-3 weeks. It was clearly more effective on a number of species such as _Plantago_ spp, _Convolvulus arvensis_, _Urtica dioica_ and _Rumex_ spp than paraquat or glyphosate (TABLE 1).

By 6-9 weeks the effect of paraquat on many species was reduced except on _Elymus repens_. Glyphosate was, in general, more effective at this assessment than at the earlier one.

Results from sequential applications (TABLES 2 and 3) where treatments were applied approximately 8 weeks apart, show that two applications of glufosinate-ammonium can give very effective and long-lasting control, particularly in comparison to paraquat.

An alternative to sequential applications is to tank-mix glufosinate-ammonium with residual herbicides such as diuron or simazine. From the results given in TABLE 4 it is clear that these are effective mixtures giving excellent weed control for a period of 8-12 weeks, comparable to the standards.

## DISCUSSION

Glufosinate-ammonium has been shown to be an effective and relatively quick-acting contact herbicide for total weed control in orchards. In comparison to paraquat products, although initially slower acting, glufosinate-ammonium has shown a broader spectrum of activity and a longer control period, particularly on perennial species. It has also been shown to give faster initial control than glyphosate, although effects on perennial species are generally not as long-lasting. Similar results in orchards from other European countries were reported by Langeluddeke _et al_., (1982 and 1985). He also reported on the good crop safety of the product in and around fruit trees. Glufosinate-ammonium is not taken up through lignified bark even if this is accidentally sprayed. It is taken

TABLE 1. Perennial weed control in top fruit.

| Weed | % Weed Control (Weeks after application) Glufosinate-ammonium (2-3) | (6-9) | Paraquat (2-3) | (6-9) | Glyphosate* (2-3) | (6-9) | Untreated % Weed cover (2-3) | (6-9) | No of trials |
|---|---|---|---|---|---|---|---|---|---|
| *Elymus repens* | 91 | 86 | 87 | 80 | 82 | 98 | 48 | 53 | 7 |
| *Urtica dioica* | 84 | 91 | 57 | 30 | 37 | 79 | 39 | 47 | 2 |
| *Sonchus* spp | 95 | 90 | 89 | 74 | 83 | 95 | 32 | 52 | 3 |
| *Rumex* spp | 90 | 85 | 67 | 35 | 74 | 94 | 46 | 60 | 2 |
| Range of dicots | 94 | 93 | 72 | 53 | 75 | 96 | 21 | 27 | 5 |
| Mean of all species | 92 | 90 | 78 | 63 | 75 | 95 | 37 | 36 | 19 |

Range of dicots - *Plantago* spp, *Sonchus* spp, *Epilobium angustifolium* *Convolvulus arvensis*, *Picris echiodes*

* Note rate of glyphosate was 6 l/ha product in fifteen of the above trials

up through leaves and green stems but its effect is localised to those parts directly contacted with spray, so no serious damage to the tree will occur if an occasional leaf is sprayed (Bahat, 1985).

TABLE 2. Perennial weed control in top fruit - sequential application

| Weed | Trial No. | % Weed cover: Glufosinate-ammonium | Paraquat | Glyphosate | Untreated (% weed cover) |
|---|---|---|---|---|---|
| **2-4 Weeks after 2nd Application** | | | | | |
| Urtica dioica | 01 | 92 | 30 | 68 | (87) |
| Elymus repens | 02 | 95 | 93 | 88 | (87) |
| Elymus repens | 03 | 98 | 98 | 92 | (80) |
| Rumex spp | 04 | 92 | 72 | 93 | (67) |
| Convolvulus arvensis | 04 | 93 | 72 | 65 | (13) |
| Mean | | 94 | 73 | 81 | (67) |
| **6-7 Weeks after 2nd Application** | | | | | |
| Urtica dioica | 01 | 86 | 30 | 75 | (90) |
| Elymus repens | 02 | 88 | 98 | 85 | (94) |
| Elymus repens | 03 | 95 | 97 | 88 | (100) |
| Rumex spp | 04 | 85 | 55 | 88 | (55) |
| Convolvulus arvensis | 04 | 75 | 40 | 30 | (50) |
| Mean | | 86 | 64 | 73 | (78) |

Glufosinate-ammonium has also proved suitable for tank-mixing in these situations with a range of residual herbicides, including diuron and simazine. Weller (1984) and Langeluddeke et al., (1985) have also presented results on successful tank-mixtures with residual herbicides.

Results of trials in non-crop and industrial situations are not reported in this paper. However, it is clear that glufosinate-ammonium is a very effective product for controlling the species found in such situations which are often similar to those found in orchards.

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TABLE 3. Perennial weed control in top fruit - sequential applications

| Weed | Trial No. | % Weed cover: Glufosinate-ammonium | % Weed cover: Paraquat | % Weed cover: Glyphosate | Untreated (% Weed cover) |
|---|---|---|---|---|---|
| **3 Weeks after 2nd Application** | | | | | |
| *Urtica dioica* | 01 | 95 | 48 | 72 | (100) |
| *Sonchus* spp | 02 | 99 | 96 | 96 | (71) |
| *Rumex* spp | 03 | 97 | 45 | 75 | (80) |
| *Convolvulus arvensis* | 04 | 95 | 0 | 70 | (25) |
| Mean | | 97 | 47 | 78 | (69) |
| **6-8 Weeks after 2nd Application** | | | | | |
| *Urtica dioica* | 01 | 95 | 37 | 82 | (100) |
| *Sonchus* spp | 02 | 97 | 90 | 95 | (75) |
| *Rumex* spp | 03 | 95 | 70 | 78 | (80) |
| *Convolvulus arvensis* | 04 | 95 | 0 | 27 | (40) |
| Mean | | 96 | 49 | 71 | (61) |
| **9-11 Weeks after 2nd Application** | | | | | |
| *Urtica dioica* | 01 | 88 | 40 | 73 | (100) |
| *Sonchus* spp | 02 | 98 | 90 | 93 | (75) |
| Mean | | 93 | 65 | 83 | (88) |

TABLE 4. Weed control in orchards with tank mixtures of glufosinate-ammonium with residual products. (Mean of six trials).

| | % Control (Weeks after application) | | Total % Cover of plots at end of trial |
|---|---|---|---|
| | (4-6 ) | (8-12) | (12) |
| Untreated | | | 99 |
| Glufosinate-ammonium + simazine + MCPA | 95 | 80 | 67 |
| Glufosinate-ammonium + diuron | 93 | 79 | 63 |
| Glufosinate-ammonium + simazine | 89 | 84 | 64 |
| Simazine + paraquat | 71 | 59 | 69 |
| Glyphosate + simazine | 79 | 86 | 41 |
| Glyphosate | 88 | 86 | 43 |
| Diuron + aminotriazole | 93 | 88 | 40 |

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