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SOME EFFECTS OF GRASS WEED CONTROL ON THE ARTHROPOD FAUNA OF CEREALS

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Summary In both 1973 and 1974 two 5 ha parts of a field of winter barley were sprayed either with mecoprop or a mixture of metoxuron and simazine. The elimination of Poa trivialis in the second treatment resulted in a significant reduction in the numbers of 16 of the 49 arthropod taxa considered; the largest difference was in the numbers of Staphylinidae (Tachyporus spp.). Cereal aphids were the only arthropods which were significantly more abundant in the metoxuron and simazine plots and it is possible that some of this difference could be attributed to reduced predation in these plots.

The elimination of P. trivialis reduced the biomass of insects useful to partridges by 43%. On a large scale this effect would further reduce the survival of their chicks.

INTRODUCTION

There is little evidence about long term changes in the weed populations of cereal crops, although it is now generally accepted that grass weeds such as Avena fatua, Alopecurus myosuroides, Agropyron repens, Agrostis gigantea and Poa trivialis have increased in abundance (Attwood, 1970; Fryer and Chancellor, 1970). New herbicides are being introduced to deal with these problems and the acreage of cereals treated is escalating rapidly (see Potts and Vickerman, 1974a). The ecological repercussions of this are unknown.

There is little information available on the long term side effects of herbicide usage in cereal crops on arthropods, apart from the work of Davis (1965). There have also been few studies on the short term effects, direct or indirect. Some direct effects on insects have been demonstrated, for example by Adams (1960). Changes in the soil fauna following the application of herbicides have been reported by Fox (1964) and Curry (1970) and mainly attributed to indirect effects. The indirect effects of dicotyledonous weed removal on the fauna of various crops have been reported by Southwood and Cross (1969), Smith (1969), Dempster (1969) and reviewed by van Emden (1965, 1970).

The present work is a preliminary report on the indirect effects of monocotyledon (grass weed) removal on the insect fauna of cereals and forms part of a continuing and larger study on the ecology of farmland by the Game Conservancy Partridge Survival Project (see Potts and Vickerman, 1974b).

METHOD AND MATERIALS

The trials were carried out on a 15 ha field of winter barley (cv Malta). In both 1973 and 1974 two 5 ha portions of the field were sprayed either with mecoprop or a mixture of metoxuron and simazine ("Fylene"). The crops were drilled on 7 October, 1972 and 29 September, 1973 and the herbicides applied on 16 March, 1973 and 18 February, 1974.

The insect fauna was sampled with the Dietrick vacuum insect net. Four samples, each consisting of ten randomly placed sub samples of 0.092 m^2 were taken in each plot. In 1973 the field was sampled twice in June, and in 1974 once at the end of May.

RESULTS

Weeds

In both 1973 and 1974 there was a dense growth of Poa trivialis on the plots sprayed with mecoprop. Other weeds were Veronica spp., Viola arvensis, Myosotis arvensis, Polygonum convolvulus and P. aviculare agg.

In both years the plots sprayed with metoxuron were virtually weed free and in this respect were strikingly different from the plots sprayed with mecoprop. The only weed present was P. convolvulus, and even this was scarce in 1973.

Insect Numbers

In both 1973 and 1974 more arthropods were found in plots treated with mecoprop than in plots treated with the mixture of metoxuron and simazine (see Tables 1 and 2). However, the difference was significant only in early June 1973.

Table 1

Mean number of arthropods per m^2 in plots of winter barley treated with mecoprop or a mixture of metoxuron and simazine, June, 1973.

	5 June 1973		23 June 1973	
	Mecoprop	Metoxuron and simazine	Mecroprop	Metoxuron and simazine
Araneae	8	6	78	37 *
Dermaptera	0	0	0	1
Psocoptera	0	0	1	0
Hemiptera	42	46	44	50
Thysanoptera	108	48 *	266	270
Hymenoptera	62	40	35	41
Coleoptera	672	132 **	164	81 **
Diptera	126	56 *	50	56
Total per m^2	1018	326	638	536

Significance (P) of difference between treatments, using the t-test
** $P < 0.01$ * $P < 0.05$

In early June 1973 significantly more Thysanoptera, Coleoptera and Diptera were found with the mecoprop treatment. In late June Araneae, mostly immatures, and Coleoptera were more numerous in this treatment.

In 1974 populations of Diptera ($P < 0.01$) and Coleoptera ($P < 0.001$) were significantly higher with the mecoprop treatment whereas populations of Hemiptera were significantly ($P < 0.05$) higher in the plot treated with metoxuron and simazine (see Table 2).

Table 2

Mean number of arthropods per m^2 in plots of winter barley treated with mecoprop or a mixture of metoxuron and simazine, May, 1974.

	Mecoprop	Metoxuron and simazine	
Araneae	19.25	18.25	
Opiliones	0.25	0.00	
Hemiptera	370.25	455.00	*
Psocoptera	0.00	0.25	
Thysanoptera	106.25	95.00	
Lepidoptera	0.25	1.25	
Hymenoptera	65.25	66.50	
Coleoptera	156.25	48.75	***
Diptera	42.25	19.25	**
Total per m^2	760.00	704.25	

*** $P < 0.001$

** $P < 0.01$

* $P < 0.05$

The majority of the Hemiptera consisted of Aphididae, mainly Sitobion avenae and Metopolophium festucae (see Table 4a). Significantly more ($P < 0.05$) cereal aphid apterae and alatae were found in the metoxuron and simazine treatment. There was however no significant difference in the numbers of non-cereal alatae (mainly Myzus ascalonicus). Significantly more ($P < 0.05$) Javesella pellucida (Delphacidae) and Calocoris norvegicus (Miridae) were found in the mecoprop treatment.

In the Coleoptera (see Table 4b) the greatest effects were apparent in some of the Staphylinidae. Significantly more Tachyporus adults ($P < 0.05$) and larvae ($P < 0.001$) were found in the mecoprop plot. Crypotophagidae, mainly Atomaria atricapilla, were also more numerous in the mecoprop plot.

Significantly more ($P < 0.05$) sawfly larvae (Tenthredinidae) were found in the mecoprop plot in 1974 (see Table 4c). A similar difference was also found in late June 1973. There were no other significant differences amongst the Hymenoptera.

Although the numbers of most Diptera were generally low in 1974, significantly more Psychodidae ($P < 0.05$), Cecidomyidae ($P < 0.05$), Mycetophilidae ($P < 0.05$), Lonchopteridae ($P < 0.05$), Agromyzidae ($P < 0.05$) and Sphaeroceridae ($P < 0.01$) were found in the mecoprop plot (see Table 4d).

Cereal Aphids

Cereal aphids were the only group of arthropods which were significantly more abundant in the metoxuron and simazine plot. This effect was not economically important during this study, but it could be economically significant in a year when the aphid reproduction rate was high. Cereal aphids were relatively scarce in most of the 300 fields in the West Sussex study area in 1973 and 1974.

The most notable difference between the two treatments was in the numbers of Tachyporus adults and larvae. In 1973 several feeding trials were carried out in the laboratory to assess some arthropods as cereal aphid predators. Although full details will be published later, the results of one trial are given in Table 5.

Table 5

Mean number of apterous cereal aphids (S. avenae) consumed per day by Coccinella 7-punctata (second instar larvae) and Tachyporus hypnorum (adults and larvae) over a period of 5 days.

	C. 7-punctata larvae	T. hypnorum adults	T. hypnorum larvae
Number of animals tested	20	20	20
Mean number of cereal aphids consumed per day	6.2	5.5	4.8

There was no significant difference between the numbers of cereal aphids eaten by C. 7-punctata larvae (well known aphid predators) and T. hypnorum adults and larvae. Analysis of their gut contents showed that the Tachyporus adults were also predators of cereal aphids in the field.

Vertebrates

Young grey partridge (Perdix perdix) chicks feed mainly on insects and these are essential for their survival. The insect samples obtained in 1974 were therefore dried and the biomass of insects useful as partridge chick food calculated (see Potts, 1970).

The biomass of insects with the mecoprop treatment was 0.14 kg/ha; in the metoxuron and simazine area the biomass was 0.08 kg/ha, a reduction of approximately 43%.

Other things being equal such an effect could have a marked adverse effect on chick survival. Current studies at North Farm are designed to assess the relative importance of agricultural changes such as these on game over large areas of farmland.

DISCUSSION

It is likely that most of the differences described in this work were caused by indirect effects of the herbicides on the insect fauna. Although some species were probably reduced in number in the metoxuron and simazine treatment by the virtual eradication of their host plant (e.g. Phytomyza crassiseta (Agromyzidae) on Veronica spp.) the majority were apparently affected by the alteration in the crop environment caused by the removal of the weeds.

Weed removal decreases the amount of cover, decaying plant material and associated micro-organisms and changes the micro-meteorological conditions within the crop. Insects such as Tachyporus, the Lonchopteridae, Mycetophilidae, Sphaeroceridae and Cryptophagidea either require cover and high humidity conditions or feed on decaying plant material, moulds and fungi. These groups were probably affected by such changes in the micro-habitat. Edwards and Lofty (1969) and Edwards (1970) investigated many herbicides and noted that apart from DNOC, only simazine decreased the numbers of soil arthropods; particularly predatory mites and isotomid Collembola. Numbers were decreased for a period of four to six months.

Cereal aphids were the only group of arthropods which were significantly more abundant in the metoxuron and simazine plot. It is possible that this was due to reduced predator pressure especially since significantly fewer potential cereal aphid predators (Tachyporus adults and larvae) were found in this treatment. Although the role of predation, and particularly predation on cereal aphids, in the cereal ecosystem is at present being studied at North Farm, some preliminary results have already been given (Potts and Vickerman, 1974a and b). These studies suggested that predation is important in determining field to field variations in the numbers of cereal aphids.

Similar indirect effects of weed control on the crop fauna have been found by Dempster (1969). He found that the presence of weeds within a crop of brussels sprouts provided cover which was more suitable for some of the predators of the small cabbage white butterfly (Pieris rapae) and that the survival of Pieris caterpillars was significantly less on weedy than on hoed plots. Dempster (l.c.) further noted that the numbers of the cabbage aphid (Brevicoryne brassicae) were higher on hoed than on weedy plots. Smith (1969) showed that more alate B.

brassicae colonized sprout plants in bare soil than in weeds and that larger populations developed on the bare-soil plants. According to Smith (l.c.) many more Anthocoris nemorum were found and some syrphid species laid more eggs on the sprouts surrounded by weeds than on those surrounded by soil.

van Emden (1970) reviewed some inter-relationships between weeds, pests and beneficial insects and concluded that "any small beneficial contribution weeds may make to pest control is far outweighed by their harmful effects, and the advantages to crop growth of their removal." According to van Emden (1970) "the application of weedkillers will occasionally make the plant more susceptible to a particular pest (especially to aphids) but this would seem a justifiable risk in the light of the infrequency with which such problems have been reported in practice."

A similar conclusion might be reached from the present investigation since the yields from the metoxuron and simazine plots were significantly higher than those from the mecoprop treatments in both 1973 and 1974. However such a conclusion may not be tenable if pest problems increased in frequency, and there is some evidence, at least with cereal aphids, that this is already happening (Potts and Vickerman, 1974a and b).

The virtual eradication of weeds from cereal crops is now possible and this is likely to have undesirable side effects on other forms of wildlife and in particular the grey partridge. Some details of the decline of this species in Britain have already been given by Potts (1970, 1971).

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Table 4

Mean number of arthropods per m^2 in plots of winter barley treated with mecoprop or metoxuron and simazine, May 1974.

a. Hemiptera

	Mecoprop	Metoxuron and Simazine	
Aphididae Apterae (mainly *S. avenae* & *M. festucae*)	303.00	384.25	*
Alatae (mainly *S. avenae* & *M. festucae*)	43.75	57.50	*
Alatae (mainly *M. ascalonicus*)	12.50	9.75	
Jassidae	0.50	0.25	
Delphacidae *J. pellucida*	7.00	2.50	*
Psyllidae	0.00	0.25	
Miridae *C. norvegicus*	3.50	0.00	*
Others	0.00	0.50	
Total per m^2	370.25	455.00	*

* $P < 0.05$

Table 4 (cont)

b. Coleoptera

	Mecoprop	Metoxuron and Simazine	
Carabidae	0.25	0.25	
Staphylinidae			
Adults			
Tachyporus	3.25	1.25	*
Others	9.75	1.75	***
Larvae (mainly *Tachyporus*)	90.25	7.25	***
Cryptophagidae (mainly *Atomaria atricapilla*)	18.00	7.75	*
Lathridiidae (*Enicmus transversus*, *Lathridius bifasciatus* & *Stephostethus lardarius*)	31.25	24.25	
Phalacridae *Stilbus testaceous*	2.00	4.00	
Others	1.50	2.25	
Total per m^2	156.25	48.75	

*** $P < 0.001$

** $P < 0.01$

* $P < 0.05$

Table 4 (cont)

c. Hymenoptera

	Mecoprop	Metoxuron and Simazine
Tenthredinidae	1.75	0.00 *
Ichneumonidae	0.25	0.00
Braconidae Aphidiinae	39.50	48.25
Alyssinae	7.50	5.50
Cynipidae	0.50	0.25
Proctotrupoidea	0.50	0.00
Chalcidoidea (except Mymaridae)	12.25	10.50
Mymaridae	3.00	2.00
Total per m^2	65.25	66.50

* $P < 0.05$

Table 4 (cont)

d. Diptera

	Mecoprop	Metoxuron and Simazine
Tipulidae	0.25	0.00
Psychodidae	1.25	0.25 *
Cecidomyidae	8.50	2.75 *
Bibionidae	0.25	0.00
Mycetophilidae	8.25	2.75 *
Chironomidae	0.25	0.25
Culicidae	0.25	0.00
Ceratopogonidae	0.25	0.00
Empididae	1.00	1.25
Lonchopteridae	3.75	0.50 *
Phoridae	0.75	0.75
Agromyzidae	4.50	2.00 *
Sepsidae	1.00	0.00
Opomyzidae	0.00	0.50
Drosophilidae	0.75	1.00
Sphaeroceridae	8.25	2.25 **
Ephydridae	0.25	0.25
Chloropidae	2.00	4.00
Scatophagidae	0.75	0.75
Total per m^2	42.25	19.25 **

** $P < 0.01$

* $P < 0.05$

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SOME OBSERVATIONS ON HERBICIDAL EFFICACY AND CROP SELECTIVITY OF TRIFLURALIN-LINURON IN WINTER CEREALS

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Summary Trifluralin + linuron, a preemergence soil-applied herbicide combination for winter cereals, has been developed to give control of annual grass and dicotyledonous weeds in cereals. Some examples of this control are reported. In particular, the mixture gives good to excellent season-long control of *Galium aparine* under Dutch and German conditions. In France control was very good in the autumn months, but decreased in the spring to an unsatisfactory level of 56%. These differences in control are correlated with different patterns of soil decline of trifluralin in the various regions of France, Germany and the Netherlands. Selectivity of trifluralin + linuron on major Dutch winter wheat cultivars is discussed.

INTRODUCTION

Results from France reported by Cordelier *et al* (1973 a,b) and Quere *et al* (1973) indicated that preemergence surface applications of trifluralin + linuron provided very good to excellent weed control of annual grass weeds (*Alopecurus myosuroides*, *Apera spica-venti*) and most dicotyledonous weeds.

This combination herbicide has shown excellent selectivity in all French and German winter barley, winter wheat (both durum and soft) and rye varieties at the recommended application rate of 0.96 kg a.i./ha of trifluralin and 0.48 kg a.i./ha of linuron (Cordelier *et al*, 1973 a,b, Satori *et al*, 1973 and Döhler *et al*, 1973). A slight yield depression was observed in a few instances after treatment with the twice normal rate (2X) by Cordelier *et al* (1973 a,b). Quere *et al* (1973) noticed a slight reduction in crop stand at elevated rates of trifluralin + linuron in some cases in winter wheat, but never in winter barley. Both Cordelier *et al* (1973 a,b) and Quere *et al* (1973) felt that there were no indications to relate these observations to decreased selectivity in any particular variety but conversely, to inadequate or improper seedbed preparation, resulting in uncovered seeds which came in direct contact with the herbicide mixture.

Döhler *et al* (1973) observed that trifluralin + linuron gave considerably better control of *Galium aparine* in Germany and the Netherlands than in France. Further studies were conducted in order to determine if the enhanced activity against *G. aparine* under German conditions would be consistent during another growing season. An attempt is made in this paper to explain these differences in activity against this important weed.

Döhler and co-workers (1973) concluded that all major European winter cereal cultivars were tolerant to trifluralin + linuron with the possible exception of the major Dutch variety "Manella". A special selectivity experiment was conducted in the Netherlands to establish whether this apparent lack of selectivity in "Manella" could be attributed to physiological characteristics of this cultivar, since it is known to be sensitive to the urea herbicides chlortoluron and metoxuron. The results from this experiment will be discussed in detail.

MATERIALS AND METHODS

Herbicidal efficacy Trifluralin + linuron were applied preemergence to the soil surface after seeding winter cereals at a rate of 0.96 and 0.48 kg a.i./ha for trifluralin and linuron, respectively. The combination product was formulated as an emulsifiable concentrate containing 240 g of trifluralin and 120 g of linuron per litre. The compound and the reference products were applied with Azo Gas Plot sprayers fitted with 2 metre spray booms and Birchmeyer J60 nozzles. The spray volume ranged between 300 and 800 litres/ha. In all instances, the experiments were laid out in a randomized block design with 25-50 m^2 plots and 4-5 replications.

In Germany, 15 experiments were conducted in winter barley and 16 in winter wheat during the 1972/73 season. Effects of weed control on crop yield were determined in 12 winter barley and 16 winter wheat experiments. Soil texture varied from sandy loam to loamy clay. Chlortoluron and methabenzthiazuron were included in most trials as reference compounds and used according to label recommendations. Herbicidal efficacy was assessed by weed counts and/or weed control ratings. Data obtained were analyzed statistically using Duncan's Multiple Range test, and converted to percent control.

Cultivar selectivity The cultivar selectivity experiment in the Netherlands was conducted at Nieuw Biltzijl on a loamy sand soil with 18.0% clay and 2.0% organic matter. This site was chosen to ensure optimum seedbed preparation. Potential phytotoxicity could readily manifest itself due to ideal leaching conditions in this very light marine clay. The following cultivars were included: "Manella", "Caribo", "Clement", "Cyrano" and "Lely". The seeding date was 22nd November, 1973, and the herbicides were applied one day later.

Residue decline studies Soil samples were collected from efficacy trials described above, during the 1972/73 and 1973/74 season at 3 sites in each of the following areas; Germany, the Netherlands and the Bordeaux and Rhone Valley regions of south-west and south-east France, respectively. Ten random subsamples were collected from each replication to a depth of 10 cm with a 2 cm diameter tube.

Samples were collected at approximately monthly intervals, with the first taken as soon after application as possible. All samples were placed in sealed, aluminium-lined bags and sent to the laboratory immediately after collection. Subsamples were thoroughly mixed and stored at -20°C. The samples were extracted with methanol and the trifluralin partitioned into methylene chloride prior to analysis by gas liquid chromotography according to methods based on that described by Tepe et al.

Results were based on single assays corrected to 100% recovery. The standard recovery of trifluralin from the samples was 80%. All data were calculated as µg/g of air dried soil. Only the data for the 1973/74 season are discussed. Assays for linuron were carried out simultaneously and will be reported elsewhere.

RESULTS

Herbicidal efficacy Data on herbicidal efficacy from the experiments conducted in Germany during the 1972/73 season are presented in figures 1 and 2.

The combination product provided acceptable control of Alopecurus myosuroides in most instances (81% in winter barley and 87% in winter wheat): chlortoluron was more effective. On the other hand, trifluralin + linuron was more active against A. myosuroides than methabenzthiazuron.

Apera spica-venti was more susceptible to all three herbicides than A. myosuroides. Trifluralin + linuron and chlortoluron were approximately equal in activity against A. spica-venti in both winter barley and winter wheat, while methabenzathiazuron was slightly less effective.

Trifluralin + linuron provided an average of 93% control of Galium aparine in winter barley (9 trials) and an average of 74% control in winter wheat (9 trials), compared to an average of 66% and 58% control obtained with the reference product chlortoluron in winter barley and winter wheat, respectively. Trifluralin + linuron was also more effective than chlortoluron against Veronica spp. and Lamium amplexicaule (encountered in 6 winter barley trials only).

Treatment with trifluralin + linuron resulted in average yield increases in comparison to untreated controls of 18.4% and 15.6% in winter barley and winter wheat, respectively (fig. 3). These were equal to or better than the yield response to treatment with the reference products.

Fig. 1 WINTER BARLEY

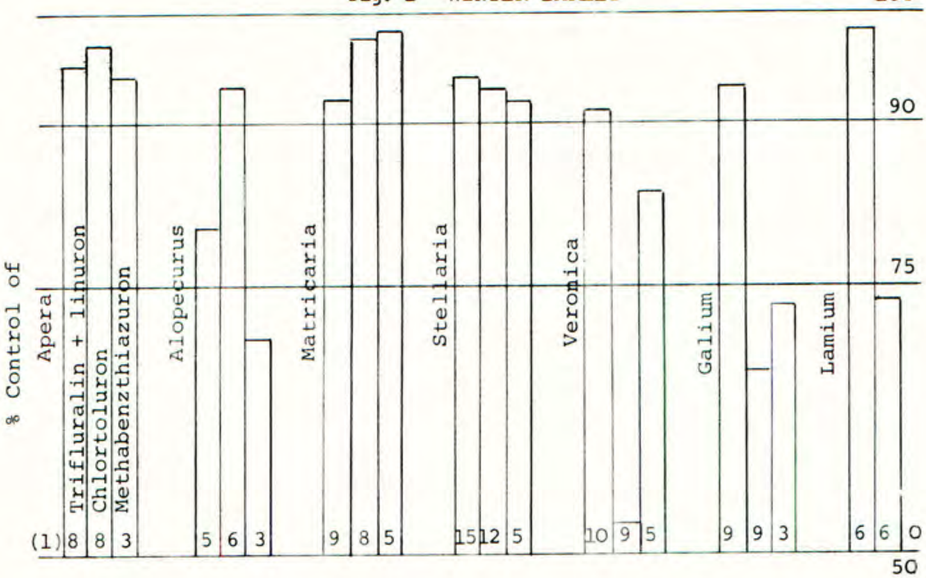
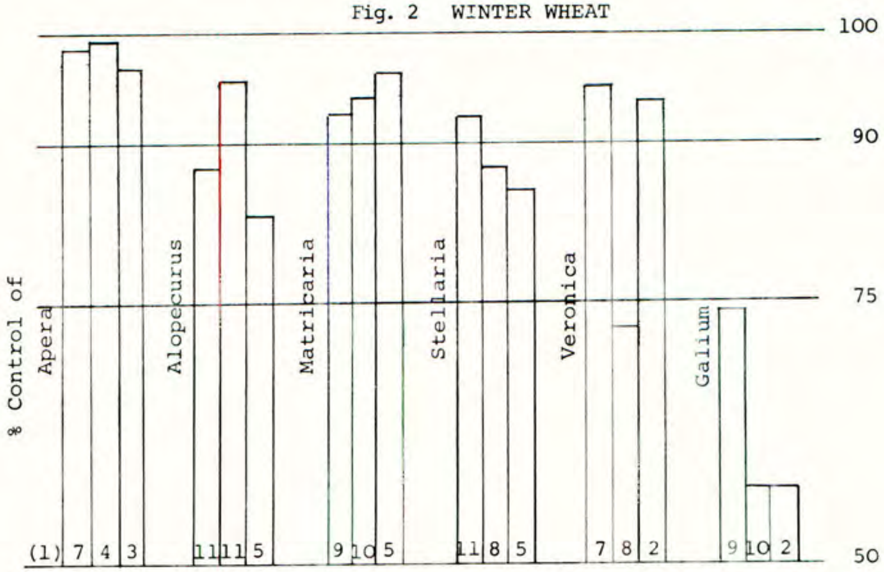
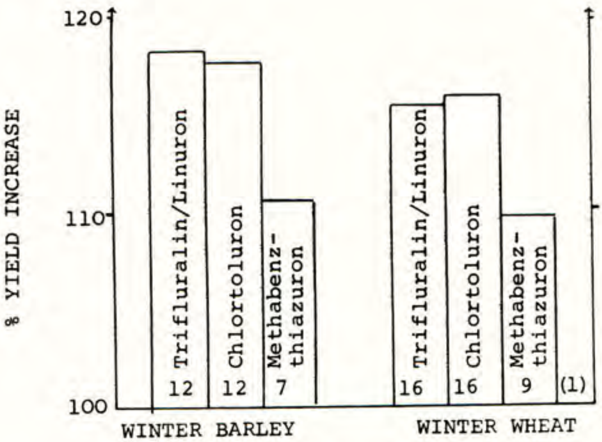


Fig. 2 WINTER WHEAT



(1) Numbers at the base of each bar correspond to the number of trials in which the weed occurred.

Fig. 1-2 Control of major weeds in winter barley and winter wheat, respectively, with trifluralin + linuron applied pre-emergence at (0.96 + 0.48) kg a.i./ha in Germany during the 1972/73 trial programme.



(1) Numbers at the base of each box correspond to the number of trials from which yield data were collected.

Fig. 3 Effect of trifluralin and linuron treatments (0.96 + 0.48) kg a.i./Ha on crop yield of winter wheat and winter barley in Germany during the 1972/73 trial programme.

<u>Cultivar selectivity</u> Treatment with trifluralin + linuron at the X-rate resulted in significant increases in yield in all cultivars in comparison to the untreated controls. Yields obtained in plots treated with the 2X rate were significantly higher in "Clement", "Manella" and "Lely".

Chlortoluron caused slight yield depressions in "Manella" and "Lely", notwithstanding excellent weed control. In the other varieties, chlortoluron treatment resulted in yield increases comparable to those in the trifluralin + linuron plots, while methabenzthiazuron treatment resulted in significant yield increases in "Manella" and "Lely".

<u>Trifluralin residue decline studies</u> Decline data for trifluralin in the top 10 cm of soil after surface applications of trifluralin + linuron in south-west and south-east France, Germany and the Netherlands are presented in figure 4. In all cases, initial samples failed to yield residue levels greater than 60% of the calculated amount expected at zero time.

Slopes of the decline curves obtained for trifluralin in soils from the Netherlands, Germany and the Rhone Valley area were virtually identical where levels of trifluralin had declined to 0.1 µg/g at 130, 140, and 120 days after application in the Netherlands, Germany and the Rhone Valley, respectively.

The decline of trifluralin in the soils of south-west France was considerably faster than in the other areas, and only 0.1 ppm of trifluralin remained 58 days after application.

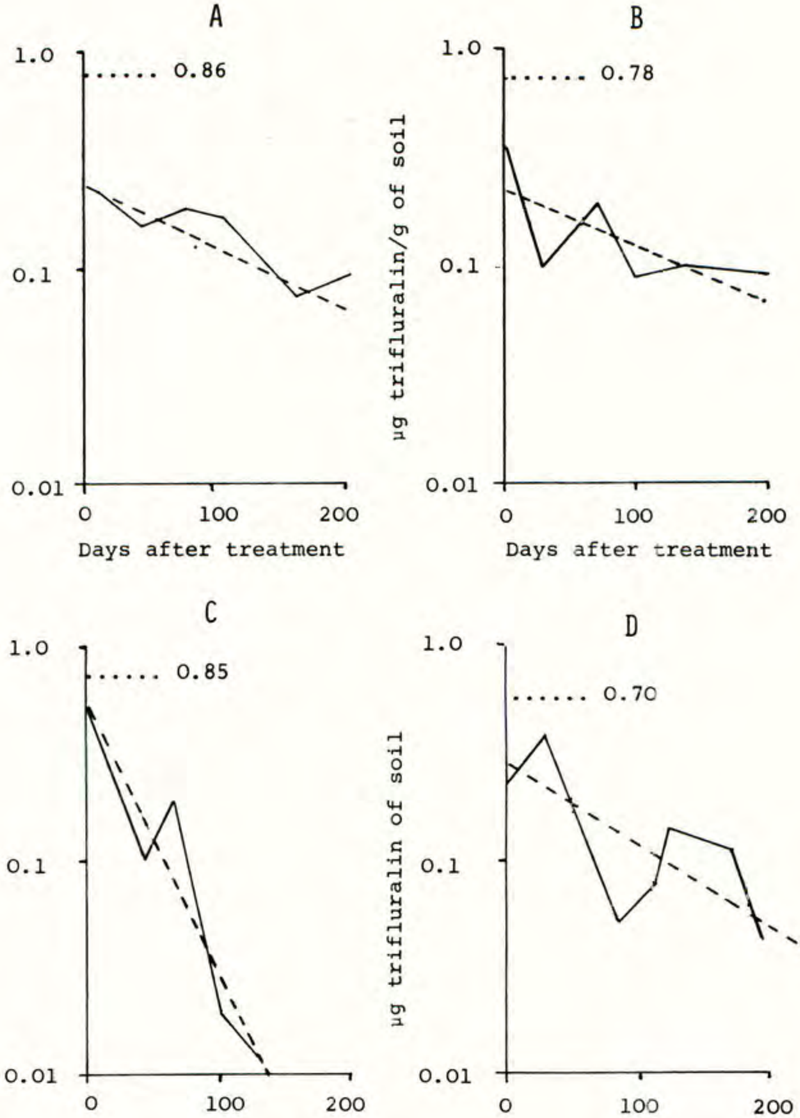


Fig. 4 Decline of trifluralin in soils after pre-emergence surface application at 0.96 kg a.i./ha. A. Netherlands, B. Germany C. S.W. France, D. S.E. France (..... 0.70 = calculated trifluralin residue at zero-time; ----- linear regression curve for trifluralin decline).

DISCUSSION

Apera spica venti is generally considered to be more sensitive than *Alopecurus myosuroides* to soil applied herbicides. This is borne out by these studies where all three products, especially trifluralin + linuron and methabenzthiazuron, were considerably more active against the former species. Control of *Alopecurus* was slightly superior in winter wheat as compared to winter barley. This is partially attributed to higher soil moisture which resulted in improved leaching of the herbicides and shallower germination of the weed seeds.

Trifluralin + linuron gave 98% control of *Galium aparine* in winter barley and 73% control in winter wheat in trials conducted in Germany during the 1972/73 season (figs 1 and 2). These additional trials proved that trifluralin + linuron when applied under German conditions provided consistently better control of *G. aparine* than in France (an average of 58% in 13 trials, Cordelier *et al*, 1973 a,b and Quere *et al* 1973).

Cordelier and co-workers (1973 a) indicated that trifluralin gave an average of 51% control of *Galium* and the combination product 58%. Döhler *et al* (1973) reported that in German trials trifluralin gave 87% control of *Galium* (16 trials) and the combination product 92% (8 trials). These data indicate that the activity against this weed should be attributed to the trifluralin component. The excellent season-long control of *G. aparine* obtained in Germany and the Netherlands is probably due to the slower decline of trifluralin (fig. 4).

Plants germinating during the autumn in France were adequately controlled when a sufficiently high trifluralin concentration was present (Quere *et al*, 1973). Residue levels in the spring under French conditions appear to be too low to provide control of *Galium* plants germinating during that period. Conversely, the trifluralin concentration in German and Dutch soils in the spring (fig. 4) is such that plants germinating then are controlled. Effects of seed germination over extended periods of time and/or from depth below the herbicide zone, on season-long control of Galium were not assessed in these experiments.

The cultivar selectivity experiment in the Netherlands proved that trifluralin + linuron was selective to all major Dutch cultivars including "Manella" both at the X and 2X rate when the seedbed was carefully prepared. In fact, trifluralin + linuron treatments resulted in significant yield increases. Yields of "Manella" and "Lely" were slightly depressed in plots treated with chlortoluron. This depression can only be explained on the basis of enhanced sensitivity to chlortoluron.

The rapid decline of trifluralin in soils in south-west France, in comparison to the other areas, is attributed to the mild, wet conditions prevailing during the winter months. With the exception of south-east France, similar winter conditions exist in most of the winter cereal belt of France where *Galium* is an important weed problem. The wide range of soils encountered did not allow correlation of trifluralin decline with soil texture.

The initial loss observed in all samples collected at zero time or very close to that date may be explained by assuming significant losses of the active ingredient during and shortly after application, due to volatilization and to some extent photodecomposition. The vapour pressure of trifluralin is relatively high (1.99×10^{-4} mm Hg at 29.5°C), and in view of the low water solubility (<1 ppm at 27°C) this compound tends to linger at the soil surface in comparison to more water soluble compounds. An additional factor could be adsorption of the active ingredient by refuse from the previous crop.

One would expect this initial loss to be greater in winter barley which is planted in north western Europe from 15th September to 31st October than in winter wheat where planting starts in the second half of October, since during the early autumn enhanced chances of physical decomposition exist.

Nevertheless, as shown in figures 1 and 2, the herbicidal activity of trifluralin + linuron against *Galium* in winter barley was generally comparable to or better than that obtained in winter wheat.

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PHYSIOLOGICAL AND ECONOMIC TARGETS FOR PLANT GROWTH REGULATORS

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Summary Although the first significant use of a plant growth regulator in agriculture was as early as 1932, relatively few major commercial applications have emerged in relation to the vast research efforts over the past forty years. A survey of physiological and economic targets for growth regulators is presented and examples of the problems encountered with some of the currently available growth regulators are described. It is concluded that the main future requirements are likely to be for compounds which modify plant shape and subsequent yield and for compounds which either promote or inhibit floral development. They must be equally effective on different varieties of the same species but must be highly specific in their effects on physiological processes. Although new chemicals will be required, further attention should be paid to the possibilities of varying the formulations of currently available products.

The first significant usage of a plant growth regulator in crop production can be traced back as early as 1932 when Rodrigues (Wittwer, 1971) discovered that flowering in pineapple could be induced by treatment with ethylene. Within the following 20 years the ability of auxins to promote rooting of cuttings, to control fruit drop and to promote seedless fruit development was utilised in the horticultural industry. The discovery by Hamner and Tukey in 1944 (Wittwer, 1971) of the selective herbicidal properties of 2,4-D and 2,4,5-T subsequently led to the revolutionary science of chemical weed control which has had such great impact on the whole technology of crop production. Although the gibberellins were first isolated in Japan in the late 1930's, it was not until 1954 that detailed physiological studies (Brian et al, 1954) indicated the potential of this group of growth regulators (Stodola, 1957). The practical value of gibberellic acid to aid fruit setting, to stimulate seed germination and to enhance flowering is now well recognised (Stuart and Cathey, 1961). Apart from a few specialised uses of these chemicals, however, little further advance was made until the discovery of the first of the synthetic growth retardants. In 1960, Tolbert (1960) reported the favourable effects of chlormequat chloride on wheat and subsequently the dwarfing properties of this chemical have been utilised commercially in Europe to prevent lodging of cereals. Over the last decade a number of other growth retardants viz. daminozide, chlorphonium chloride and ancymidol have been used commercially on fruit and ornamental plants and the ethylene-generating compound 2-chloroethylphosphonic acid (ethephon; Ethrel) has found wide application in the horticultural industry.

In considering this brief resume of the history of growth regulator use in agriculture and horticulture, it would be easy to stand back complacently and point out the achievements and the benefits to the industry. Indeed, some of the discoveries, particularly the herbicidal effects of auxins, have completely revolutionised the production and marketing of crops. On the other hand, in view of the enormous effort put into growth regulator research, as reflected by the thousands of bulletins, technical papers and reviews written on the subject, a cost-benefit analysis could very well indicate that we still have a large deficit of commercial applications to make up before we can be satisfied with our progress.

Of course, there are a number of extenuating circumstances, but Wittwer (1971) had quite rightly pointed out that only a small percentage of the many publications on growth regulators have dealt with their application or use in agricultural practice. Another major factor contributing to this lack of success has been the prohibitive development and after-sale costs which have led to a decrease in the commercial screening of potential growth regulators. In 1973, an estimate of the cost of producing one new commercially-useful growth regulator was £1.75 million (Bryant, 1969) so it is not surprising that manufacturers are loath to initiate new development programmes. However, there is a greater awareness of the importance of full screening for growth regulator activity and most major agrochemical companies now employ standard screening techniques. In view of this revival of interest in growth regulation it seems particularly appropriate to now take stock, to consider what has been achieved and to formulate physiological and economic targets for growth regulators in order to improve the production of crops in the future.

What do we mean by physiological targets? Quite simply we are referring to ways in which we can advantageously modify the natural growth processes of the plant. These modifications, when suitably controlled, may result in the achievement of some economic target. An example to illustrate this point is the use of growth retardants such as daminozide to break the apical dominance of Brussels sprout plants. The economic advantage of this treatment is the enhancement of yield and uniformity of the lateral buds or sprouts which are the harvestable portions of the crop. A completely successful treatment of this type could be an important aid to the mechanical harvesting of sprouts for the processing industry. A convenient way in which to formulate these targets is to examine each stage of plant development and consider how the performance of the plant can be modified to achieve specific objectives depending on the particular crop under consideration. An objective analysis of this type is presented in Table 1 and some examples of current or proposed uses are given.

A survey of the current literature indicates that although some notable successes have been achieved with growth regulators, many seemingly useful treatments have not been adopted on a commercial scale for a variety of reasons. In the remainder of this paper the physiological targets will be examined more closely and some of the problems involved in the use of existing growth regulators to achieve these aims will be highlighted.

Table 1

SOME PHYSIOLOGICAL TARGETS FOR GROWTH REGULATORS

Physiological processes	Agricultural objectives	Some current examples
1. Seed germination	Earlier and more uniform seedling emergence	Gibberellin and cytokinin seed soaks
2. Seedling growth	More rapid plant development. Improved establishment of transplants.	Gibberellin treatment of seedlings Antitranspirants on nursery stock
3. Vegetative development	Repartitioning assimilates to:-	
	i. increase the proportion of harvestable material	Retardant treatment of cereals and root crops
	ii. improve uniformity of product	Retardant treatment of Brussels sprouts
	iii. improve appearance of plant	Retardant treatment of ornamentals
	iv. promote/inhibit lateral branching	Methyl ester treatment of fruit trees
4. Reproductive development	i. Changes in sex expression	Gibberellin treatment for producing hybrid seeds
	ii. Earlier and more uniform flower initiation	Gibberellin treatment of ornamentals Retardant treatment of azaleas
	iii. Increased or decreased flower production	Gibberellin and retardant treatment of fruit trees. Chemical disbudding of ornamentals.
	iv. Prevention of bolting or flowering in crops sown out of season	No example known
	v. Increased or decreased fruit set	Auxin treatment of tomatoes. Fruit thinners on top fruit
5. Ripening and senescence	Improved fruit ripening Delayed senescence of harvested vegetables	Ethephon treatment of tomatoes and apples Cytokinin treatment of green vegetables
6. Abscission	Defoliation and fruit abscission as harvesting aids	Ethephon and HI on nursery stock Ethephon treatment of blackcurrants
7. Dormancy	Improving storage of crops. Breaking dormancy of overwintered crops.	Maleic hydrazide treatment of onions Gibberellic acid treatment of rhubarb

Seed germination

The beneficial effects obtainable by improving the performance of seeds in the field have been discussed at a previous meeting (Osborne, 1972; Scott et al, 1972; Thomas et al, 1972). In brief, it can be concluded that greater uniformity and increased earliness of crops may well be achieved by improving initial plant stands. A number of methods have been employed to improve seed germination and seedling emergence, such as scarification, hardening, chilling and pregermination, and hormone-treatments have also met with limited success. Gibberellic acid promotes the germination of seeds of a wide range of species but almost always the emerging seedlings are elongated and weak. Sometimes gibberellins alone are not effective but may stimulate germination in combination with other growth regulators (Thomas et al, 1972) and in such instances the adverse effects of the gibberellins on seedling vigour may be avoided. The need for growth regulators to enhance seed germination is very real, particularly in crops such as sugar beet. However, such chemicals must not affect the subsequent performance of the seedlings, e.g. by promoting abnormal development or stimulating bolting or flowering. One exception to this rule is the use of growth regulators to stimulate the germination of weed seeds which could then be destroyed by conventional herbicides. Ethylene gas, which stimulates germination but causes considerable distortion of the ensuing seedlings has been used commercially for this purpose.

Seedling growth

In most instances the maintenance of a high, steady growth rate during seedling development is essential for the production of high-yielding, uniform crops. In some vegetable crops this has been achieved by treating them with gibberellic acid but in general such treatment is not successful because the plants either fail to maintain this high growth rate or become prone to bolt or flower. On the other hand, reductions in plant height during seedling development can be advantageous as has been demonstrated by the use of chlormequat chloride on tomatoes (Krause, 1970). Treated plants were more resistant to transplant check, subsequent fruit-number and quality was increased and a completely new system of production seems feasible because very high plant densities can be employed and the crop then harvested mechanically. However, this type of treatment would not be successful on other crops where although increased yields were desirable, the decrease in plant height would be an embarrassment. One of the common problems encountered with growth regulators is that the beneficial effects of treatment can often be counteracted by other gross effects which are undesirable.

Of current interest is the effect of abscisic acid in stimulating stomatal closure and thus behaving as an antitranspirant. The role of such chemicals in preventing excessive water-loss from transplants in the field has been studied extensively (Gale et al, 1966; Mizrahi et al, 1974; Mizrahi and Richmond, 1972; Fieldhouse et al, 1966) and a number of problems have emerged. In the case of abscisic acid, although plant establishment is improved, the regrowth of the transplant is inhibited since this chemical is an inhibitor of cell extension. Thus, it might be necessary to find another chemical to promote growth once the transplant becomes established. However, a more convenient solution would be to find an antitranspirant which also stimulates further development.

Vegetative development

The establishment of uniform, sturdy plants is only the beginning in the sequence of events leading up to the marketing of a high quality product. The current trend towards supermarket selling has increased the demand for all-the-year-round, uniform produce and the constant increase in world population can only be satisfied by increased yields of edible products. In order to meet these requirements we must formulate new methods of modifying plant growth to obtain a more efficient partitioning of assimilates within the plant. Of course, it is impossible to make something from nothing and it must be recognised that there will be a minimum photosynthetic area required to produce the assimilates necessary for the growth of the plant and the accumulation of its storage reserves. However, we must look for methods which will minimize the proportion of assimilate that is wasted on the non-marketable or non-ornamental portion of the plant, and it is here that the use of plant growth regulators may be particularly relevant. Re-partitioning by the use of growth retardants may lead to improved appearance in ornamentals by producing a plant of more compact form. In general, it would seem that in recent years, the most successful uses of growth regulators have been in the floriculture industry, particularly since considerations of mammalian toxicity are not so important as with edible crops. However, the problems of high specificity and undesirable side effects can be well demonstrated with ornamentals. Table 2 shows the response of Hibiscus trionum and Celosia plumosa cultivars to chlormequat chloride (as Cycocel) and demonstrates the ineffectiveness of another growth retardant, daminozide (as B-Nine), on these species.

TABLE 2. Effects of foliar spray application of chlormequat chloride and daminozide on height (cm) of ornamentals

Treatment	Hibiscus trionum	Celosia plumosa "Giant Scarlet"	Celosia plumosa "Fire feather"
Nil	87.7	44.5	34.8
daminozide (2500 ppm)	84.2	43.6	32.0
chlormequat chloride (3000 ppm)	16.9	22.5	12.7
l.s.d. (P = 0.05)	3.5	2.3	1.5

FROM DICKS (1972/3)

On the other hand, neither chlormequat chloride nor daminozide are effective in restricting stem growth of Mid-Century hybrid lilies, whereas ethephon is extremely effective but causes a delay in flowering and reduces flower numbers. A new growth retardant, ancymidol, is also very effective. It does not delay flowering to any great extent but has the deleterious effect of inducing senescence of the basal leaves (Dicks et al, 1974). Ancymidol effectively controls extension growth in a wide range of ornamentals and is effective at very much lower application rates than are other growth retardants (Dicks, 1972/3). White (1971) highlighted another of the problems associated with the release of new chemicals for commercial use when he indicated that ancymidol might not be used on ornamentals unless other more economically-rewarding applications are discovered.

In view of this comment, it is perhaps paradoxical that in this particular case, ancymidol is now marketed in the U.S.A. and several European countries as a growth retardant for floriculture.

The modifying effects of growth regulators on root/shoot ratios may also have great significance in the production of high value root crops such as sugar beet. As yet experiments with this crop have met with little success, but the potential of growth retardant treatment can be recognised from the results obtained with other root vegetables (Dyson, 1972; Thomas et al, 1973). Table 3 shows the effect of both chlormequat chloride and daminozide on the root/shoot ratio and yield of carrots but again the question of specificity arises since some varieties are much more responsive to the retardant treatment than are others.

TABLE 3. Effect of foliar sprays of growth retardants on yield and root/shoot ratio of carrots

Variety	Treatment	Total root yield (t/ha)	Canning root yield (t/ha)	Root/Shoot ratio by weight
Nantes 1003	daminozide	46.9	27.6	10.0
	chlormequat chloride	54.1	33.5	12.6
	water	42.1	23.6	9.0
Chantenay red-cored	daminozide	40.9	21.8	7.8
	chlormequat chloride	42.8	23.0	8.7
	water	34.7	20.2	7.0
	l.s.d. (P = 0.05)	6.12	4.01	1.27

FROM THOMAS ET AL, 1973

The effect of growth regulators on partitioning with subsequent alteration of plant form is also very relevant to the fruit industry where methods of increasing "feathering" or lateral branching are continually being sought. This leads eventually to the production of more fruit-bearing spurs. A number of research chemicals have been tested with some success, particularly the methyl esters of C_6-C_{12} fatty acids, but no major breakthrough has yet been achieved. These methyl esters form the basis of commercial formulations such as "Off-shoot-O". They have been used with considerable success for disbudding ornamental plants such as chrysanthemums in order to improve the shape of the plant and quality of the flowers. The economic advantages of chemical treatments as compared with manual pruning are very considerable and could result in substantial cuts in the production costs of many horticultural plants. This is particularly true of tomato production in the U.K. The Glasshouse Crops Research Institute Annual Report for 1971 quotes figures of approximately 2,000,000,000 side shoots removed annually at a cost of about £500 per acre. This is almost 5 per cent. of the total production costs, the process involves waste of photosynthate, damage to the plant and helps spread disease. One of the more recent compounds to be investigated for chemical pruning is 2,3-dihydro-5,6-diphenyl-1,4-oxathiin (Uni-P-293) (Cathey, 1974), which selectively inhibits meristematic growth but, unlike the methyl esters, does not actually destroy the tissue.

Reproductive development

It has already been mentioned that the earliest use of a growth regulator in horticulture was that of ethylene to initiate floral development in pineapple. Since then there have been numerous reports on the effects of growth regulators on reproductive development, some of which have received wide usage in the industry. The effects of such chemicals in altering sex expression of plants is not immediately significant but nevertheless has considerable importance in the production of hybrid seed of cucurbits. There is a real requirement for chemicals to act similarly on a wider range of species and for more effective chemicals to induce male sterility. Of current interest in this respect is the new chemical DPX-3778 which has been shown to prevent pollen release in corn and other crop plants (Barrier et al, 1974). Continuing research with these chemicals could open entirely new horizons in the production of hybrid crop plants.

The beneficial effects of modifying the reproductive development of agricultural crops have already been listed in Table 1 and the main successes have been in the fruit-growing industry. The growth retardants, chlormequat chloride and daminozide, will promote flowering of apples trees when applied in the previous season. Ethephon has been used in the U.S.A. for a similar purpose. In fruit growing practice, the growth retardants have been of value in bringing young, over-vigorous trees into early cropping. However, there are problems associated with the use of such chemicals and these must be considered carefully by the grower. Daminozide is not recommended on mature trees as it may reduce fruit size. On young trees it delays fruit maturity and may increase the incidence of core-flush and breakdown (Table 4) especially in the cultivars Fortune and Cox (Sharples, 1972/3).

TABLE 4. Effect of daminozide on the incidence of breakdown and core-flush in Cox apples after storage at 39°F until mid-March
(Storage conditions - 5% CO_2; 3% O_2)

Picking date	16 Sept.	25 Sept.	6 Oct.	15 Oct.
Breakdown				
daminozide	11.9	6.6	10.6	2.8
control	0.3	0.3	0.3	0.7
Core-flush				
daminozide	72.3	75.2	74.3	72.3
control	21.8	17.5	30.4	45.2

FROM SHARPLES (1972/3)

From these observations it seems obvious that currently available chemicals have serious limitations and alternatives must be found which will affect shoot growth and flowering without adversely affecting fruit size, shape, quality or storage characteristics. However, the beneficial effect of existing growth retardants on apple has been dramatically demonstrated in the Long Ashton Meadow Orchard system. Treated trees can be made to initiate flower buds in the first year of growth and plant densities of up to 30,000 per acre are envisaged. These would be cropped in the second year of growth and then cut back to a stump which would produce a new fruiting shoot. This is an example of how growth regulator treatments could make possible an entirely new system of production (Luckwill, 1972/3). As a generalisation, growth regulators which will reduce the juvenility phase and consistently enhance flowering of fruit trees are required.

Of equal importance is the need to prevent overproduction of flowers and fruit because of the possibilities of subsequent abscission and loss of quality. Fortunately methods are available to prevent this, i.e. carbaryl to thin fruits and naphthalene acetic acid to prevent fruit drop.

The prevention of flowering may be just as important as its promotion. For example, there is a real need to find methods of suppressing flowering and bolting in crops sown out of season. The production of autumn- and spring-sown biennial vegetable crops is limited to some extent because of the stimulating effect of daylength and low temperatures on bolting and flowering. It is well known that changes in endogenous hormones, particularly gibberellins, are involved. Anti-gibberellins (e.g. chlormequat chloride, daminozide) may be partially effective but an anti-flowering compound which has no deleterious effect on subsequent vegetative development has yet to be found.

Other physiological processes

The role of growth regulators in the ripening and senescence processes has been studied in great depth over the last few years, particularly since the advent of ethephon in the 1960's. Ethephon is now used to ripen tomatoes on a vast scale in the U.S.A. and may also be used to develop colouring of apples. Conversely, gibberellic acid is used to delay ripening of citrus fruit as an aid to transportation and storage. More recently glyphosine has been shown to induce sugar cane ripening with subsequent increases in sugar content of up to 10 per cent. (Brown et al, 1974).

The processes of leaf and fruit abscission are closely associated with ripening and senescence, hence problems of over-ripe fruit can arise when chemicals such as ethephon are used as abscission-inducing agents, e.g. in blackcurrant harvesting. The importance of finding suitable abscission-inducing chemicals is reflected in the fact that the Florida Department of Citriculture has a major screening programme in which up to 8,000 chemicals will be screened this year. The major requirement is for a chemical which will loosen fruit without leaf loss and which will discriminate between mature and immature fruit. In some crops the removal of leaves as an aid to harvesting, e.g. Brussesls sprouts, is equally important but in these instances high selectivity and lack of side-effects are essential.

The importance of controlling dormancy either by prolonging or foreshortening the rest period is relevant to the storage of crops, e.g. onions, or to the regrowth of overwintered crops, e.g. fruit trees, rhubarb. In the latter case it may be possible to obtain early, high value yields by chemical treatment.

CONCLUSIONS

From the examples discussed in this paper it is apparent that specialised growth regulators are required to aid in the production of a wide range of crops. Three major requirements emerge and these can be listed as follows:-

1. Growth regulators are required to change the partitioning of assimilates within the plant, and thus modify plant shape and subsequent yield.

2. There is an increasing demand for chemicals which will affect reproductive processes either by promoting or inhibiting floral development including sex expression.

3. To be useful any growth regulators must be specific in their action, i.e. they must not adversely affect other physiological processes. Ideally these must be equally effective on different varieties of the same crop.

In general, it can be concluded that although some current growth regulator treatments are satisfactory, many of the targets described in this paper may only be attained by new highly-specific compounds. However, some potential uses with currently-available growth regulators are unacceptable because of the initial damaging effects of treatment such as severe leaf chlorosis and varying degrees of growth inhibition. The possibility of eliminating these adverse effects by adjusting the formulation of growth regulator solutions should not be discounted. The advantages of encapsulated formulations of chlormequat on bedding plant species have already been demonstrated by Read et al (1974) and further investigations along these lines could be most rewarding.

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2,3-DIHYDRO-5,6-DIMETHYL-1,4-DITHIIN-1,1,4,4-TETROXIDE

A NOVEL PLANT REGULANT

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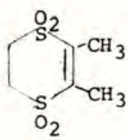
Summary 2,3-Dihydro-5,6-dimethyl-1,4-dithiin-1,1,4,4-tetroxide, coded N-252, has shown promising activity as a potato vine desiccant and cotton defoliant. Tests indicate that this new plant regulant is active in the 0.28 and 1.12 kg a.i./ha range depending upon the species treated and desired response. This paper discusses the results of tests with N-252 on potato and cotton.

INTRODUCTION

2,3-Dihydro-5,6-dimethyl-1,4-dithiin-1,1,4,4-tetroxide, code number N-252, has the following structural formula:



It is a joint development of Uniroyal Limited Research Laboratories in Guelph, Ontario, Canada and the Agricultural Chemicals Research Laboratory in Bethany, Connecticut, USA. Results of the initial screen indicated that N-252 has herbicidal and growth regulant properties. Field trials with N-252 as a post-directed herbicide on cotton, revealed that the chemical has activity as a cotton defoliant. Crittendon et al (1974) and Ames et al (1974) have reported that this chemical is a plant regulant with desiccant, defoliant and fruit abscission properties. The plant regulating response obtained with N-252 is dependent upon the species treated, and the dosage of the chemical applied. The plant regulant properties of N-252 have been extensively studied in the field. This research report will present the results of work with N-252 as a potato vine desiccant and a cotton defoliant.

MATERIALS AND METHODS

Physical and Chemical Properties of N-252. The compound is a white crystalline solid with a mild odor. It has limited solubility in water and a range of solubility in a number of organic solvents.

Molecular weight	210
Physical form	White crystalline solid
Odor	Mild
Melting range	162 - 167°C
Solubility	g solute/100g solvent, 25°C: Distilled water, 0.30; Dimethyl formamide, 32.40; Benzene, 1.96; Xylene, 0.57; Methanol, 0.05; Chloroform, 7.92; Ethylene dichloride, 7.59.

Mammalian Toxicity The mammalian toxicity indicates that N-252 is not hazardous to handle. The acute oral LD-50 on rats is 1150 mg/kg (technical material). The acute dermal on rabbits is greater than 8000 mg/kg (technical material).

Formulation N-252 is formulated as a 50 percent active wettable powder or 179.7 g/l flowable.

Potato Field tests were conducted to determine the efficacy of N-252 as a potato vine desiccant. Plots were established in Evesham, Worcestershire, England. Mature potato vines were treated on August 20 with 0.56, 1.12 and 2.24 kg a.i./ha. Agral (90 alkylphenyl ethylene condensate) was added as an adjuvant at 0.7% of the final spray solution. Paraquat was applied at 0.75 lb. a.i./ac (0.84 kg a.i./ha) as a standard. The chemical was applied in dilute solution at 467.7 l/ha to plots 3.66 x 3.05m. The dilutions were applied with a knapsack sprayer and a hand carried boom with four Spraying System Tee Jet 8004 flat spray utilizing CO_2 as a pressure source at 50.9 gm/cm^2. The traveling speed was 2 mile/h. Percent leaf and stem desiccation evaluations were made four and twenty days after treatment. The evaluation parameters used were; 0-5: 0= no effect, 1= 75% green on stems, 2-3= 50% green on stems, 4= 25% green on stems, and 5= complete kill. These numbers were then converted to % desiccation.

Additional potato vine desiccant plot work was conducted at Bethany, Connecticut, USA. Mature vines were treated on August 8 with 0.56, 1.12 and 2.24 kg a.i./ha with 0.5% and 1.0% U-1126 (an adjuvant) in the final spray solution Dinoseb was applied at 2.8 kg a.i./ha as a standard. Diesel fuel was applied at 2.3 l/ha as an adjuvant with the dinoseb. The treatments were applied and the plots were evaluated as described in the test at Evesham.

A third test with N-252 as a potato vine desiccant was conducted at Perham, Minnesota, USA. The mature vines were treated on August 1. N-252 was applied at 0.56, 1.12, 2.24 and 4.48 kg a.i./ha with 1.0% U-1126 as an adjuvant in the final spray dilution.

The vines in this test were very dense making total coverage difficult. The treatments were applied and the plots were evaluated as described above.

Cotton In 1973, N-252 was tested as a cotton defoliant throughtout the cotton production areas of the United States. Plots in Georgia and Mississippi were machine applied using high clearance sprayers delivering 280.6 l/ha. Spraying Systems TX 12 cone nozzles were used with three nozzles per row directed at the cotton plants. The spraying pressure was 81.4 gm/cm^2, and the sprayer traveled at 2 mile/h. N-252 was applied at 0.14, 0.28 and 0.56 kg a.i./ha with 1.0% U-1126 as an adjuvant in the final spray dilution. N-252 used in this experiment was formulated as a 50% active w.p. S, S, S-Tributyl phosphorotrithioate was applied at 1.28 kg a.i./ha as a standard in these tests. The varieties used were Coker 301 and Stoneville 213 for Georgia and Mississippi, respectively. Visual estimates of percent defoliation were made ten days after treatment. This test was run at two locations in each state.

In California, USA, N-252-50 w.p. was applied by hand boom. The rates of application were 0.28, 0.56 and 1.12 kg a.i./ha with 1.0% U-1126 as an adjuvant. The commercial standard was described above. The treatments were applied with a hand held boom with two Spraying Systems TK 2.5 nozzles delivering 187.1 l/ha at 91.6 gm/cm^2 . The variety used was S-J1. The percent defoliation was rated visually ten days after treatment. This test was run at three locations in the San Joaquin Valley in California.

A test was conducted in McAllen, Texas, USA to evaluate the 179.7 g/l N-252 flowable formulation. N-252 was applied at 0.28 and 0.56 kg a.i./ha with 1% U-1126 as an adjuvant in the final spray dilution. The commercial standard was as described above. The plots were machine applied as previously described for the Georgia and Mississippi experiments. The cotton variety was Stoneville 213. Percent defoliation and percent bolls open were determined by making leaf and boll counts on ten plants randomly selected in each treatment. The observations were made ten days after treatment.

RESULTS

Potato The results obtained at Evesham are reported in Table 1. At four days after treatment, the leaves were completely desiccated with all treatments. However, stem desiccation was not complete. N-252 produced 65, 45 and 35 percent stem desiccation at 0.56, 1.12 and 2.24 kg a.i./ha, respectively. Stem desiccation with paraquat was 50% at 0.84 kg a.i./ha. At twenty days after treatment, the plants were completely desiccated for all treatments.

Table 2 presents the results obtained at Bethany. At four days after treatment, all treatments resulted in 100% leaf desiccation. Four days after treatment, stem desiccation with N-252 ranged from 25-40% with the various dosages and adjuvant rates. Dinoseb at four days after treatment produced only 10%

stem desiccation. At twelve days after treatment, all treatments had 100% stem desiccation. The percent U-1126 in the final spray solution did not effect the results.

The data in Table 3 indicate that N-252 requires increased dosages for effectiveness under conditions of extremely dense vegetation. For complete leaf desiccation, 4.48 kg a.i./ha were required. The standard, dinoseb, did not perform well in this test.

Cotton N-252 gave commercially acceptable cotton defoliation in both Georgia and Mississippi in 1973 (Table 4). In Georgia 0.56 kg a.i./ha N-252 was superior to the commercial standard, S,S,S-tributyl phosphorotrithioate. N-252 was equal to the commercial standard at 0.28 kg a.i./ha. At the two locations, N-252 resulted in 86 and 95% defoliation while the commercial standard gave 73 and 77%. In Mississippi, defoliation for the two locations was 95% with N-252 and 92% with the standard.

Table 5 reports the results of the three locations in California. There was no commercial standard for location 1, but at the other two locations N-252 produced better cotton defoliation than the commercial standard. At location 2, 0.24, 0.56 and 1.12 kg a.i./ha resulted in 25, 40 and 75% defoliation, respectively, while S,S,S-tributyl phosphorotrithioate, the commercial standard, resulted in only 15% defoliation. The commercial standard resulted in 13% defoliation at location 3 with N-252 resulting in 43 and 74% defoliation at 0.28 and 1.12 kg a.i./ha, respectively.

In the Texas test (Table 6) N-252 was slightly less active than the commercial standard. At 0.24 and 0.56 kg a.i./ha defoliation with N-252 was 87 and 82%, respectively, while the commercial standard resulted in 90% defoliation. All treatments promoted boll opening. Percent bolls open was 87, 77, 81 and 65% for the two N-252 dosages, the commercial standard and the control respectively.

Other Crops Other uses have been explored with N-252. As indicated in the cotton defoliation tests, N-252 is active in forming an abscission layer. This activity is apparent when N-252 is applied to oranges and apples. Fruit abscission has been obtained with 100 and 250 ppm respectively, sprayed to runoff.

Table 1

Percent leaf and stem desiccation at four and twenty days after application of N-252 and paraquat to potato vines in Evesham, Worcestershire, England.

	Dosage (a.i.)	Leaf Desiccation (%)		Stem Desiccation (%)	
Chemical	kg/ha	4 days	20 days	4 days	20 days
N-252*	0.56	100	100	65	100
N-252*	1.12	100	100	55	100
N-252*	2.24	100	100	35	100
Paraquat	0.84	100	100	50	100

* These treatments contained 0.1 Angral as an adjuvant in the final spray dilution.

Table 2

Percent leaf and stem desiccation at four and twelve days after application of N-252 and dinoseb to potato vines in Bethany, Connecticut, USA.

	Dosage (a.i.)		Leaf Desiccation (%)		Stem Desiccation (%)	
Chemical	kg/ha	% U-1126	4 days	12 days	4 days	12 days
N-252	0.56	0.5	100	100	25	100
N-252	0.56	1.0	100	100	35	100
N-252	1.12	0.5	100	100	35	100
N-252	1.12	1.0	100	100	40	100
N-252	2.24	0.5	100	100	40	100
N-252	2.24	1.0	100	100	30	100
Dinoseb	2.80	---	100	100	10	100
Control	---	---	0	70	0	70

Table 3

Percent leaf and stem desiccation at fifteen days after application of N-252 and dinoseb to potato vines in Perham, Minnesota, USA.

Chemical	Dosage (a.i.) kg/ha	Desiccation (%) Leaves	15 Days after Treatment (%) Stems
N-252*	0.56	28	0
N-252*	1.12	48	10
N-252*	2.24	73	70
N-252*	4.48	100	70
Dinoseb**	2.80	8	0

* These treatments contained 1.0% U-1126 as an adjuvant in the final spray dilution.

**This treatment contained diesel fuel at 2.3 l/ha.

Table 4

Percent defoliation obtained with N-252 and S,S,S-tributyl phosphorotrithioate (DEF) in Georgia and Mississippi, USA in 1973.

Chemical	Dosage (a.i.) kg/ha	Defoliation (%)			
		Georgia		Mississippi	
		Loc.1	Loc.2	Loc.1	Loc.2
N-252*	0.14	43	30	---	---
N-252*	0.28	63	50	95	95
N-252*	0.56	86	95	93	92
DEF	1.28	73	77	92	92

* These treatments contained 1.0% U-1126 as an adjuvant.

Table 5

Percent defoliation obtained with N-252 and S,S,S-tributyl phosphorotrithioate (DEF) in California, USA in 1973.

Chemical	Dosage (a.i.) kg/ha	Defoliation (%)		
		Loc.1	Loc.2	Loc.3
N-252*	0.28	52	25	43
N-252*	0.56	70	40	--
N-252*	1.12	73	75	73
DEF	1.28	--	15	13

* These treatments contained 1.0% U-1126 as an adjuvant.

Table 6

Percent defoliation and bolls open on Stoneville 213 cotton obtained with N-252 and S,S,S-tributyl phosphorotrithioate (DEF) in Texas in 1974.

Chemical	Dosage (a.i.) kg/ha	Defoliation (%)	Bolls Open (%)
N-252*	0.28	87	87
N-252*	0.56	82	77
DEF	1.28	90	81
Control	---	0	65

* These treatments contained 1% U-1126 as an adjuvant.

DISCUSSION

Potato   N-252 is active as a potato vine desiccant in the range of 0.56 to 1.12 kg a.i./ha. The data presented indicate that results obtained with this new plant regulant are similar to those obtained with paraquat. The test at Perham, Minnesota indicates that where foliage is particularly dense, the rates may need to be adjusted upward. Perhaps lower dosages with two times of application would be needed in these situations.

Cotton   As with potato, the cotton studies indicate that N-252 compares favorably with the commercial standard. Cotton defoliation can be achieved with N-252 in the range of 0.28 to 0.56 kg a.i./ha. In California where defoliation is difficult, N-252 performed better than the commercial standard.

Other Uses   Another area of interest is defoliation of nursery stock. Perhaps defoliated nursery stock could be transplanted without transpiration loss. N-252 should be tested in other area associated with harvest physiology.

References

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THE TIMING OF POST-EMERGENCE HERBICIDE SPRAY APPLICATION FOR BROAD-LEAVED WEED CONTROL IN CEREALS

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Success in following recommendations for the use of post-emergence broad-leaved-weed herbicides in cereals depends largely on two things.

First, the dose of herbicide retained on the target must be correct.

Second, the herbicide must be applied at the right time.

The main concern of this paper is the second of these. The two factors however are related.

A. CORRECT DOSE

The correct dose should be the minimum for the required effect.

If a rapid and total kill of weeds is not required but only a suppression to allow the crop to gain the upperhand it is possible to consider minimal doses.

New developments at the WRO and NIAE on application techniques indicate how the dose can be reduced, whilst still retaining biological activity, by the use of "controlled droplet spraying" using very low volumes of spray.

Minimising the dose can lead to greater efficiency in the use of herbicides. The benefits can include reduced costs, reduced energy input, greater safety to operators and wild life, reduced residues and greater crop safety. But, in addition reduced doses can widen the period of crop safety (eg low-dose MCPA used before the 5-leaf stage).

(This in turn may extend the time available for spraying, easing the workload and reducing the risk of wrongly-timed sprays on the rest of the farm).

Misapplication, ie overdosing, makes correct timing more important. Munro et al (1973) showed that on winter wheat overdoses of 2, 3, 6-TBA had a much greater deleterious effect compared with normal doses when applied at the wrong time than at the right time.

In this paper the accurate application of the currently recommended doses through the normal farm sprayer is assumed.

B. CORRECT TIME

Unless the time is reached when post-emergence herbicides are safe to the crop at any stage there will be a need to define stages at which herbicides may be safely applied.

The factors determining the correct time to spray are first, the aim to maximise the beneficial effect of the spray on the crop/weed relationship; second, the constraints put upon spraying by herbicide and crop/weed interactions and third practical field problems.

I. CROP/WEED RELATIONSHIP - COMPETITION EFFECTS

1. Spring cereals

The work of Elliott (1955) with MCPA on oats showed the trend for improvements in yields with earlier control of weeds. He was working on oats at the 1-4-leaf and 6-7-leaf stages and gained about 14% more yield from the earlier sprays than the later ones. Later work by Evans and Hubbard (1968) using pre-emergence herbicides suggested that there was little advantage from removing weeds before about the 3-leaf stage of the crop. This ties in with the work of Nieto and others which have shown that there are definite periods within the life of a crop when weeds should not be present if competition effects are to be avoided; this period is one which extends within the life of the crop over several days or weeks, starting sometime after crop emergence.

The 3-leaf stage coinciding with the period of sensitivity of spring cereals to weeds is interesting because this is the time when the ear primordia are beginning to form and when tillering begins. It is, of course, the time when growth regulator herbicides can cause ear deformities, although it is now recognised that ear deformities are not necessarily correlated with yield loss. The fact that it is the time when weed competition begins to have an effect may be due to the influence of weeds on the number of tillers surviving to produce an ear and/or on the size of the ear. The large number of trials reported on the influence of weed control on yield seldom explain which component of yield has been affected. Would we not have a better chance to understand competition if we paid more attention to the components of yields (number of heads per unit area, number of grains per head and size of grains), rather than looked at total yield only?

2. Winter cereals

Broad-leaved weeds are not normally controlled in winter wheat until they can be sprayed at the fully tillered stage of the crop. At this time ear primordia will have developed up to some stage between glume differentiation and the first anther initials. At this stage the production of new spikelets has generally stopped. Tillering too, by definition, has stopped. Weed competition up to this stage will have already influenced head and grain numbers. Any beneficial influence of weed control beyond the fully-tillered stage may be, rather, on grain size although there seems little published evidence to support this idea.

The influence of weeds before tillering may be, as in spring cereals, to reduce the number of surviving tillers and spikelets and by analogy with spring cereals it would seem better to prevent weed competition before this stage.

Most herbicides are not recommended for use before the "fully tillered" stage. Some can be used earlier in the spring. Ioxynil and bromoxynil mixtures are "safe" from the 5-leaf stage, dinoseb at the 3-leaf stage and MCPB is safe "anytime in the spring". I have seen no evidence of better yield response from the early use of these herbicides compared with more normal applications.

There is as well the autumn available. Could this be used for weed control? There is now on the market a pre-emergence herbicide for use on winter wheat - methabenzthiazuron - and there is some evidence of better yields from treatment with this than from spring treatments (Hewston 1974).

There seems a good case for looking more closely into the general possibilities of autumn treatment of winter cereals.

In both spring and winter cereals the evidence suggests that best response of the crop to weed removal is likely to be achieved when weeds are removed very early in the life of the crop.

II. HERBICIDE/PLANT INTERACTION

1. Weed Control

We have seen that weed removal in spring barley should be before the 3-leaf stage of the crop. This means spraying relatively early for which there can be an advantage as far as weed control is concerned. At the second British Weed Control Conference 20 years ago Elliott and Fryer (1954) pointed out that "By applying relatively light doses of MCPA at the early stage a good control was obtained of such weeds as redshank, mayweed, speedwell, which are normally classified as resistant or moderately resistant to MCPA".

The tables of weed susceptibility in the Weed Control Handbook show weeds to be more sensitive to herbicides as "seedlings" rather than "young plants". There seem to be no instances where weeds are not more sensitive the younger they are.

In winter cereals, autumn spraying may control some weeds more easily than a spring treatment of the more mature weeds that have over-wintered. The only recommendation in the Weed Control Handbook that might support this idea is for mecoprop which may be used before the "end of the year to control chickweed (Stellaria media)".

I have often heard farmers say that they will not spray "until all the weeds have come" and this is a reason why spraying may, I believe, be unnecessarily delayed. In a paper to this conference in 1966 (Evans, 1966), I showed some evidence that by the time spring cereals have reached the 5-leaf stage the vast majority of weeds will have germinated and often this position may be reached at the 3 or 4-leaf stage of the crop. In any case what is the significance of weeds germinating once the crop is at the 3-leaf stage? If, as a good crop should, it maintains its supremacy over these weeds, few are likely to be of significance. It might be argued that some species, such as Polygonum convolvulus, even when germinating as the crop has 3 leaves or more could still be a problem at harvest. If this is so then let us identify those types of weeds and deal with them as a separate problem.

2. Crop Safety

The decision on when it is safe to spray a crop has three requirements. First, it is necessary to know the crop's reaction to herbicides applied at various stages and to know the 'safe' stages. Second, the safe stages must be capable of being defined sufficiently accurately for practical purposes and third, it is necessary to know how much the crop's reaction to herbicides is influenced by factors such as moisture stress, disease and so on.

a. Determination of 'safe' stages of growth

As we have seen the best time for removal of weeds in spring barley seems to be up to about the 3-leaf stage. The evidence for winter wheat is rather lacking; early removal, or even removal in autumn, seems desirable. There are however some constraints on using herbicide because of the sensitivity in the crop at certain stages. Let us look first at normal recommendations. In spring barley the earliest safe stages according to the Weed Control Handbook (7th edition) are:-

HERBICIDE	NO. LEAVES ON MAIN STEM OF SPRING BARLEY
MCPA - normal dose	1-3 and 5 onwards
MCPA - reduced dose	3
2,4-D	5
MCPB	1
2,4-DB	1
Mecoprop	1
Dichlorprop	1
Ioxynil and bromoxynil esters + MCPA	0
Ioxynil and bromoxynil salts + dichlorprop etc	0
Dinoseb	3
Dicamba mixtures	1
2,3,6-TBA mixtures	3
Bentazon (alone)	0

The "jointing" stage is the time when spraying is no longer recommended except for bromoxynil and ioxynil esters with MCPA which can be used "at all stages of growth".

There are then few weed-killers that are not recommended for use in spring barley at the time weed control is desirable.

In winter wheat the earliest safe stages are given in the Handbook as:-

HERBICIDE	STAGE GROWTH OF WINTER WHEAT
MCPA	"Fully tillered"
2,4-D	"Fully tillered"
MCPB	"Any time in the spring"
2,4-DB	"Any time in the spring"
Mecoprop	"Fully tillered" or "before the end of the year"
Dichlorprop	"Fully tillered"
Ioxynil and bromoxynil esters + MCPA	Not recommended
Ioxynil and bromoxynil salts + dichlorprop etc	5 leaves in main stem
Dinoseb	Any time in winter or spring
Dicamba mixtures	"Fully tillered"
2,3,6-TBA mixtures	"Fully tillered"
Bentazone (alone)	Any time

Again the latest stage is the "start of jointing".

At the first British Weed Control Conference Fryer and Elliott (1953) produced tables for spring barley and oats, showing "Mean percentage reduction in yield due to spraying MCPA and 2,4-D". The reduction occurred over a range of growth stages. More recently Munro et al (1973) report yield reductions from correct use of herbicides in winter wheat. What is the mechanism of yield loss from herbicides? Two periods are generally considered critical. First, ear differentiation and development and second, shooting up to anthesis. The period before ear differentiation also needs consideration.

i. Ear Differentiation

Whilst the spikelet primordia are being laid down it is possible for growth regulator herbicides to interfere with normal cell division and produce deformities known as "opposite spikelets", "whorls" and so on (Myers 1953). Spring barley may be beneficially sprayed at this stage despite the appearance of malformed ears.

If, by analogy with spring barley, weeds have to be controlled in winter wheat by about the time of ear initiation, this means treating wheat in mid-February to mid-April - when the growing point is at the so-called "double ridge" stage. In spring cereals, growth regulator herbicides such as mecoprop, dichlorprop and, with dose adjustment, MCPA can be used at this stage of crop development. What evidence is there that they cannot be as safely used on winter wheat?

Is it possible however that as spikelet components are differentiating normal development may be interrupted and undesirable effects produced, such as reduced potential grain size or aborted flowers, which may lead to yield reductions?

Kirby (1974) has suggested that the period of ovary formation may determine the potential size of grain.

If we are to get yields of cereals towards their potential maximum of around 5 tons/acre, we would probably have to be much more precise in growing the crops and make a conscious effort to control the ear numbers and ear and grain size. For example to control tillering, which determines head numbers, precision planting of the seed may be necessary to ensure even interplant competition. Under such conditions we will need to know more about the effect of post-emergence herbicide use on the growth pattern of the crop.

ii. Shooting and anthesis

Some years ago in order to take photographs to illustrate "rat-tailing", one of the symptoms that can be caused by late spraying - ie at the jointing stage and later - I sprayed some winter wheat at anthesis with growth regulator herbicides at about twice normal dose. I tried this in two successive years but failed to produce any symptoms both times. And yet only 3 years ago we had a lot of poor wheat crops largely of Joss Cambier as a result of, it seemed, spraying too late. In most years, a few fields of damage of this sort seem to occur. There must be many thousands of acres of wheat sprayed at the jointing stage, if my observations on farm practice reflect the general, without any dire results.

Some herbicides may be more prone to cause trouble than others. Evans and Holroyd (1962) showed that with correct use some herbicides have a greater margin of safety to the crop than others, eg 2,3,6-TBA was more prone to damage the crop than mecoprop. The work of Munro et al already referred to showed greater harm from 2,3,6-TBA and ioxynil, but not MCPA or dichlorprop, at stage 7 (jointing) than at stage 5 (fully tillered).

One has to question whether the crop at the "jointing stage" is any more sensitive to some herbicides than at the "correct" stage. Is the sensitive period relatively short? At about the 2-node stage, floret differentiation is likely to be at the stage when anthers are forming. Is there any evidence that this is a particularly critical stage?

In some ADAS trials in the South East (Hughes 1974) some components of yield have been looked at and the indications are that loss of yield from spraying at the "jointing" stage (GS 6-7) has come more from reduced numbers of ears per acre and to some extent reduced numbers of grain per ear rather than from reduced grain size. This suggests that the influence of spraying is on the shoot and floret survival. If so it could be argued that it might be safer to spray nearer to anthesis when shoots and florets are more fully established, particularly where the main benefit of weed control is likely to be the easing of harvesting problems.

There can be disparate ear development in different tillers of the same plant as tillers develop, but by the time of jointing or noding, ear development in tillers can have caught up with the stage of the main stem so all might be equally vulnerable. It is noteworthy that when late-spraying symptoms occur practically all the heads seem more or less affected.

It was suggested when Joss Cambier was the variety most affected by seemingly late spraying that modern varieties of winter wheat might develop internally more rapidly than external morphology would indicate. There seems little or no evidence to support this view. From casual inspection of a number of growing points I drew a tentative conclusion that modern varieties are not likely to differ radically in their development from Cappelle Desprez.

Does something trigger off wheats susceptibility to late sprays? Water stress can cause failure of ears to fill properly (Swain and Melville 1973). Take-all disease causes similar problems. A report in 1966 (Evans) gave an example of where take-all caused an undesirable effect in wheat which was made much worse by a growth regulator herbicide which, on the parts of the field unaffected by take-all, had no apparent effect on the crop. If the possibility of damage is tied up with conditions should we not put constraints on spraying according to, say, moisture deficits (as has been done with diquat for potato haulm desiccation) rather than stage of growth?

iii. Before ear differentiation

The use of herbicides before ear differentiation has had relatively little attention but as autumn spraying of winter wheat could have advantages - better weed control, better crop response and easing of the spray programme - more evidence on autumn treatments seems desirable.

There would be no ear deformity from growth-regulator herbicides for the primordia would still be vegetative. Malformation of leaves could occur - so-called "onion leaves" have been recorded. The effect of these on yield is not known. They may physically trap emerging ears and this may interfere with normal development. The effect however may be dependent on timing of the spray. Robinson and Fenster (1973) report less effect from autumn spraying of wheat with growth regulator herbicides than they had expected from reading the literature. They found autumn to be one of the safest periods.

b. Definition of "safe" stages of Growth

One of the problems of defining a stage of development for any particular crop is that, as already discussed, tillers within that crop may be in disparate stages of development. Normally by harvest time all tillers ripen together so that there is from the time of tillering onwards a narrowing of the gap between development stages of tillers. From a limited number of winter wheat growing points that

I have looked at, the indication is that by the time the noding is clearly visible - and very often the second node is noticed before the first - the stage of spikelet differentiation is often very similar in all tillers. Earlier, the differences must be greater. This is illustrated by the occurrence of normal and malformed heads and the varying positions of malformation along the rachis in crops treated with a growth regulator herbicide at the time of ear initiation.

Ear differentiation in winter wheat starts in the spring after vernalisation and as days lengthen. Ear primordia may appear on different dates in different crops according to sowing date, weather conditions and perhaps variety. Is it really possible to judge the stage of ear development from external morphology of the plants? Presumably the term "fully tillered" was conceived because it was felt that the ear would be well formed in all tillers at this stage.

What does "fully tillered" mean? How is this stage judged? I do not know when winter wheat is fully tillered except when the nodes can be seen; so the phrase "fully tillered to jointing" to me defines a zero period!

Farmers in Yorkshire this last spring sprayed much of their wheat in early May when it was just about at the jointing stage, despite having had a wonderful April when much spraying could have been done. It seems to me that farmers tend to recognise the fully tillered stage as the early jointing stage.

The ability to clearly define stages is necessary when trying to test crop sensitivity at various stages. The ADAS work on late spraying of winter wheat has produced some rather random results. For example in the ADAS West Midland Record of Investigation for 1973, Cappelle Desprez is reported to have behaved as expected. Yield was reduced when sprayed with a herbicide at jointing (GS7) but not when sprayed at tillering (GS5). Maris Huntsman had its yield reduced equally by the herbicide at both times of application. Perhaps if development of the crop had been more precisely defined a clearer picture could be discernible in some of these sorts of results.

In spring barley there seems little problem at present in determining the safe and desirable time of using herbicides.

III. FARM PROBLEMS

Even when the stages of growth at which spraying should be carried out are adequately defined there can still be practical problems of getting the spray on at the right time. These are broadly two. First, the period suitable for spraying, may be restricted. The main restrictions are wind, rain, temperature and soil conditions. Second, the spraying machine takes time to get round the farm and fairly large acreages may have to be dealt with by one man and a machine. In addition available time may be restricted by the constraints imposed by other pesticides (eg minimum periods between using barban and some growth regulator herbicides).

It is surprising how few suitable days there are for spraying in the spring. Wind and rain, mainly, prevent spraying.

Some data from Leconfield meteorological station in Humberside has been analysed by Tyldesley (1974). This shows that with a wind speed not in excess of about 5 mph at boom height there is only the equivalent of about 1 day in 5 suitable for spraying in April and May. To increase this figure to 3 days in 5 it would be necessary to spray regardless of the wind in April and to accept a wind speed of 10 mph in May. This however means sometimes spraying at a speed on the Beaufort scale of 4 to 5 - a moderate to fresh breeze - which is generally recognised as being too windy, but which nevertheless is the sort of condition in which some farmers, at least in Yorkshire, do spray.

Producing an application system less influenced by wind would help increase the efficiency of herbicide use but what is also needed are herbicides that can be independent of rainfall. Rainfall is the second most important restriction on spraying.

Less dependence on the weather is one way of reducing delays. The other is to increase the output of sprayers and to this end reduction in filling time by using larger tanks and lower volume rates and increasing speed of working by widening booms is all to the good. The value of pesticides put through spraying machines and the resulting profits are these days considerable and should warrant greater expenditure of suitable sprayers and greater meticulousness in their use. Tottman (1974) goes into this matter more fully in his paper later in the Proceedings.

The work on weed competition and on weed sensitivity to sprays both suggest that early spraying is desirable. Objections to the practicality of early low dose systems on cereals are that the weather is not suitable in early spring, low temperatures reduce the activity in herbicides and late germinating weeds escape. It is interesting that some observations made in Yorkshire suggest that in some years at least, there may be more good spraying days in April than May. The effect of low temperatures when studied under critical conditions has generally been to subdue the activity of herbicides although some herbicides are claimed to be little affected by low temperatures (eg mecoprop at least for chickweed control and 2,3,6-TBA). Increasing temperatures are normal in spring and it is questionable whether spraying should be delayed in spring because the day is cold. Even though cold weather does slow the effects of weedkiller is it deleterious in the long run? Hanf (1957) in Germany has shown that cool weather is generally no detriment to the effectiveness of growth regulator herbicides providing frost does not occur at night. A little more critical information on the effects of low temperatures in the field would be useful. The criticism that early spraying misses later germinating annual broad-leaved weeds has already been discussed. The criticism has validity in relation to perennial weeds like creeping thistle.

Interaction between pesticides is still a field open to much study. Knowing more about the mechanism of interaction could lead to ways of overcoming a relatively recent problem that can interfere with correct timing of sprays.

It seems to me that many farmers could start their spraying programmes earlier than they do. This could spread the work leading to more accurate timing on a larger proportion of their crops. But what is needed is a clearer guide to the available times of spraying the various post-emergence broad-leaved herbicides, particularly in relation to winter wheat. Can safe stages be more clearly determined for the various herbicides and varieties of wheat; and can they be defined so as to be understood by men in the field?

Many acres are sprayed successfully each year but yield reductions and bad effects are not unknown. Broad-leaved weed control is big business and enhanced efficiency could pay off. Even though it's 30 years on from the start, we still have much to learn.

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POSSIBLE APPROACHES TO THE ENHANCEMENT OF HERBICIDE EFFICIENCY

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Summary Criteria by which to judge herbicide efficiency include weed kill, crop tolerance, reliability, economy and safety. The general principles concerned with increasing weed kill and crop tolerance are considered in terms of the steps involved in herbicide activity. Examples are given of how herbicide efficiency may be enhanced by manipulation of the crop, exploitation of the biology of the weed, consideration of environmental factors and correct choice of herbicide application technique and adjuvants.

1. INTRODUCTION

The costs of buying and applying herbicides are rising steeply while the possible risks of contaminating the environment with these compounds continue to cause concern. Consequently means of improving herbicide efficiency are particularly appropriate at the present time.

Criteria by which to judge herbicide efficiency include weed kill, crop tolerance, reliability, economy and safety. Only the first two criteria are considered in this paper, but in many instances, reliability, economy and safety are improved as a consequence of enhancing these.

Enhancement of weed kill may lead to a given dose of herbicide producing one or more of the following:- (1) a higher percentage kill, (2) control of a wider range of species and (3) prolonged control. In the crop situation it is essential that there is no adverse effect on selectivity, and conversely methods of improving crop tolerance should not reduce the control of the target weed. Increased crop tolerance to a herbicide may improve efficiency by allowing (1) use of a high dose of herbicide resulting in more effective and consistent weed control, (2) treatment at more crop growth stages giving greater flexibility in timing of application, and (3) application under a wider range of climatic and soil conditions.

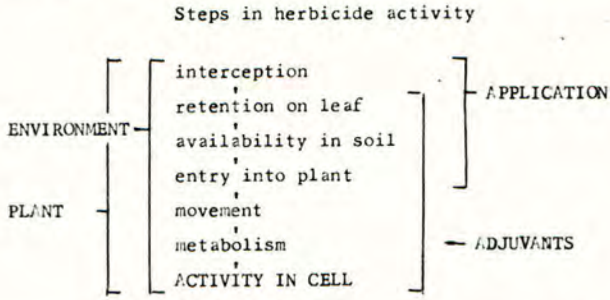
The objective of this paper is to consider briefly the general principles underlying the enhancement of weed kill and crop tolerance and to illustrate this with examples.

2. FACTORS THAT INFLUENCE HERBICIDE ACTIVITY

The progress of a small proportion of the herbicide from the applicator to the site of action within the plant cell may be considered to be accomplished in a number of steps (Fig. 1). Enhancement techniques may exert their influence at one or more of these steps.

Fig. 1

Factors that affect the steps involved in herbicide activity



Heightened toxicity may result from an increased proportion of the applied compound reaching the site of action and/or the activity of the herbicide there being increased. Conversely crop tolerance depends on minimising the quantity and/or activity at the site of action.

The factors that affect herbicide performance may be considered in terms of the degree of control that man has over them, thus application and formulation of the herbicide rank first as they may be selected to suit the situation. Man can manipulate the sowing and to some extent the genetics of the crop, but not of the weed and both are influenced by the climate over which he has no control. However, the influence on weed kill and crop tolerance of uncontrolled factors such as temperature can be determined and conditions for maximum and minimum herbicide performance quantified. With such background information the dose of herbicide, the method of application and choice of adjuvant can be manipulated to try to overcome the effects of suboptimal conditions.

3. ENHANCEMENT OF HERBICIDE EFFICIENCY

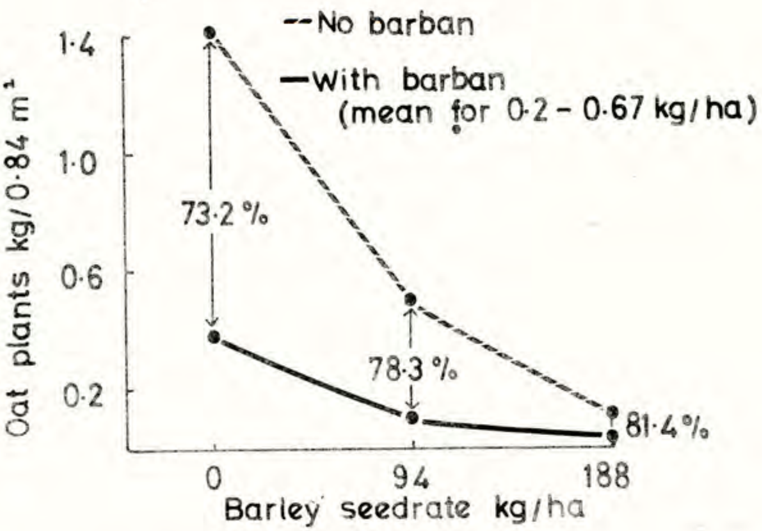
3.1. Contribution of crop

3.1.1. Competition. The growth and subsequent propagation of the weed may be substantially reduced by competition from the crop for light, nutrients and water and consequently enhance herbicide efficiency.

The farmer can adjust the planting density or even select the crop in order to obtain the most effective competition. Increasing the seed rate of spring barley 'Zephyr' from 94 to 188 kg/ha halved the number of *Avena fatua* seeds produced from a pregerminated planted population of 36 plants/m^2 (Bates *et al* 1970). When a herbicide is added to this crop/weed situation competition from the crop continues to play a major role as shown in Fig. 2 (Pfeiffer and Holmes 1961). In this experiment cultivated oats (62 kg/ha) were grown in competition with barley and treated with barban. The percentage reduction in weight of oats due to barban was almost constant for all barley seed rates and maximum control was achieved at the highest seed rate of barley.

Fig. 2

Effect of barley seedrate alone and barley seedrate plus barban on total fresh weight of oat plants/unit area. The figures between the arrows give the percentage reduction due to barban treatment at each seedrate of barley
(After Pfeiffer and Holmes 1961)



The role of crop competition in enhancing herbicide efficiency is widely recognised and concern has been expressed by Cussans (1972) that plant breeders in their quest for higher yields may produce plants that are less competitive i.e. dwarf types with fewer tillers. An interesting development in the way in which crops may compete with weeds has been reported by Dubey (1972). He found that root exudates from onion and tomato stimulated and depressed respectively the germination of the tropical weed Digera alternifolia. It is proposed here that the plant breeder could make a substantial contribution to herbicide efficiency by selecting for crops with root exudates which have one or more of the following characteristics: (1) stimulate germination of weed seeds so that more weeds can be killed with a single dose of herbicide, (2) inhibit germination of weed seed, and thus reduce the number of weeds to be killed, (3) have a toxic effect on growing weeds and reduce their vigour.

In relation to point 3 above, a convincing case for an allelopathic mechanism in Agropyron repens has been presented by Ferdinandez (1974). Because of the close taxonomic relationship, the potential for an allelopathic mechanism may well exist in cultivated wheat. If so, this could be exploited by plant breeders to compensate for less tillers and height in certain high yielding varieties.

3.1.2. Crop tolerance. Enhanced crop tolerance may be achieved in a limited number of situations by use of adjuvants (see section 3.4.4.) while another promising approach is to include tolerance to herbicides in plant breeding programmes. However, in the WRO Annotated Bibliography No. 46, 'Selected references to the selection and breeding of cereals and other crop varieties for increased tolerance to herbicides 1953-1972' it was concluded that although the potential value of selecting for increased herbicide tolerance was recognised no active breeding programme had been reported.

Following collaborative experiments between the Weed Research Organization and the Plant Breeding Institute crop tolerance to herbicides is being actively pursued and the programme at PBI includes the inheritance of resistance to chlortoluron and metoxuron in winter wheat.

3.2. Exploitation of the biology of the weed

3.2.1. Dormancy is a key factor contributing to the success of many important weeds. One reason for this is that dormant seeds and buds are frequently resistant to herbicides, while seedlings and sprouting buds on perennials tend to be particularly susceptible to herbicide treatment. Thus dormancy breaking chemicals have a great potential for increasing herbicide efficiency as an increased number of weeds are made vulnerable at one time and can be treated at the most susceptible growth stage. Some success in field treatments has been achieved with ethylene which can substitute for host root exudate and cause 90% germination of the parasitic *Striga* spp. (Egley and Dale 1969). Up to now no chemical treatments have been reported which release temperate weed seeds from dormancy in the field. However substantial increase in germination of weed seeds has been achieved with ethephon (proposed common name for 2-chloroethyl phosphonic acid) under laboratory conditions (Chancellor *et al* 1970). Cultivations release some seeds from dormancy by altering depth of burial and brings into play other environmental factors, but innate dormancy is not usually affected.

Minimum tillage, compared with ploughing, results in an increased number of seeds in the surface layer of the soil and this would facilitate the use of dormancy breaking chemicals as less depth of soil would have to be permeated in order to reach the seeds.

3.3. Consideration of environmental factors

The amount of herbicide necessary for effective and reliable weed control is greatly affected by environmental factors before, at and after herbicide application. This is illustrated by reference to work on the control of *Agropyron repens* with glyphosate conducted at WRO.

The prespraying environment affects the size, form, habit and cuticular characteristics of the shoots and the development of the rhizome to which herbicide must be transported for effective control. To some extent field assessments can indicate the degree of infestation, but it is important to consider factors other than the amount of foliage; as shown in Table 1.

Table 1

Growth of *A. repens* at three light levels while temperature and humidity were constant at 16°C and 80% RH respectively

Light W/m^2	203	50	13
Number of shoots	22	15	11
Rhizomes fresh wt (g)	22	8	2
Number of nodes on rhizome	82	37	8
Shoots: Nodes	1:3.8	1:2.5	1:0.7

At lowered light level found for example within a cereal canopy during the summer or in open ground in winter, the high shoot to node number is conducive to control by foliage-applied herbicides.

Conditions several hours before and after spraying are important especially in relation to retention and penetration. An experiment to investigate the effect of humidity level 2 hours after application of glyphosate to *A. repens*, while temperature and light levels were constant at 16°C and 200 W/m^2, showed that glyphosate activity was favoured by high humidity at this time (Table 4). During the weeks after spraying low temperatures increase glyphosate effectiveness, while warm conditions favour recovery of the plant (Caseley 1972).

In the field situations when *A. repens* is being controlled in the autumn following a cereal crop, a sequence of desirable environmental conditions obtain which are conducive to herbicide efficiency. The weed will have grown in a low light competitive situation in the crop, while autumn conditions may provide humid conditions for spraying followed by falling temperatures as winter approaches.

3.4. Manipulation of herbicide application and adjuvants to increase efficiency

3.4.1. *Techniques to increase interception and retention*. Many biological and physical factors influence the interception and retention of foliage applied herbicides and only a limited proportion of the applied spray reaches the target weed foliage. Consequently manipulation of application techniques has considerable potential for improving herbicide performance. While considerable scope exists for increasing the performance of application machinery currently in use it is proposed to refer briefly to one speculative technique, electrostatic charging, which has potential to increase interception and retention.

This technique of enhancing application has been used with success for improving deposition of fungicides and insecticides dusts on plants (Coffee 1973).

The principle is relatively simple. Charged particles repel one another and are therefore more uniformly distributed and the size of the spray cloud is thus increased. If the particles are negatively charged they attract free positive charges to the surface of the plant closest to the cloud and negative charges are repelled to earth. The negatively charged particles are then attracted to the positively charged plant.

Modern electrostatic charging equipment, as used in paint spraying, enables high charges to be induced on the drops and a more uniform deposition occurs over the targets including undersides of leaves.

Exploratory work on the electrostatic charging of aqueous sprays at the University of Sheffield indicates that deposition of drops on single 3-leaf barley plants can be doubled by this technique (Hopkinson 1974).

3.4.2. *Techniques to increase weed kill*. Various materials may be added to the herbicide active ingredients to heighten their toxicity, thus enhancing herbicide efficiency. However increased kill of the weed may be accompanied by reduced selectivity and manipulation of formulation requires to be tested in specific situations.

Surfactants generally enhance retention and penetration and sometimes movement of herbicide in the plant, but response depends on the concentration and type of surfactant and the species involved. The data in Table 2 show that surfactant increases chlorpropham penetration into *Ipomoea* sp., but has an opposite effect in the case of *Setaria* sp.

Oils as adjuvants or carriers have advantages over aqueous carriers in certain situations and enhance uptake through the lipophilic pathway and the use of an isoparaffinic oil carrier resulted in the maximum uptake of chlorpropham in both species (Barrentine and Warren 1970) (Table 2).

Table 2

The influence of adjuvants on the percent penetration of ^{14}C-chlorpropham into leaves of Ipomoea hederacea (L. Jacq) and Setaria faberii Hamm.

Chlorpropham (2.4×10^{-2} M)	Ipomoea sp.	Setaria sp.
no adjuvants	14	10
0.25% v/v Triton X 77 surfactant	24	4
in isoparaffinic oil	47	25

(after Barrentine and Warren 1972)

Improved post-emergence performance by employing oils is not restricted to oil miscible herbicides such as chlorpropham. The performance of water soluble compounds such as glyphosate and herbicides such as atrazine with low solubility in both water and oil may also be enhanced.

Increased herbicide performance achieved with adjuvants may in some situations mitigate adverse environmental conditions. When glyphosate application is followed by a low **compared** with a high humidity regime its activity is reduced; however the addition of acid butyl phosphate (ABP) overcomes this adverse environmental effect (Table 3).

Table 3

The effect of ABP on the performance of glyphosate against Agropyron repens at two humidities

Treatment	Fresh weight of plants (g)			
% RH for 2 hr after spraying	45%		95%	
ABP 10 kg/ha	–	+	–	+
Control	20.7	20.5	20.9	21.3
glyphosate 0.1 kg/ha	5.0	1.5	2.9	1.1
glyphosate 0.2 kg/ha	3.5	0.8	1.8	0.8

Many other compounds may be employed as adjuvants including plant nutrients and other herbicides.

3.4.3. Techniques to prolong activity. In many situations some degree of residual activity is required to control weeds which emerge over a period of time. The dose of herbicide has to be increased above that required to control a single emergence of weeds as compensation has to be made for losses by physical, chemical and microbial processes. Compounds such as EPTC which have a high vapour pressure are particularly subject to loss by volatilization. This can be reduced by incorporation in the soil. Gray and Weierich (1965) found that loss of EPTC could be reduced from 89% when left on the surface to 25% following incorporation to 8 cm in the soil.

Incorporation into the soil also reduces loss due to photodecomposition but this technique accentuates other forms of loss such as absorption and may reduce the activity of some soil-acting herbicides.

Another approach to prolonging activity, which overcomes some of the disadvantages of soil incorporation is to mix the active ingredient with an inert carrier and form granules. The active ingredient is then leached from the granule or released by diffusion over a period of time. The concentration of active ingredient, size of granule and number applied per unit area may be adjusted and a limited degree of control over duration and concentration of active ingredient at the soil surface may be achieved.

Greater control over the release of the active ingredient is obtained by using polymers as the inert carrier in which the active ingredient is dissolved or encapsulated. In the case of certain herbicides such as 2,4-D the active ingredient may be chemically attached to the polymer and released by biological degradation. Thus the granule may be applied under dry conditions and the 2,4-D will not be released until moisture and other requirements for biological activity and weed growth obtain.

Allen et al (1971) used a timber industry by-product, Kraft lignin, as the polymer in a combination with 2,4-D and obtained up to a fivefold increase in duration of herbicide effectiveness compared with the same dose of 2,4-D alone.

3.4.4. Techniques to increase crop tolerance to herbicides. Increasing crop tolerance to herbicides with a low margin of selectivity was until fairly recently exclusively based on preventing the herbicides reaching the crop. Techniques included placement in the soil, directed sprays and timing of applications to hit the weed before crop emergence.

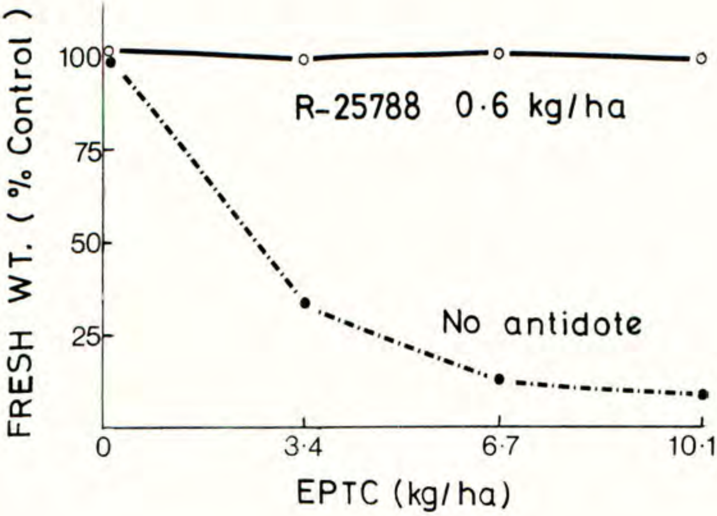
Activated charcoal has been used as an adsorbent berrier applied direct to roots and seeds before spraying and as a band treatment above seeds.

Antidotes such as naphthalic anhydride and N,N-diallyl-2,2-dichloroacetamide, R-25788, do not prevent the herbicide from coming into physical contact with the crop, but exert their protective influence within the plant. The mechanisms involved are not understood at present.

Fig. 3 shows that 0.6 kg/ha of R-25788 applied as a tank mix with EPTC and incorporated into the soil, completely protected corn from EPTC injury at all rates including 10.1 kg/ha. The toxicity of EPTC to green foxtail (*Setaria viridis* (L.) Beauv.) was unaffected. The same degree of protection was obtained by treating the corn seed with 0.5 g of R-25788 active ingredient per 100 g of seeds (Chang et al 1973).

Fig. 3

Effect of R-25788 (N,N-diallyl-2,2-dichloroacetamide) on EPTC toxicity to Zea mays L. 'United Hybrid 106' (after Chang et al 1973)



At present there are only a few antidotes and herbicides with which they can be used, but this concept is being followed up at WRO and other research centres.

CONCLUSION

Successful herbicide use is dependent on many factors and potentially herbicide efficiency may be enhanced through any of these. Generally methods of enhancement cannot be applied across the board, each technique being specific to a particular or limited range of situations.

All enhancement techniques cost money whether they involve a plant breeding programme to increase the competitive ability of the crop or surfactant to increase retention of herbicide on the weed. However, as the cost of herbicides and chemical adjuvants continues to rise the desirability of non-chemical approaches to enhancement of herbicide efficiency may well increase.

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TO ENHANCE OR NOT TO ENHANCE, THAT IS THE QUESTION

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The chances of producing a new herbicide which will competitively find a commercially attractive position in the market are, in common with other pesticides and with pharmaceutical products, becoming more and more difficult. Statistics show that over 10,000 compounds must now be screened before a new product is found by random screening; this figure may seem somewhat conservative to those at the 'front end' of research (Hunter, 1974).

Table 1

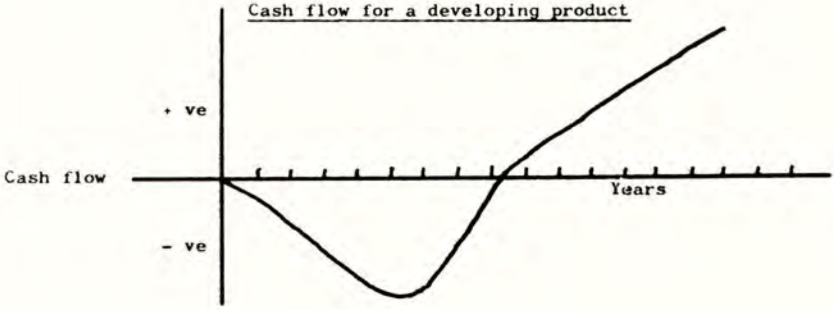
Number of compounds passing through each R & D stage per commercial product

Activity	1956	1964	1967	1969	1970	1972
Synthesis & initial bio-screen	1800	3600	5500	5040	8000	10000
Advanced screening	60	36	NA	126	80	NA
Field evaluation	6	4	NA	9	4	NA
Development	2	2	NA	2	2	NA
Sales	1	1	1	1	1	1

When the new compound has been found, the standard form of the cash flow graph (Fig. 1) may indicate that the commercial future for the product becomes less and less attractive as costs spiral upwards and demands, e.g. by registration authorities become more exacting - especially as analytical techniques improve to the stage where they can reveal residues where there formerly appeared to be none, or undisclosed impurities or metabolites become evident.

Fig. 1

Cash flow for a developing product



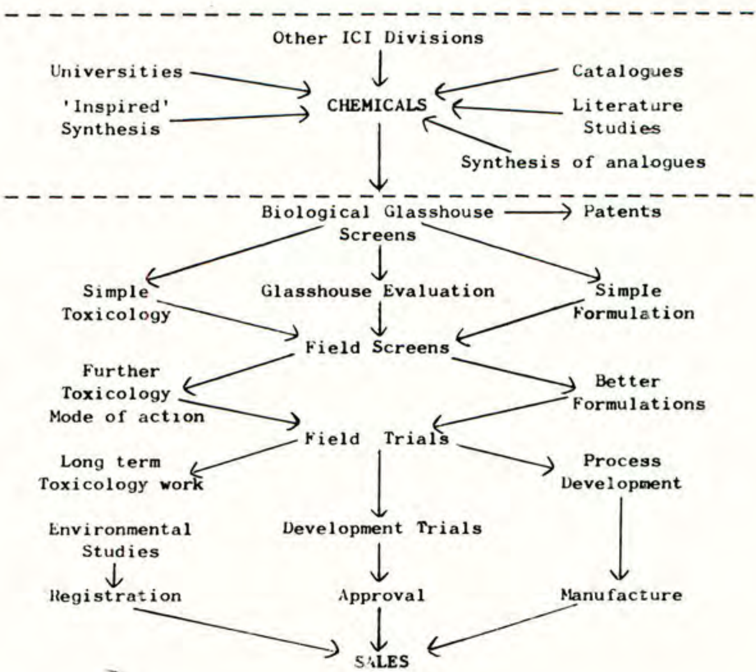
Those responsible for research and development within a company must, therefore, take all steps possible to ensure that the expenditure within their control produces the maximum income or, preferably, the maximum gross margin for their company.

Having found activity within a certain class of chemical compounds a decision has to be made as to the best way of finding the most active compound within what may be an area containing many thousands of analogues. A relatively early success in screening and evaluation could produce a worthwhile product and subtle patenting must then be used to protect, as far as possible, the remaining unsynthesised compounds.

The chosen compound will undoubtedly have some deficiencies in its overall herbicidal activity with regard to dosage rate, selectivity, spectrum of activity, etc. Consideration may well turn to further synthesis of analogues in the hope of finding a better product, but it is unlikely that chemical manipulation will solve all the problems. It is at this stage that enhancement warrants an allocation of research and development effort. It will be seen from Table 2 that although enhancement by-passes the discovery stages there may still be a great deal of work to be done.

Table 2

Discovery and development of a new pesticide



Enhancement can be directed towards the following areas:

1. Improving activity within the known spectrum of weed control resulting in a lower usage of the compound to produce the same effect.

2. Improving activity within the known spectrum for the use of the same dosage.

3. Broadening the spectrum of activity.

4. Improving the margin of selectivity.

5. Improving the 'user appeal'.

If enhancement is a worthwhile objective a number of ways of approaching the problem should be considered. Those who know best the mode of action of the chosen compound and preferably the reasons why it does not exhibit all the desired properties must choose the optimum approach.

The five possible areas of enhancement can be considered in terms of the problems involved and means of overcoming them.

1. Improving activity within the known spectrum of weed control resulting in a lower usage of the compound to produce the same effect.

Unless the chemical reaches the crop in a form suitable for its transmssion to the site of activity at or above the optimum dosage rate, it will not perform as expected. This is a simple statement but the practice is very difficult to achieve. Many difficulties are met when spraying foliage especially where a high cost necessitates a low dosage rate. The type of foliage, its waxiness, rates of drying, droplet spectra, etc. must all be considered and the use of viscosifiers, humectants, surfactants and so on should have been investigated, using, for example, radio labelled active ingredients, fluorescent compounds, and accurate analyses to ascertain the success of such trials (Turner, 1974; Turner & Loader, 1970).

In the case of soil-applied materials, for example, in granular form, the rate of breakdown of the granules, the rate of release of the compound from the granule and the even distribution of the applied granules must be examined. It is known that the base exchange value and absorption capacity of the soil may control the movement of the chemical to the zone of root uptake, and the lipophilicity of the compound itself may again be a major factor in final activity. All these points are a matter of concern for the development team and the resolution of what may at times be conflicting parameters must be achieved to reach the optimum dosage rate. This work involves a number of actions which should be included in attempts to enhance activity. If the work is well done a dose rate should have been achieved which in practice is the minimum to produce the desired result with the expected spectrum of activity. This is the first prime objective.

2. Improving activity within the known spectrum for the use of the same dosage.

Naturally, development work cannot stop at this stage and it is now necessary to look at the next step of how still to reduce the dosage rate. Essentially this may consist mainly of more detailed investigations of some of the parameters already tried in the establishment work. Literature surveys will reveal innumerable formulation techniques including a very wide variety of additives which it is claimed will enhance activity. The great differences which exist between exciting results which may be obtained in the glasshouse and those finally established in the field are now well known. This difference in activity is most noticeable when different formulations are compared, and the replacement of an established product by a new and novel mixture needs a considerable amount of replication in glasshouse and field, on different weed and crop conditions, before the risk can be taken. This section has been deliberately kept to the discussion of maintaining the required spectrum of activity and it must be emphasised that a change in formulation may well alter the spectrum of activity or increase other problems, e.g. the damage to adjacent crops from drift. Care must also be taken to get toxicological clearance for the enhanced formulation as the use of wetters, oils, viscosifiers, etc. may modify both the percutaneous absorption of the active ingredient and the transfer through body lipid systems thereby increasing or at least changing the mammalian toxicity.

3. Broadening the spectrum of activity.

The third category involves what is probably the greatest spur to enhancement - the need to broaden the spectrum of activity associated with the main active ingredient. The use of mixtures is well known and as more and more established products become free from patent the need is bound to extend, and if unexpected synergism and other effects are produced, the possibility of patenting that particular mixture can produce a major commercial advantage. If no patent can be obtained one may have only opened the market to competitive attack, resulting in no greatly increased market for any one company. The skills of the formulating chemist may well be taxed to provide an advanced formulation of two or more herbicides with vastly different physical properties but, again, if success is achieved a useful patent could result from the work. The wording of such a patent may be difficult as one would need to claim possibly a special advantage of a mixed formulation, for example, with respect to its handling properties or advantageous physical properties simplifying or safening application methods, or unexpected synergism (Turner, 1974; Turner & Loader, 1970), between the mixed compounds which would have wider justifiable claims.

It may be wise to review briefly the possible interaction of these compounds which have been mixed together and the new formulation which may have been produced. Foliar-acting herbicides may interfere with the separate activity of the individual compounds by modifying the amount of compound landing on or retained on the leaf surface. Different surfactant systems may modify penetration, increase wetting, etc. (Foy & Smith, 1965; Smith et al, 1966). Photosynthetic inhibitors may greatly increase movement after penetration through the cuticle. Fast-acting herbicides may destroy the translocation system and so reduce the uptake of a slower-acting compound.

For soil-acting compounds, uptake through the roots may be affected by interference of one compound with the uptake of another. Movement of the parent compound through the soil is unlikely to be greatly affected by the separate components of a mixture but it is extremely unlikely that each compound will move at the same relative rate in soils of different textures and of different water contents. It is therefore important that claims for enhanced effects are corroborated under a variety of conditions.

4. Improving the margin of selectivity.

The inherent selectivity of the major compound must first be determined by carrying out appropriate uptake experiments covering a representative selection of crop and weed species preferably, at the start, using soilless culture and labelled chemical. Equivalent uptake in different plant species producing major differences in biological activity - indicating inherent selectivity - probably needs little further work with soil-acting chemicals. Similar experiments using foliar sprays should be done, care being taken to mask the soil so that chemical cannot get on to the soil via leaf run-off or misdirected spray thereby being taken up by the roots and translocated through the plant. If tests with the experimental formulation show enhanced selectivity, indicating that the inherent toxicity of the parent compound is increased within the plant by the use of the additive, the indications are that the mixture is basically useful. If selectivity is shown to be only similar to that of the parent compound then the mixture is not useful in these conditions.

It would exceed the remit of this paper to suggest that an answer to this problem would be to synthesise new compounds which had modified partitions between aqueous and lipid phases. One way to contemplate modifying the selectivity of the prime compound in practical application is to look at the environment in which the compound finds itself. Within the plant, saturation of areas of adsorption by non-herbicidal compounds of similar adsorption characteristics may well modify movement and thereby alter selectivity.

Where selectivity depends on the physical characteristics of leaf surfaces, the modification of the physical properties of the spray droplet can well affect the degree of rejection of the droplet from certain crop surfaces thereby enhancing or possibly increasing retention and thereby activity.

The above aspects are only some of those which might be examined to modify in general, uptake and translocation.

5. Improving the 'user appeal'.

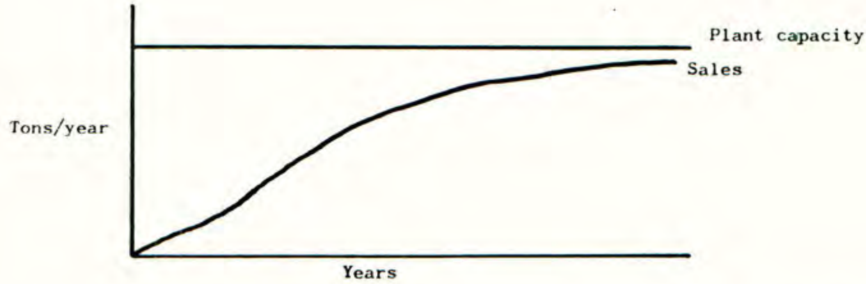
Another aspect of 'enhancement' often overlooked is the improvement of the product in the eyes of the user. There are still many herbicides in use which are difficult or unpleasant to use perhaps because of a dust hazard, poor dilution properties, incompatibility, etc. From the salesman and buyer aspects, major improvements in appeal, in ease of use, in simplicity in measurement, increased safety, and lower cost are worthwhile approaches to enhanced sales.

CONCLUSIONS

Most aspects of enhancement cost money in research, in re-registration, in toxicology, in analysis, in glasshouse and field trials and so on. If the costs/benefit ratio is acceptable, the probable answer to the title of this paper is Yes, enhancement is worthwhile. How worthwhile must depend on the relative sizes of these costs and benefits. If the enhanced formulation is protected by a strong patent cover then it would seem reasonable to offset costs against benefits over a fair number of years. If there is no firm patent protection then world wide development costs, conservatively estimated at some hundreds of thousands of pounds must be recouped within a few years by which time competitive action may have been taken, resulting in potential loss of sales.

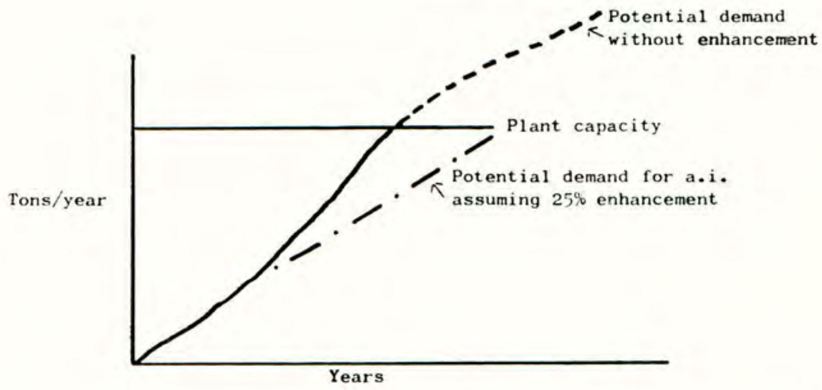
When considering the benefit to be derived from the replacement of the active ingredient in a formulation by another additive, it is important to remember that it may be the marginal cost of the active ingredient which is being saved. If one is concerned with a situation in which manufacturing plant is running at well below capacity, and it is expected to do so for some time, (Fig. 2), then the marginal cost of the chemical saved is only the variable operating costs (i.e. the raw materials and conversion energy, steam, electricity, etc.) per ton.

Fig. 2



If however, sales are at, or approaching plant capacity (Fig. 3) then the cost of supplying further quantities of active ingredient beyond plant capacity to meet new potential demand must include the cost of further capital investment.

Fig. 3



However, suppose that a 25% enhancement of activity enabled future sales to be met with existing capacity, thereby delaying the need for a further capital investment of £1 million for 5 years. The saving in 'interest value' on that capital at 15% over 5 years would be £150,000 per annum worth a present value of £390,000 over the 5 year period.

This would be added to the value of the variable cost saving in calculating the total benefit.

In conclusion therefore an earlier comment that enhancement is worth very serious consideration is strengthened particularly in those cases where, as a result of the work, the manufacturing plant need not be extended.

Acknowledgements

I wish to extend thanks to my colleague Mr B.W. Lever for the comments on marginal costs.

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INTRODUCTION TO SESSION ON WEED CONTROL IN AMENITY, AQUATIC, FORESTRY AND NON-CROPPED AREAS WITH SPECIAL REFERENCE TO THE ROLE OF HERBICIDES IN AMENITY

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This title suggests an odd assortment of topics as if the organisers of the Conference had decided to group in this Session all papers that would not fit conveniently into one or other of the main sessions. However, this was not the case for weed control in each of these areas has links in some way with most of the others and each can benefit by a spin-off of information.

Man derives pleasure from diversity and contrast in the landscape. Amenity areas are created for pleasure and often contain planted,open and aquatic areas. The maintenance of such amenity areas is becoming increasingly difficult due to escalating costs combined usually with a high labour input. These areas can benefit much from advances in weed control in forestry which relate directly to shrub, tree and ground cover plantings, from weed control in non-cropped areas which provide information on the management of roadways, paths and patios and from weed control in aquatic areas for the control of undesirable vegetation in ornamental lakes and ponds.

There are also links between weed control in non-cropped areas and forestry. The forester must maintain roads and fire-breaks free from tall growing woody plants and fence lines free from vegetation. Moreover forestry and non-cropped areas share the common problem of brush control. The forester will often want to control woody weeds e.g. hardwoods in established conifer stands; the same weedy hardwood species are tending to become more prevalent on non-cropped land in some areas where herbaceous species are often more easily controlled by current herbicides.

Amenity areas can often be made more beautiful by the complete absence of weeds in non-cropped ground e.g. by enabling the surface texture of paving to be fully appreciated. But must all non-cropped areas be completely plant free? Can not some be regarded as amenity areas in their own right? The newly developed dominance of some previously rare prostrate herbs such as Hypericum humifusum in fruit plantations treated with standard orchard herbicides indicates that there is scope for developing herbicide-tolerant, prostrate plant communities for non-cropped land. In some cases, e.g. utility rights of way, a low-growing, herbicide-tolerant plant community may be more desirable than bare ground for reasons of aesthetics, ecology and erosion control. Specialists in amenity are accumulating information on ground cover plants, such as Sedum acre which is highly tolerant of simazine, and should be able to help scientists engaged on weed control on non-cropped ground where a low-growing, ground-cover plant would be acceptable.

Many of the papers at this Session should be of interest to a wide cross-section of participants because of the possibility of a cross-fertilisation of ideas between scientists engaged in these separate but linked weed control areas. For example, the reported tolerance of Rhododendron species to the new brushwood killer ammonium ethyl carbamoylphosphonate could be useful to the landscaper wishing to control Rubus spp and other woody weeds in amenity plantings. Even a negative result in any one paper might well provide a spark of inspiration that could stimulate progress in a new direction.

The scarcity of papers on amenity in this Session is disappointing because this is one of the great neglected areas in weed control. It is impossible to put an accurate figure on the potential acreage but it is considerable including parks, sports grounds, landscaped areas around factories, offices and schools, national parks, many of the 14.5 million small private gardens in Britain and numerous great gardens. It is ironical that many of these great gardens were planted over 100 years ago and are only now reaching maturity and revealing the vision that the designer had in his mind's eye when he planned them. Regrettably too few have survived partly because the cost of weed control and maintenance in pre-herbicide days defeated all but the wealthiest and the most enthusiastic of owners.

The amenity sector has been neglected by herbicide manufacturers for several reasons. The potential market is difficult to assess; in addition the areas involved are relatively small and are characterised by a vast number of plant species and cultivars, grown under widely different systems of management and often on variable soil types.

In spite of these problems, herbicides can be used effectively in amenity areas and landscape contractors are gradually being forced to use them as labour for landscape maintenance is disappearing in many areas and soon there may be no alternative. The same herbicides used successfully at present by most soft fruit growers and nurserymen can reduce substantially the work involved in controlling weeds in amenity areas. Where herbicides are used and soil cultivation ceases the quality of trees and shrubs is generally better than where weeds are controlled by cultivation.

The slow acceptance of herbicides for amenity areas has been partly due to the difficulties of applying them accurately in small areas and also because of widespread but unsubstantiated fears that herbicides might build up in the soil. Growers experienced in the use of herbicides in fruit crops and nursery stocks have little difficulty in applying herbicides to amenity areas. Others must acquire the skill needed to calibrate a sprayer, calculate doses of herbicides and apply them accurately. When this skill is acquired, the rewards in terms of easy landscape management are very great.

The labour input required to manage an amenity area whether a small or large garden, park or other public authority area can be greatly reduced in several ways:-

(a) By eliminating annuals and bedding plants and planting shrubs and trees which are more resistant to herbicides.

(b) By killing unwanted grass areas with paraquat or glyphosate and planting shrubs directly into the killed sward. This eliminates grass mowing which is very time consuming.

(c) By treating all areas planted with trees and shrubs with a residual herbicide. Wherever possible the soil should be left undisturbed after spraying.

Many recent developments are now facilitating the use of soil-acting herbicides in amenity areas. These include the discovery of the broad spectrum, translocated herbicide glyphosate (Baird et al 1971), which is effective against Agropyron repens and many other perennial weeds. Soil-acting herbicides may be used more effectively when trees and shrubs are planted into ground that is free of perennial weeds. The use of the Weed Glove (Holroyd 1972) with glyphosate will be helpful when dealing with certain weed problems in established amenity plantings. More information is now available on ornamental species that are resistant or susceptible to a number of soil-acting herbicides (e.g. Ivens 1964, 1965, Fryer and Makepeace 1972 and Kelly 1972). Genera that are well known to be susceptible e.g. Deutzia to simazine should be omitted from new plantings. Most woody plants show satisfactory tolerance of soil-acting herbicides at doses that give control of germinating annual weeds and the omission of susceptible species of shrubs should not present any great problem.

The use of herbicides in amenity plantings will receive a boost as more local authorities realise that, with labour costs rising steadily, it will often be cheaper in urban areas to maintain roadside verges by ground cover shrubs plus herbicides rather than by means of closely mown grass. Well kept grass is very attractive but in this period of rapidly rising labour costs less expensive methods of providing ground cover for extensive areas must be developed. Admittedly most shrubs need occasional pruning but this operation may be done during the winter when labour is more readily available. There is enormous scope for beautifying some roadside verges with shrubs plus herbicides, a system which, if assessed over a 10-year period, will prove less expensive than grass maintenance.

Garden fashions have changed throughout the centuries according to the circumstances and needs of the time. For example labour-intensive formal gardens, ornate Victorian gardens and Paradise gardens have all enjoyed a period of popularity. Scientific advances in the last 15 years provide great scope for the development of a new type of amenity area which can help to satisfy the increasing need for more and better landscapes and gardens and at the same time overcome current labour problems. In particular, the development of rapid methods of plant propagation and advances in the chemical control of weeds can contribute much to amenity planning and maintenance in the late 20th century. New propagation methods for such plants as rhododendrons, azaleas, conifers, heathers and other ground cover shrubs have simplified production techniques and will provide great scope for diversity of planting at reasonable prices. More and more landscapes in the future are likely to be planned or modified to take full advantage of the weed killing properties of the wide range of herbicides that can be used on shrubs and trees. It seems likely that large areas will be planned to facilitate machine spraying and that, by utilizing suitable combinations of chemicals and ornamental plants, the role of herbicides in amenity areas can be greatly expanded.

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REPORT ON THE 4TH INTERNATIONAL SYMPOSIUM ON AQUATIC WEED CONTROL, VIENNA, SEPTEMBER 1974

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The 4th International Symposium on Aquatic Weeds initiated by the European Weed Research Council was held in Vienna between 17 and 20 September 1974. It was supported by the Austrian Federal Ministry of Agriculture and Forestry (Bundesministerium für Land- and Forstwirtschaft) and six other local organizations. The Federal Ministry provided funds that made an invaluable contribution to the meeting by subsidising the printing of the Proceedings and supplying simultaneous translation facilities for the three days spent in the Conference Hall. The Conference Hall itself was a modern very well-appointed room designed to seat 400 delegates in comfort. It was made available by courtesy of the Pro-Rector of the Technische Hochschule.

The local arrangements, the programme and the pre-printing of the Proceedings were in the hands of an Organizing Committee chaired by Dr. Kahl, Director of the Federal Institute of Plant Protection (Bundesanstalt für Pflanzenschutz) Vienna. Much of the day-to-day work fell to the secretary of the committee, Dr. H. Neururer, of the same Institute, and his assistant Ing. Stangelberger.

The Symposium was attended by about 200 delegates from 17 different countries. Most of the participants were from Austria although many came from other countries in Western Europe. One of the reasons for selecting Vienna as the venue for the meeting was the hope that research workers in Eastern Europe would be able to attend. In the event only 2 from Rumania, 3 from Hungary and 6 from Yugoslavia came. There were 17 participants from the United Kingdom and from further afield, 5 from the United States and one from Kashmir, India.

On the first morning the Symposium was opened by the State Secretary of Federal Ministry of Agriculture and Forestry, Herr Haiden, on behalf of the Federal Minister. Participants were also welcomed by the Pro-Rector of the College, Herr E. Bukovics, and by Mr. T.O. Robson on behalf of the E.W.R.C.

The programme was arranged in 5 Sessions each with a particular theme. A total of 40 papers were pre-printed in the Proceedings with summaries in the official languages of the Symposium (English, French and German). In a few cases the full text of the paper was not printed. Copies of the Proceedings may be purchased from the Secretary of E.W.R.C. at the Instituut voor Biologisch en Scheikundig, Wageningen, The Netherlands.

The first session was concerned with the biology of aquatic plants and the effect of weed control on aquatic ecosystems. It also included an excellent slide presentation of the range of freshwater environments and vegetation in Austria and an account of the distribution of water plants in the Kashmir lakes in India. The importance of bacteria on living plants for cleansing water and breaking down organic matter as plants die was discussed by Kohl while Dawson and Westlake presented the results of an experiment in a British river to demonstrate the uptake of N and P from the water by some aquatic vascular plants.

The remainder of the papers in this session were concerned with the effects of herbicidal weed control on freshwater ecosystems. Johannes reported on a large scale collaborative field experiment and felt there was a need for mathematical models to predict the changes following weed control measures. Useful information on the reaction of organisms other than plants to various herbicides was presented in a number of the other papers. One of the most interesting of these discussed the behaviour of the caldoceran Simocephalus vetulus in relation to the partial clearance of submerged plants. Regrowth of Ranunculus trichophyllus in the year following the destruction of all plant growth in a pond by dichlobenil provided a suitable habitat for Simocephalus vetulus. The author, Newbold, considered it possible that the large population of S. vetulus which then developed grazed the algae, including Rhizoclonium hieroglyphicum and prevented their re-establishment. In this work the plant and animal biomass was carefully measured and Newbold's hypothesis is interesting since it indicates the possibilities of controlling weeds by encouraging native predators through the judicious use of herbicides. It was not certain, however, that the alga R. hieroglyphicum would have regrown in that pond and clearly much more work is needed.

The second session was devoted to mechanical methods of clearing weeds from ditches. Most of the machinery discussed was much the same as that discussed at previous symposia although some had been modified to improve efficiency. A film presented by Krinke showed an improved version of the Berky mower for slopes up to 1:1 and the unique Birkenheger ditch cleaning device which straddles the bottom of the ditch, cuts and rakes the emergent weeds and dredges the channel at the same time.

In the third session 3 papers were presented on methods of biological control. Experience with grass carp (white amur), in The Netherlands, Austria and the United States was described. In the U.S. and Austria it has been released into certain large enclosed water bodies indicating an increasing confidence in the use of this fish for weed control purposes. In Austria the detrimental side effect of phytoplankton blooms caused by the grass carp was checked by introducing another exotic, algae-feeding fish Hypophthalmichthys molitrix (silver carp). The grass carp is now being bred artificially in Austria. The main work in The Netherlands is to study the effect of grass carp on the indigenous fish of commercial importance. The results of a large scale experiment will be available in 1975.

The other papers in this session were concerned with organisms varying from viruses and other plant pathogens to insects and the prospects of a small, submerged, mat-forming competitive plant Eleocharis acicularis growing on the bottom of some lakes in Germany. Apart from the success of some insects in the tropics and subtropics the work reported was in a preliminary stage and much has still to be done.

The use of herbicides was dealt with in the fourth session which consisted of 15 papers. Dichlobenil and the new herbicide WL 63611 (cyanatryn) received most attention. The latter is a very active algicide which also kills many submerged vascular plants when they are exposed to it for at least 14 days. A special pelletted slow release formulation has been developed for use in flowing water. The fate of both herbicides in freshwater ecosystems through absorption, breakdown and, in the case of dichlobenil, volatilization were discussed. Attention was also given to their effect on other components of the ecosystem and this too was the theme in some of the more general papers in this session.

Two papers discussed dichlobenil and fish. Tooby et al working with small rainbow trout and roach found that if the fish were held in a concentration of

1 mg/l of dichlobenil the median survival time for trout was 58 $\pm$ 5 days and for roach 16 $\pm$ 4 days. At 2-3 weeks however both species stopped eating and lost condition. Verloop et al found that ^{14}C dichlobenil was rapidly accumulated in fish tissues but it was also rapidly eliminated as the concentration in the surrounding water dropped. This was supported by the Tooby et al paper.

The fate of WL 63611 was studied by Roberts using ^{14}C labelled material. There was evidence of it being metabolised in plants and the metabolites then being returned to the water. Van Doort et al reported some long term fish toxicity studies with a number of herbicides showing clearly the need for observation on fish deaths and behaviour to continue after the herbicide concentration has been reduced and the need for long term toxicity tests. Another new herbicide, glyphosate, was shown by Barrett to be very effective against Nuphar lutea and needed only to be applied to the surface of the floating leaves to kill the large rhizome in the mud. Zonderwijk and van Zon discussed the change of attitude in The Netherlands towards the use of herbicides in water over recent years. They reported the findings of a Working Party that investigated the problem of weed control in The Netherlands and recommended that preference should be given to mechanical and biological methods. Herbicides should only be used when their side effects are "fully predictable and acceptable". Various criteria to be met by a herbicide before it may be studied for use in water were drawn up by the Working Party and are given in the paper.

The meetings ended with the fifth session in which papers on the regulatory measures governing the use of herbicides in water in the Federal Republic of Germany and in Austria were presented.

Most of the participants took advantage of the excursion to Burgenland and Lake Neusiedl arranged for the final day. Demonstrations of herbicides, granule application equipment and mowing machinery were seen and the interesting saline areas around Lake Neusiedl examined by those with botanical and ornithological interests. Perhaps the main advantage of this outing and also of the official receptions given by the Minister of Agriculture, the Burgermeister of Vienna and the President of Burgenland was the opportunity they gave participants to meet informally and get to know one another. This is always an important function of these meetings.

Comments in retrospect

Looking back over this symposium and the other three held in 1964, 1967 and 1971 there appears to have been a definite trend during the past decade away from the purely weed killing approach towards a broader one concerned with the effect of weed control on other components of the ecosystem. At the first symposium in La Rochelle in 1964 of the 20 papers presented 18 were on herbicides and although a few of them warned of the possible effects on other organisms e.g. Lhoste and Blok, the majority were concerned solely with killing the weeds. At Vienna there were 20 papers dealing with herbicide phytotoxicity. Of these only 6 did not draw attention to the effect of the treatment on non-target organisms and in at least 2 of them this was because it was dealt with in detail in separate papers at the symposium.

There are probably a number of reasons for this trend some of which are an increasing appreciation of the multi-purpose role of freshwater, the introduction of official regulatory procedures, a growing concern about pollution risks and the occasional instance of misuse through carelessness or lack of sufficient knowledge.

The interest in biological control has increased over the decade probably for the same reasons and in the hope of finding more environmentally acceptable alternatives to herbicides. In 1964 biological control was only mentioned in passing in a paper reporting research in U.S.A. In 1967 there was one paper on grass carp, in 1971 there were 4 papers on biological control and in 1974 there were 7.

These trends have been noticeable in some countries more than others. In The Netherlands as reported by Zonderwijk and van Zon there has been a reaction away from herbicides altogether and a decision taken to concentrate their effort on biological control agents - especially the grass carp (white amur). This may be the correct approach in The Netherlands, but although this fish shows great promise, it can also cause side effects - e.g. increasing available plant nutrients leading to phytoplankton blooms; disturbed habitats of other fish species; and as with herbicides, it would be unwise to depend upon it entirely.

The inadequacies of short-term toxicity testing of herbicides were brought out in a number of papers e.g. Tooby, van Doort et al on toxicity to fish, and it is clear that this is one area where much more long-term research is needed. It is essential that this work should include field research with well grown fish and normal residue regimes.

Long-term studies are also required on the reaction of other organisms and the ecosystem as a whole. These are needed primarily to predict the results of a particular treatment and to determine its suitability for the problem in hand. The idea of building mathematical models to predict what might happen (Johannes) is an attractive one which has been considered for some time. A similar approach to terrestrial ecosystem management is gradually developing but is proving very complicated. In freshwater the problem is perhaps even more complex because of the diverse physical, chemical and biological components found in each situation. However more thought should be given to trying to predict some changes of major importance e.g. dissolved oxygen, nutrient levels, important trophic groups of plants and animals which may be possible with less complicated models.

One important area of ecosystem management in which we should be attempting to progress was I believe indicated by Newbold's observations on the effect of the water flea Simocephalus vetulus on the re-establishment of the filamentous alga Rhizoclonium hieroglyphicum. Whilst it must be appreciated that these observations are based on the results in one pond without definite proof that R. hieroglyphicum and the other species of filamentous algae originally found in the pond would regrow, there is enough evidence to indicate that a form of management using herbicides - or any other weed control agent - to produce conditions that allow native herbivores to reassert themselves is possible. The successful application of this form of management will depend upon a full understanding of the ecosystem, a clear definition of the objective in biological terms, the extent of weed control required and a knowledge of the effect of weed control techniques on the ecosystem. It will also require the control by man of other components of the ecosystem e.g. the regulation of fish populations. This kind of approach requiring as it does a high degree of biological understanding may be considered too sophisticated for practical use. But I believe it is the ideal which must be aimed at in cases where fish and other organisms are important. It is a form of 'integrated control' whose success will depend upon selecting the right tool from as wide a range of control agents as possible. Newbold used dichlobenil but another herbicide may have been equally good or better. The main point is that herbicides can play an important and essential part in integrated control. There is, however, a need to ensure that they are used carefully and with full regard to safety precautions.

At a business meeting it was decided that the fifth symposium in this series will be held in 1977.

Proceedings 12th British Weed Control Conference (1974)

THE USE OF A GLYPHOSATE SALT FOR WEED CONTROL IN AMENITY AND NON CROPPED AREAS

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Summary A review is given of much of the work done to date on glyphosate and its salts. Favourable toxicity, broad spectrum of weeds controlled and mode of action are discussed relating these to potential useage in amenity and non cropped areas. Experience gained to date indicates that most annual weeds are killed at 0.5 - 1.0 kg a.e./ha. Perennial grasses are usually killed at 1.0 - 2.0 kg a.e./ha but perennial broad leaf species require rates often in excess of 2.0 kg a.e./ha. Late season applications when the weeds are at or just after flowering are the most effective. Good control was achieved of *Pteridium aquilinum* and *Phragmites communis* from late season applications. Glyphosate salts have a short soil life and where persistent residual herbicides are applied as a tank mix antagonism is produced which gives a reduced control of many perennial weeds. Potential uses are as a pre-plant or post crop renovation treatment, and for temporary total weed control in amenity areas. Spot or carefully directed applications could be made in forestry or in non cropped areas especially the latter where difficult perennial weeds have grown through persistent residual soil applied herbicides.

Résumé On donne apercu d'une grande partie des travaux effectués jusqu'à présent avec le glyphosate et ses sels. Sa toxicologie favorable, le contrôle d'une grande quantité de mauvaises herbes et son mode d'action sont discutés, particulièrement concernant son utilisation possible en zones d'aménagement et en zones non cultivées. L'experience acquise jusqu'à ce jour permet de signaler que la plupart des adventices annuelles sont détruites de 0.5 à 1.0 kg é.a./ha. Les graminées pérennes sont normalement maîtrisées de 1.0 à 2.0 kg é.a./ha mais des doses supérieures à 2.0 kg é.a./ha sont souvent necessaires pour détuire les dicotylédones vivaces. Les applications tardives effectuées lorsque les mauvaises herbes ont atteint le stade de floraison ou juste après ce stade, sont les plus efficaces. La destruction de *Pteridium a* et *Phragmites communis* est excellent lors de traitements en fin de saison. Les sels de glyphosate ont une courte activité dans le sol et lorsque les herbicides à action résiduaire persistante sont utilisés en mélange extemporané, il en résulte de l'antagonisme et une diminution d'action sur de nombreuses adventices pérennes. Les applications possibles du glyphosate sont des traitements avant mise en culture ou après récolte et pour la destruction totale temporaire des adventices en zones d'aménagement. Des traitements localisés ou soigneusement dirigés pourraient avoir lieu en zone forestière et particulièrement en zones non cultivées où des plantes vivaces résistantes ont pu croître en dépit des applications d'herbicides résiduaires persistants.

INTRODUCTION

The situation During the past decade there has become an increasing trend for chemicals to replace scarce and expensive labour for weed control in amenity and non cropped areas. More recently with the increased pace of modern life and the demand for more leisure time, there has developed a need for a chemical means of weed control in the domestic market. Robinson (1972) has shown how both amateur and professional workers can make the most efficient use of a wide range of modern herbicides in amenity horticulture. However the professional working in amenity horticulture and in total weed control areas has a wider range of herbicides at his disposal. He may choose root absorbed residuals such as simazine, atrazine, diuron; foliage and root absorbed materials such as picloram or sodium chlorate; and finally foliage absorbed herbicides such as aminotriazole, dalapon, paraquat and the hormones such as MCPA.

Although these herbicides are very efficient when used correctly in specific situations, often a very much broader spectrum of activity is required. A combination of contact and residual activity may be required. The professional weed control specialist will resort to mixtures such as those recommended for total weed control in the Weed Control Handbook (1972). The use of tank mixtures often gives a broader spectrum of control with maximum efficiency and reduced costs, when compared with proprietory mixtures which are usually only available to the amateur. Examples of such mixtures would be simazine + paraquat + diquat, and simazine + aminotriazole. All these mixtures give a combination of contact and residual action. They are useful for weed control in non crop, industrial, local authority and other amenity areas.

Residual soil applied herbicides are often very persistent, particularly when used at high rates for total weed control. However, often long term persistent herbicides are undesirable because of the requirement to plant ornamental or crop species later in the season. They may also 'creep' down sloping ground in wet weather. Deep rooted difficult perennial weeds often come through residual soil applied herbicides particularly where low rates have been used for annual weed control and even in some cases where higher rates have been used for total weed control. The use of long lasting residual herbicides can raise other phytotoxicity problems for the unskilled operative in amenity horticulture. They are best handled by skilled contractors which specialise in this operation.

There has developed a need for a broad spectrum non toxic, non persistent, post-emergence herbicide to be used for the control of annual and perennial weeds, and to act as a partner to low doses of residual soil acting herbicides.

Glyphosate salts.Baird et al (1971) raised considerable interest in this area of weed control when they introduced a new broad spectrum post-emergence herbicide class with utility for herbacious perennial weed control. The class included N-(phosphonomethyl) glycine (glyphosate) and certain of its salts which had an exceptional degree of herbicidal activity, translocation which killed perennial weeds with vegetative propagules. Indications were given of good control of a broad spectrum of grassy and broad leaf species including both annuals and perennials. The class was non herbicidal on contact with most soils and had good toxicological properties. This herbicide class therefore offered great potential to the operative in amenity horticulture and in non cropped areas.

Weed Control.During the early development period various glyphosate salts were shown by Baird and Begeman (1972) and Baird and Upchurch (1972) to be effective for the control of perennial grassy weeds. The first work in Europe using the mono(dimethylamine) salt confirmed the earlier work in the United States and was reported by Evans (1972). Of the various salts tested the isopropylamine salt of glyphosate was selected for commercialisation.

Following the early work with overall applications Baird and Begeman (1972) indicated that directed applications could be made with a wide margin of selectivity to crops with woody stems. Overall application to various fruit crops, even during the dormant season proved to be phytotoxic due to shoot and bud uptake (Clay(1972)). Early trials in top fruit in the United Kingdom were reported by Hodkinson (1973) where carefully directed sprays gave good weed control with no crop damage. A more comprehensive programme was set up and has been reported by Seddon (1974). This shows that directed pre-bud burst applications made to the trees were very safe. However, phytotoxicity was observed due to leaf contact from summer applications which was more pronounced in pears than apples. In the main phytotoxic symptoms only appeared in the season following application.

The bulk of the work conducted so far in the U.K. has concentrated the control of Agropyron repens and other perennial grasses in agriculture and top fruit. Davison (1972) showed that the isopropylamine salt of glyphosate controlled 21 species of perennial weeds including many broadleaf species.

A limited amount of work has been conducted in the areas of amenity horticulture and total weed control. The purpose of this paper is to report and discuss the limited results obtained to date and to suggest areas for future lines of research.

METHOD AND MATERIALS

Some early work was done with the mono(dimethylamine) salt of glyphosate (MON-0468). However, the majority of the work has been done with isopropylamine salt of glyphosate code No. MON-2139 (Roundup). This formulation contains 360 grammes a.e./l. The rates used have varied from 0.5 - 4.4 kg a.e./ha applied post emergence to a wide spectrum of perennial grasses and broadleaf weeds.

Work with Agropyron repens in the United States reported by Baird and Begeman (1972) indicated the rate of 2.2 kg a.e./ha. Later work in the United Kingdom has indicated that lower rates could be used later in the season (Hodkinson 1974), W.R.O. (1974). MON-2139 was also found to be more effective on perennial broad leaf weeds when applied at or near flowering particularly during the late spring and summer period but before the autumn when these weeds had usually senesced.

Other herbicides tested as additives to MON-2139 either as separate applications or as tank mix combination were bromacil an 80% W.P., diuron an 80% W.P. and simazine 50% W.P. Other comparative herbicides used were asulam 40% w/v, and the sodium salt of dalapon, a water soluble powder containing 74% a.e. Some proprietory mixtures of diquat + paraquat + simazine and aminotriazole + simazine were tried comparatively in some trials.

The herbicides were usually applied with an Oxford Precision Sprayer fitted with a 91 cm boom and four nozzles of various sizes to give from 200 - 1200 l/ha of water at a pressure of 1.4 kg / cm^2. However, some applications were made with a watering can usually applying 5,000 - 10,000 l/ha of water.

Weed assessments were made visually using a 0 - 100 scale (100 = 100% weed control) usually twice during the season of application and also approximately one year after application.

Toxicological and environmental studies were carried out in the U.S.A. by the Monsanto Company and its associate laboratories.

RESULTS AND DISCUSSION

Toxicology. The isopropylamine salt of glyphosate has an acute oral LD_{50} of 4,900 mg/kg for mixed sex rats. It is therefore classed as slightly toxic. In the case of skin absorption the LD_{50} is greater than 7,940 mg/kg for mixed sex rabbits, and it is therefore classed as practically non toxic. MON-2139 is classed as a mild skin and severe eye iritant to mixed sex rabbits. The eye irritation produced is less than that from a 10% solution of toilet soap.

Fish toxicity studies have shown the four day TL_{50} for rainbow trout to be 38 - 48 ppm, and for blue gill trout to be 24 - 78 ppm. Tests revealed no deaths in eight different fish species when exposed to 100 ppm for 96 hours. MON-2139 has a very low toxicity to Daphnia pulex the 48 hour LC_{50} value being 192 ppm. Honey bees tolerated 100 micro grammes per bee for 48 hours, for both technical and formulated product.

Long term studies including sub acute feeding, mutagenic, terratogenic and tissue accumulation have shown no adverse effects.

Lack of Soil Residues. MON-2139 is bio-degradable and on most normal soils with adequate microbial populations degradation to CO_2 and water takes place rapidly and at about the same rate as sucrose. No pre-emergence effects have been seen even where rates up to 34 kg a.e./ha have been applied immediately pre-seeding crops on fields of mineral and organic soil. Some pre-emergence activity in mineral and organic soils was recorded on cereals (Thomas 1974) and horticultural crops (MacNaeidhe 1974) using rates in excess of commercial recommendations during greenhouse experiments. Usually no glyphosate residues can be detected in soil after a period of 4-weeks. Similar degradation rates occur in the sediment and bottom mud of water courses but in the case of clear natural water a slower degradation takes place due to a lower microbial population. There should be no residual problems in mineral or organic soils at rates up to 4 kg a.e./ha under commercial conditions.

MON-2139 has been cleared under the Pesticides Safety Precautions Scheme for use prior to wheat, barley and oats at the present time. There should be no problems in useage for non edible crop areas.

Other uses such as those out-lined below will be added to the product label on the successful completion of the development programme. However, no firm recommendations may be given at the present time.

Mode of Action. N-(phosphonomethyl) glycine when applied to the foliage of plants appears to inhibit the aromatic amino acid biosynthetic pathway. In particular inhibition may take place of chorismate mutase and/or pre-phenate dehydratase. (Jaworksi (1972)).

Annual weed species of both grasses and broad leaf weeds are generally killed at rates from 0.5 - 1.0 kg a.e./ha. The exception to the rule is Urtica urens which may require up to 4.0 kg a.e./ha. Perennial grasses are generally very sensitive to rates of MON-2139 within the range of 1.5 - 2 kg a.e./ha, whereas broad leaf perennial weeds generally require rates in excess of 2.0 kg a.e./ha.

In the case of Agropyron repens and Agrostis gigantea field observations have shown that once the foliage begins to wilt and turn yellow some 10-14 days after spraying then the growing points of the rhizomes also show necrotic effects. They become softer and translucent in appearance and show that the chemical accumulates there first. The rhizomes then progressively show symptoms of decay backwards from the growing point of the rhizome to the mother plants, some of which in certain climatic conditions may stay green for some time. Broad leaf species take longer to show similar symptoms.

Climatic effects. Experiments under controlled environments at the Weed Research Organisation (1974) using ^{14}C labelled glyphosate have confirmed field observations and show that at a soil temperature of 10°C a lethal dose of glyphosate would have accumulated in the rhizomes within 24 hours of spraying. However, the speed of kill of the foliage and appearances of the chemical in the rhizomes is influenced by temperature.
Leaf symptoms, a gradual wilting and yellowing of the foliage takes place at 5 - 7 days in the summer, 10 - 14 days in the autumn and 30 - 50 days during the winter. Performance during all these seasons is adequate providing that there is adequate green leaf at the time of spraying. Casely (1972) has shown that the level of light did not have a clear cut effect on performance, but that low temperatures and high humidity did enhance glyphosate toxicity.

On account of the temperature influence on performance it is suggested that after spraying, leaf symptoms should develop before any cultivations leading to seed-bed preparation or planting takes place. This recommendation ensures that a lethal dose of glyphosate has reached all underground propagules.

Glyphosate enters the plant slowly and at 18°C and 80 - 90% relative humidity over 90% of labelled glyphosate remained on the leaf surface after 24 hours. (W.R.O. (1974)). Thus heavy rainfall immediately after application, within a 6 hour period, is likely to reduce performance. Another potential hazard is that of transference from a sprayed area by foot traffic, onto areas of desirable species.

Stage of Growth and Timing. Adequate leaf area at the time of spraying is important for both grasses and broadleaf weeds. Applications to annual species are best made when they are still small and immature. Results are best on undisturbed perennial weeds, where there is a maximum leaf emergence from underground vegetative propagules. Perennial grasses are best controlled pre or post flowering, broadleaf weeds are best controlled post flowering but before leaf senescence sets in. Results seem to be better when there is a movement of the products of photosynthesis from the leaf downward into underground storage organs such as roots, rhizomes and stolons. Experience indicates that MON-2139 is a very efficient perennial weed killer for late season useage.

POTENTIAL USES

When toxicology, mode of action, weeds controlled and stage of growth are considered the following areas of potential useage should be considered.

Amenity Horticulture. Trial experience to date indicates that all annual grasses and broadleaf weeds are controlled by rates of MON-2139 from 0.5 - 1.0 kg a.e./ha. Many of the more difficult perennial weed species indicated in Table 4 have been controlled by spot treatment or carefully directed applications between mature desirable species. Applications may be made with a watering can, a dribble bar, a knapsack sprayer fitted with a flood jet or by means of a herbicide glove. Sprays applied at low volume, at high pressure, producing small droplets have caused damage to a range of desirable species and in particular to roses. (Rosa spp).

Where difficult perennial weeds occur amongst desirable species then carefully directed spot treatment may be a possibility but the risk of damage is very great, when these plants are in full leaf. However, the major potential appears to be in clearing up areas to be planted with ornamentals. Another possible use would be in renovating areas previously planted with ornamentals, and which have become over grown with difficult perennial weeds. In both cases the weeds could be allowed to grow unchecked until mid-summer and then sprayed off, so that after a period of 3 - 4 weeks when the chemical had had its maximum effect on all species present, cultivations could take place prior to re-planting with all ornamental species.

Where a contact and residual action is required then a mixture of MON-2139 may be applied with simazine or diuron. Antagonism occurs and is discussed under Total Weed Control, but the results obtained have been superior to paraquat-diquat+ aminotriazole, and aminotriazole+simazine mixtures where perennial weeds such as Urtica dioica and Aegopodium podagraria often survive.

Another possible useage would be for the renovation of grassy areas prior to re-turfing or re-seeding. A mid-summer application would give a complete kill of all grassy and broadleaf weeds which after a period of one month would have completely dessicated leaving almost bare ground. A light rotovation and consolidation would then give good conditions for turfing or re-seeding in the following autumn. MON-2139 can remain active on the leaf of weeds for some time after spraying, particularly under damp dewy conditions.Pets have been noticed to transfer the chemical on their feet onto areas of grass which caused some damage. The same may occur with flag stoned areas but tests have shown that if the chemical is allowed to dry thoroughly onto the leaves or flag stones then the problem of transfer is minimal, and no worse than with other herbicides.

The performance of MON-2139 may be reduced when applied in high volumes of water, such as with a watering can. The problem may be reduced by the addition of extra surfactant or lower water volumes.

Total Weed Control. Persistent residual herbicides are normally used to control weeds for long periods in non cropped areas such as those around factories and railway tracks. MON-2139 has been used to control many of these weeds particularly those which have come through the residual herbicide. Those difficult perennial weeds which have been controlled are shown in Table 4.

Where weed control is required for a shorter period, then MON-2139 may be applied in combination with a low rate of a residual soil acting herbicide such as bromacil, diuron or simazine. Tank mixtures have resulted in some antagonism which is shown in the case of Agropyron repens in Table 1.

Antagonism shows itself in the form of a slower kill of annual weeds and a much slower kill of the foliage of perennial weeds. Antagonism has also been reported by Seddon (1974) working in fruit crops and by Andrews et al (1974) working on industrial weed control in the United States. Antagonism is greatest where the weed species concerned shows some resistance to the residual herbicide. This can be seen in Table 1 where more antagonism was produced by a MON-2139 combination with simazine than with a similar combination with bromacil. Similar experiences are reported by Seddon (1974) and Andrews et al (1974).

It is possible that the MON-2139 may reduce the soil life of simazine as occurs with a paraquat+simazine mixture.

In the case of Equisetum arvense the addition of bromacil gave more foliage scorch in the year of application and better control one year later. However, timing of application has proved to be critical and erratic results have been obtained over a three year period.

Table 1.

The effect of MON-2139 on Agropyron repens when applied with residual herbicides

Rate of MON-2139 kg/ha a.e.	MON-2139 Alone 30 DAT	MON-2139 Alone 330 DAT	+ Bromacil 2.6 kgai/ha 30 DAT	+ Bromacil 2.6 kgai/ha 330 DAT	+ Simazine 1.68 kgai/ha 30 DAT	+ Simazine 1.68 kgai/ha 330 DAT
1.12	95	90	99	20	60	20
2.24	95	90	99	50	90	50
3.36	95	90	99	70	95	50
4.48	100	95	100	95	99	50

DAT = Days after treatment   Figures are the % control

When a late season (July) application has been made, particularly where a heavy infestation of grassy weeds occurs, then the decaying vegetation often forms a mulch which prevents further growth of annual weed seedlings that season.

In the case of local authority weed control MON-2139 at 2.2 kg a.e./ha and diuron at 2.6 kg a.i./ha were applied to weeds occuring in areas of pavement and along the sides of fences. Excellent control of a range of annual weeds was achieved including many of the difficult perennial weeds listed in Table 4. No transference problems were encountered or damage to adjacent grassed areas or hedgerows. The low toxicity of MON-2139 makes it an ideal product for these areas.

Forestry. MON-2139 has not shown any selective properties when applied to a number of tree species (Turner 197 3). Trial work carried out in Scandinavia in conifers has shown that rates from 0.4 - 0.5 kg a.e./ha can be applied at any time of the growing period without phytotoxicity. Later in the season a much heavier rate of application can be used without tree damage. However, this method of useage is very doubtful in the U.K. where the mild climate rarely ensures complete tree dormancy.

The main potential for MON-2139 would appear to be a pre-plant treatment in nurseries or in forests. Hand work in planted crops is very expensive at the present time often in the region of £12 - 14 an acre and in some cases contractors may charge up to £20 an acre. Directed and carefully guarded sprays may be used to control grasses and broad leaf weeds in the new transplant lines or young crops. The treatment of fallow land would leave no residues pre-planting, and is the preferred method of use.

In forests, knapsack sprayers operating at medium volume with low pressure could be used as a band application pre-planting to kill broad leaf weeds and grasses. Directed sprays using tree guards could be used on young stock but in the case of trees with mature bark, applications could be made around the trunk without guarding.

Table 2 shows that Roundup can be used to control Pteridium aquilinum and the results may be superior to those obtained with asulam. Most probably the best treatment would have to be applied pre-planting. June applications were not successful due to insuffucient frond area. Late season applications in July and August were very successful. Later applications may not be effective due to frond senescence. In the case of post planting treatments it would be difficult to keep the spray off the young trees.

Woody weeds are possibly slightly more resistant and could well be treated more successfully at young stages. Rubus, Crataegus, and Quercus species have all proved susceptible to MON-2139 at rates in the region of 2 kg a.e./ha in July and August.

Table 2.

The percentage control of Pteridium aquilinum one year after spraying MON-2139 and asulum

	MON 2139 kg a.e./ha					Asulam kg a.i./ha
Application date	1.12	1.68	2.24	3.36	4.48	4.48
4.7.72	81		93		97	90
29.8.73	90	91		92		78

It is doubtful whether sprays to control grassy weeds during the dormant season of very young trees could be used as damage has been experienced in trials conducted at a similar time in fruit crops.

A single late August spray of 2.0 kg a.e./ha may give good control of Pteridium aquilinum and woody weeds. Thus dispensing with a two spray system of asulam and 2,4,5-T.

Hill Land and Upland Amenity Area Improvement.MON-2139 may be used to control bracken and to generally improve the sward in upland areas. Festuca rubra has shown more resistance than other grasses so that when the bracken is removed a possibility of sward improvement exists. (Williams (1974)). The lack of residues and resistance to leaching of the MON-2139, makes it ideally suitable for use in upland conservation areas or even in water catchment areas. There is a possibility that rates could be adjusted to give a good kill of susceptible species such as Holcus mollis but to leave Festuca rubra. Application would have to be made from the air and so investigations should be carried out to estimate the possible drift hazards. Aerial application also involves the use of low volumes of water i.e. 50 l/ha. This must be investigated, but tests with U.L.V. have proved effective. A thick overlying canopy of Pteridium aquilinum fronds may afford sufficient protection of the sward beneath.

Aquatic Weed Control. MON-2139 has been shown to give good control of many emerged weeds in water courses and lakes. The chemical has no effect at normal rates on submerged weeds or algae. The chemical is rapidly degraded in water and should present little risk to fish or other water life.

Barrett (1974) has shown that the yellow water lily Nuphar lutea can be controlled using MON-2139 at around 2.0 kg a.e./ha and that it may be possible to reduce this rate with more critical work on timing of applications. Table 3 shows that MON-2139 can be used to control Phragmites communis and also Rorippa nasturtium aquaticum when applied in mid September, but pre-weed senescence.

Effects were noticed also on Lemna minor. Limited observational work up to the present time has indicated satisfactory control of Typha species. Test work on Phragmites communis in dykes in Lincolnshire has indicated some damage to the couch growing in the dyke bank which may well lead to soil slippage. This did appear to be quite serious at the beginning of the year but later on recolonization took place from unsprayed areas and no serious slippage did in fact occur.

Table 3.

The percentage control of aquatic weeds 228 days after spraying

Weed	MON - 2139	kg a.e./ha		Dalapon kg a.e./ha
	1.44	2.16	2.88	23.8
Phragmites communis	100	100	100	97
Rorippa nasturtium aquaticum	99	100	99	0
Lemna minor	60	70	70	0
Agropyron repens dykesides only	92	95	95	65

It may be possible to control the estuary weed Spartina maritima and Spartina townsendi but work so far has been hampered by the fact that MON-2139 requires some 6 hours of dry conditions for penetration and probably the tide would cover the weed before this took place.

Weeds Controlled. Table 4 gives a list of the more difficult weed species which have been controlled in amenity and non cropped areas. Generally speaking the grasses are more susceptible than broad leaf weeds and the best control of both occurs late in the season but before leaf senescence. The table is based on the knowledge gained up to the present date but it is possible that certain species could be controlled at lower rates when more test work is done on the timing of application.

Table 4.

The susceptibility of various perennial species to MON-2139

Species	Rate of MON - 2139			kg a.e./ha
	1.0	1.5	2.0	4.0 or more
Achillea millefolium	*	**	***	***
Aegopodium podagraria	*	**	***	***
Agropyron repens	**	***	***	***
Agrostis gigantea	***	***	***	***
Agrostis stolonifera	**	***	***	***
Alisma-plantago-aquatica	**	***	**	***
Anthriscus sylvestris	*	**	**	***
Arctium spp.	*	*	***	***
Arrhenatherum elatius	**	***	***	***
Artemesia vulgaris	**	***	***	***
Bryonia dioica	*	*	**	***
Calystegia sepium	*	*	**	***
Carex spp.	*	**	***	***
Chamaenerion angustifolium	**	***	***	***
Cirsium arvense	*	**	***	***
Convolvulus arvensis	*	*	**	***
Convolvulus sepium	*	*	**	***
Dactylis glomerata	**	***	***	***
Daucus carota	*	*	**	***
Deschampsia caespitosa	*	**	***	***
Epilobium spp.	*	**	***	***
Equisetum arvense	*	**	**	***

Table 4. (Contd)

	Rate of MON - 2139			kg a.e./ha
Species	1.0	1.5	2.0	4.0 or more
Equisetum palustre	*	**	**	***
Festuca pratensis	**	***	***	***
Festuca rubra	*	*	***	***
Filipendula ulmaria	*	**	***	***
Glyceria maxima	*	**	***	***
Hedera helix	*	*	**	***
Heracleum sphondylium	**	***	***	***
Hypericium perfoliatum	*	**	***	***
Juncus effusus	*	*	**	***
Lamium album	**	***	***	***
Lolium perenne	**	***	***	***
Mercurialis perennis	**	***	***	***
Phragmites communis	**	***	***	***
Picris echioides	*	**	***	***
Plantago lanceolata	**	***	***	***
Plantago major	**	***	***	***
Polygonum amphibium	*	*	**	***
Polygonum cuspidatum	*	**	***	***
Potentilla anserina	**	***	***	***
Potentilla reptans	**	***	***	***
Pteridium aquilinum	**	***	***	***
Ranunculus bulbosus	*	**	**	***
Ranunculus repens	**	***	***	***
Rubus fruticosus	**	***	***	***
Rumex crispus	*	**	***	***
Rumex obtusifolius	**	***	***	***
Senecio jacobaea	**	***	***	***
Solanum dulcamara	**	**	***	***
Sonchus arvensis	*	**	***	***
Symphytum officinale	**	***	***	***
Taraxacum officinale	**	***	***	***
Trifolium repens	*	**	***	***
Tussilago farfara	*	**	***	***
Typha spp.	*	**	***	***
Urtica dioica	*	**	***	***
Urtica urens	*	*	**	***

* = Foliage effect only, recovery normally occurs.
** = Severely checked, some recovery.
*** = Normally good control, little or no regrowth.

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