CONTROL OF WILD OATS (AVENA FATUA) WITH HOE 23408 IN PEAS AND BROAD BEANS

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Summary The results are presented of replicated experiments testing post-emergence applications of HOE 23408 (4- (2,' 4'-dichlorphenoxy)-α-phenoxypropionic acid methyl ester) and barban in processing crops of peas and broad beans. Applied to wild oats at growth stages up to tillering HOE 23408 gave excellent control, but control was less reliable where the plants had reached the tillering growth stage. In both years HOE 23408 gave better control than barban and proved considerably safer to the crop. The most satisfactory rate of use of HOE 23408 appeared to be approximately 1.25 kg a.i./ha, although a mixture of mineral oil at 2 l./ha with 1.0 kg a.i./ha gave comparable levels of control in two experiments.

INTRODUCTION

Wild oats (Avena fatua) frequently cause serious problems in pea and bean crops grown for processing (Gane 1968). Effective pre-sowing treatments are available (Armsby & Gane 1962, 1964; King 1976) but because of the need to sow many of the crops early, under adverse conditions, they are not always completely reliable. Post-emergence barban is not highly selective in peas (Armsby & Reynolds, 1960; Armsby & Gane, 1962, 1964), and not very effective in the absence of good crop competition. Benzolprop-ethyl, chlorfenprop methyl & difenzoquat have not been found to be selective in peas in field screening work carried out at PGRO over the past few years. In 1974, following preliminary reports of good crop tolerance in legumes from greenhouse screening at the Weed Research Organisation, the experimental material HOE 23408 (4-(2',4'-dichlorphenoxy) - α - phenoxypropionic acid methyl ester) was screened on peas (Pisum sativum), dwarf beans (Phaseolus vulgaris) and broad beans (Vicia faba) in the field. In these tests all three crops tolerated 3.0 kg a.i./ha, more than twice the dose suggested for wild oat control. In 1975 and 1976 detailed experiments were carried out in peas and in the latter year a single experiment was carried out in broad beans, the results of this work are reported in this paper. It is hoped that more detailed work on dwarf beans will be carried out in due course.

METHOD AND MATERIALS

The experiments were carried out in commercial crops using 10 sq. m plots replicated four times. The treatments were applied with a van der Weij plot sprayer at 224 l/ha and a pressure of 2.1 kg/cm^2. Birchmeir cone nozzles were used. Broad-leaved weeds were controlled using standard pre or post-emergence herbicides. Assessments were made during the season for effects on the crop and for wild oat control, but the main recordings on wild oats were made at harvest when numbers and weight of plants and panicles were measured. Three of the pea experiments and the broad beans were harvested at the green freezing or canning stages of maturity, the peas were threshed using a plot viner and the weight of produce measured together with the relative maturity as indicated by tenderometer, while in the case of the broad beans the weight of whole pods was recorded and sub-samples were shelled out for maturity measurement by tenderometer. The other pea experiment was harvested at the dry stage and threshed out using the plot viner, the produce then being dried to 16% m.c. The pea varieties were Scout at Benwick, Cambs, (site 1), Vedette (dried pea) at Ravensden, Beds, (site 2), Hurst Beagle at Helpringham, Lincs. (site 3), and Sprite at Spalding, Lincs. (site 4). The variety of broad beans at Upwell, Cambs, (site 5) was Threefold White. A 36% e.c. formulation of HOE 23408 was used and the standard 12½% e.c. formulation of barban. In 1976 the addition of mineral oil (Actipron) to HOE 23408 was also tested. Details of crop and wild oat growth stages at the time the treatments were applied are shown below:-

Site	Treatment date	Height cm	No. of expanded leaves	Leaf wax	Wild oats Stage No. leaves	Remarks
1	19/5	10-12	3-4	Low-moderate	2-tillering	Wide range
2	6/6	12-15	6	Moderate	2-tillering	" "
3	6/5	6-10	5	Good	2-tillering	Mainly tillering
4	14/5	26	7	Poor	3-tillering	" "
5	28/5	10	3	Good	2-2½	-

RESULTS

Crop effects

The assessments for injury to the crop are presented in Table 1, and are those made when the maximum amount was present and are the mean of four replicates. HOE 23408, alone, caused very few visual effects on the peas even at a rate of 2.5 kg a.i./ha, the main symptoms being a slight reduction in vigour. The addition of oil increased the effects slightly on the peas and caused very slight marginal leaf necrosis, particularly noticeable at the higher rate at site 4.

Table 1

Assessments for crop effects

Material	Rate kg a.i./ha	Site: Date:	Assessments for crop effects $ 1 29/5	2 16/6	3 24/5	4 24/5	5 18/6
HOE 23408	1.00		9.6	9.8	9.0	9.5	9.8
"	1.25		9.1	9.0	9.0	8.5	9.8
"	2.50		8.9	8.5	9.0	8.8	10.0
" + oil	1.00+2 l/ha		-	-	8.3	9.0	9.8
" "	2.00+4 "		-	-	8.5	7.8	9.8
barban	0.67		6.1	4.0	5.8	6.8	9.8
"	1.34		4.1	3.0	5.3	4.8	9.8
Untreated	-		10.0	10.0	10.0	10.0	10.0

$ 10 = No visual effects. 0 = Complete kill

All the HOE 23408 treatments appeared very safe on broad beans at site 5. In both years barban caused quite severe chlorosis, necrosis and weakening of the stems in the pea experiments and while recovery was good, by harvest many plants had tillered and the crops were more uneven in maturity than the untreated or HOE 23408 treated plots. Barban did not appear to seriously affect the broad beans.

Table 2

Percentage reduction in number and weight of wild oat plants

Material	Rate kg a.i./ha	% reduction No. of plants Site: 1	2	3	4	5	Wt. of plants 1	2	3	4	5
HOE 23408	1.00	87	69	75	4	58	96	77	90	41	78
"	1.25	95	84	81	43	53	99	89	91	51	78
"	2.50	98	82	92	24	61	99	89	96	63	81
" + oil	1.00+2. l./ha	-	-	86	9	46	-	-	97	44	77
" "	2.00+4 "	-	-	96	69	50	-	-	92	81	78
barban	0.67	18	21	67	1	0	85	30	90	45	20
"	1.34	24	57	68	13	17	88	67	92	55	47
S.E. D mean ±		11	8	9	16	8	9	6	8	8	6
No. of wild oats on untreated (per m^2)		26	163	21	14	83	-	-	-	-	-
Wt. " " " " (tonnes/ha)		-	-	-	-	-	20.9	10.8	6.2	4.4	2.0

Control of wild oat plants

As can be seen in Table 2, HOE 23408 was more effective than barban in reducing the numbers of wild oat plants in the experiments. Control from all treatments was relatively poor, however, at sites 4 and 5; at the former, the oats were at an advanced stage of development when treated and at the latter a late flush of oats appeared after the treatments had been applied. The difference in effectiveness between HOE 23408 and barban was less marked when the weight of wild oats remaining at harvest is considered. Barban caused severe stunting of the wild oats and while those not completely killed by HOE 23408 were also stunted, some of those more advanced in growth at the time of treatment recovered quite vigorously.

Table 3

Percentage reduction in number and weight of wild oat panicles

Material	Rate kg a.i./ha	% control No. of panicles Site: 1	2	3	4	5	Wt. of panicles 1	2	5
HOE 23408	1.00	96	73	94	48	94	96	81	97
"	1.25	99	89	97	60	91	99	92	95
"	2.50	100	89	97	80	96	100	92	99
" + oil	1.00+ 2 l/ha	-	-	99	60	94	-	-	97
" "	2.00+ 4 "	-	-	99	91	97	-	-	98
barban	0.67	86	28	98	56	35	88	43	50
"	1.34	92	69	99	50	65	93	75	76
S.E. D mean ±		8	9	8	8	6	7	6	6
No. of panicles on untreated (per m^2)		89	277	14	22	28	-	-	-
Wt. " " " " (tonnes/ha)		-	-	-	-	-	4.5	5.3	1.4

Control of wild oat panicles

It can be seen in Table 3 that HOE 23408 was very effective in reducing the number and weight of panicles and was in many cases superior to barban. At site 4, control from treatments applied at normal rates was disappointing, a reflection of the advanced stage of growth of the weed when treated. At site 5 good control of panicles was achieved by HOE 23408, indicating good control of those oats present at the time and the fact that the later germinating plants had not developed to the seeding stage by harvest.

Yield and maturity

At three of the five sites the herbicide treatments gave significantly higher yields than the untreated controls (Table 4). At site 1 the twice normal rate of HOE 23408 gave a significantly higher yield than the twice normal rate of the standard barban treatment, but there were no significant differences between rates of HOE 23408 or barban and between treatments at the other sites. At site 2 the extremely high populations of wild oats interfered with the harvesting of the dried crop, and although considerable yield differences were recorded between treatments these were not statistically significant.

At sites 1 and 3 there were no significant differences in maturity, but at site 4 produce from four of the HOE 23408 treatments was significantly more mature than the untreated control although in practice the differences would be less than a day's difference in harvesting. These maturity differences could have been due to reduced competition from wild oats on plots treated with these materials.

Produce quality

Samples of peas from plants treated with HOE 23408 were canned and frozen and the produce assessed by the Campden Food Preservation Research Association for possible taints. In 1975 no taints were found in any of the samples. The results for 1976 are not yet available.

Table 4

Yield and maturity data

Material	Rate kg a.i./ha		Yield % of untreated					Maturity (tenderometer readings)		
		Site:	1	2	3	4	5	1	3	4
HOE 23408	1.00		143*	186	114	107	106	173	120	96*
"	1.25		141*	229	115	105	134	180	119	99*
"	2.50		151*	257	119	108	118	172	116	96*
" + oil	1.00+2 l./ha		-	-	116	101	129	-	119	97*
" "	2.00+4 " "		-	-	116	105	131	-	118	95
barban	0.67		131*	124	115	110	116	170	119	92
"	1.34		111	190	103	103	120	160	118	94
Herbicide mean			135*	197*	114**	106	122	171	118	96
Untreated			100	100	100	100	100	168	118	93
S.E. D mean ±			13	62	6	6	15	8	2	2
S.E.D herbicide mean & untreated ±			12	48	5	4	11	6	2	2
Yield of untreated (tonne/ha)			3.8	0.4	3.5	3.3	4.3	-	-	-

* significantly different from untreated at the 5% level
** " " " " " " 1% "
*** " " " " " " 0.1% "

DISCUSSION

HOE 23408 would appear to be considerably safer than barban when used in green and dried peas. Four varieties featured in this work, including the herbicide-sensitive variety Vedette, and only minor crop effects were recorded even at the highest rate of use, while consistently high yields have been obtained. In the pea experiments, barban caused marked crop effects although the crops recovered by harvest. Neither material markedly affected the maturity of peas at harvest, the higher tenderometer readings on the HOE 23408 treated plots at one site would be less than one days difference in harvest date in practice. In the single experiment carried out in broad beans, HOE 23408 appeared to be a safe and effective treatment. The results of these experiments suggest that HOE 23408 is capable of giving very effective control of wild oats. Effects first became apparent approximately seven days after treatment and plants usually died some twenty days after treatment. Observations have shown that plants which have not reached the tillering stage are particularly sensitive and a proportion of those treated when tillering are also killed or very severely stunted; however, the remainder can grow away on occasions as at site 4. Examination of the wild oats suggested that the material was affecting the roots and even before they were dead the aerial parts of the plants could be easily separated from the roots at ground level, while the root systems themselves also decayed. It appeared to have a much more positive effect on wild oats, when applied to plants up to and including those tillering, than barban the latter material generally stunting rather than killing the plants, even those at the 2 leaf stage. The 1.25 kg a.i./ha rate of HOE 23408 was more effective and consistent than 1.00 kg a.i./ha and in most instances gave only marginally inferior control to 2.50 kg a.i./ha, indicating that there is little point in using more than 1.25 kg a.i./ha. The addition of 2 l/ha of mineral oil to 1.0 kg a.i./ha, except in the case of experiment 4, improved the control to the level of the 1.25 kg a.i./ha rate alone.

The work was carried out in two exceptionally dry seasons, where crops and weeds were under stress and when crop competition was not high. Further information under more normal conditions would be desirable.

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EXPERIMENTS WITH HERBICIDE MIXTURES FOR POST-EMERGENCE WEED CONTROL IN PEAS

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Summary The results are presented of experiments with post-emergence herbicides in peas. A mixture of cyanazine and MCPB applied at 1.00 + 0.56 kg a.i./ha proved to be a useful treatment, giving better weed control than cyanazine alone and equivalent or improved weed control compared to standard applications of dinoseb-amine and bentazone/MCPB. Cyanazine/MCPB did not cause any serious crop injury and gave improved control of *Fumaria officinalis*, *Chenopodium album*, *Sinapis arvensis* and *Papaver rhoeas* when compared to cyanazine and better control of *Polygonum aviculare*, *P. rhoeas*, *Aethusa cynapium* & *Veronica* spp. when compared to dinoseb-amine. The mixture appeared to be less critical in its temperature and crop or weed stage requirements than dinoseb-amine, and no serious effects on yields or maturity were recorded. Bentazone/MCPB caused more crop injury in these experiments than in previous work and this was reflected in yields being lower than from the other treatments.

INTRODUCTION

It has been estimated by the chemical industry that approximately 60% of the total United Kingdom vining and dried pea (*Pisum sativum*) crop is treated with a pre-emergence residual herbicide. The remainder is sprayed with a post-emergence herbicide, together with some 10% of the area originally treated with a residual herbicide. The advantages of post-emergence herbicides are that they do not rely on soil type or soil conditions to work efficiently.

Of the four post-emergence pea herbicides listed in the 1976 Approvals leaflet (MAFF, 1976) MCPB has a limited weed spectrum. It is however, useful for controlling *Cirsium arvense* and *Cirsium vulgare*. Dinoseb-amine is widely used but because of its high mammalian toxicity, critical application requirements and weakness against some important weed species it leaves much to be desired.

Cyanazine was first reported by Sandford et al (1970), Morris (1972) and King & Handley (1972) as being a safe post-emergence herbicide for peas. Cyanazine may be applied at lower temperatures and is generally less damaging to varieties susceptible to dinoseb compounds. Unfortunately, control of *Polygonum aviculare*, *Galium aparine*, *Fumaria officinalis* and *Matricaria* spp.is usually poor.

Bentazone/MCPB was reported by Taylor and May (1972), King and Handley (1972), Handley and King (1974), Lawson and Wiseman (1974) as a promising herbicide mixture for broad-leaved weed control in peas. This material has consistently given better weed control than dinoseb-amine. Control of *P. aviculare* after the two leaf stage is poor whilst *Lamium* spp. *Galeopsis tetrahit* and *Veronica* spp. are resistant. Bentazone/MCPB has always been in short supply and is now considerably more expensive than the alternatives.

In order to broaden the range of weed control achieved by post-emergence herbicides, the Processors & Growers Research Organisation (PGRO) began screening mixtures of MCPB and post-emergence pea herbicides in 1974. Mixtures of cyanazine and MCPB showed promise.

This paper reports four experiments carried out in the past two seasons evaluating a cyanazine/MCPB mixture against other post-emergence herbicides for broad-leaved weed control in peas.

METHOD AND MATERIALS

The experiments were of randomized block design with four-fold replication, the plots being 10 sq. m. in area. Each year one experiment was carried out on the Thornhaugh trial ground and the other in a commercial crop. Applications were made with a van der Weij sprayer, fitted with Birchmeier cone nozzles, at a volume of 560 l/ha. Dose rates are given in active ingredient. The mixture of cyanazine and MCPB was applied as a tank mix in 1975 and as a formulated product in 1976. Bentazone/MCPB was applied as a formulated product in both years.

Crop and overall weed control assessments were made two to three weeks after application and again at harvest. The scoring system used was 0-10, where 10 was no crop effect or complete weed control. The percentage control of individual weed species was also determined. The peas were cut by hand and threshed with a plot viner. Yield of shelled peas was recorded and maturity was measured by means of a tenderometer. Site details are shown in Table 1 below.

Table 1

Site details

Year	Code	Location	Variety	Stage of growth at application Crop≠	Weeds⧸	Date of application	Temperature at application
1975	A	Thornhaugh	Puget	7	S-EST	4/6	16°C
	B	Friday Bridge	Jade	6	S-EST	17/6	17°C
1976	C	Thornhaugh	Scout	5	S-EST	13/5	10°C
	D	Deeping St. Nicholas	Small Sieve Freezer	2-6	S-EST	5/6	10°C

≠ Crop stage - no. of leaves.

⧸ Weed stage - S = Seedling
EST = Established

RESULTS

The assessments of the effects on the crop are presented in Table 2.

Table 2

Crop assessments 1975-76 - two/three weeks after treatment

Material	Rate kg/ha	Crop effects (0 - 10) Site A	B	C	D
Cyanazine	1.10	8.0	8.8	9.0	9.3
Cyanazine	2.20	-	-	9.0	9.5
Cyanazine/MCPB	1.00 + 0.56	7.8	8.3	8.9	9.3
Cyanazine/MCPB	2.00 + 1.12	7.8	7.5	9.0	9.3
Bentazone/MCPB	1.50 + 1.50	7.4	7.0	9.5	8.5
Bentazone/MCPB	3.00 + 3.00	5.3	4.9	8.9	8.3
Dinoseb-amine	1.87	7.5	7.6	7.5	8.8
Dinoseb-amine	3.74	6.4	5.8	7.1	8.5
Untreated	-	10.0	10.0	10.0	10.0

More crop injury was recorded at sites A and B than the other two sites. This may be partly attributed to stress conditions caused by high temperatures and drought which persisted up to harvest in 1975 and also, possibly, to the crop being slightly wet when treated. In 1976 the crops were more vigorous and serious stress conditions did not develop until nearer harvest.

Crop injury from cyanazine/MCPB at sites A and B was only slightly more serious than with cyanazine alone and acceptable at both rates of use. At sites C and D also only very marginal differences were recorded. Cyanazine and cyanazine/MCPB gave less crop injury than bentazone/MCPB and dinoseb-amine.

Bentazone/MCPB produced noticeable crop effects at sites A and B and although they were considered acceptable at the normal rate, the twice normal rate gave unacceptable damage. A similar situation occurred with dinoseb-amine, but the crop scores were consistently better at both rates than those for bentazone/MCPB.

At site C a light shower of rain fell half an hour after application; all treatments gave some crop injury particularly those treated with dinoseb-amine.

No serious crop injury was recorded at site D although bentazone/MCPB and dinoseb-amine gave slightly more injury than the other materials.

Crop injury by cyanazine was recorded as slight leaf chlorosis whilst cyanazine/MCPB treatments produced slight distortion as well. The bentazone/MCPB gave more serious distortion and some necrosis especially at twice the normal rate. Dinoseb-amine caused extensive necrosis, but this was generally outgrown by harvest.

Table 3 gives overall weed scores and Table 4 the percentage control of individual weed species.

Overall weed control by cyanazine was good at site B where more susceptible species predominated. Poor control at site A was due to resistant species and reduced crop competition, whilst the level of control at site D was just acceptable. At site C the slight shower of rain reduced the efficiency of cyanazine even on susceptible weed species. Control of Stellaria media, P. convolvulus, Veronica spp.

and Capsella bursa-pastoris was good but control of P. aviculare, Chenopodium album, Papaver rhoeas and F. officinalis was poor (Table 4).

Table 3

Weed assessments 1975-76 at or near harvest

Material	Rate kg/ha	Weed control (0 - 10) Site A	B	C	D
Cyanazine	1.10	5.5	9.1	4.8	7.0
Cyanazine	2.20	-	-	6.0	7.8
Cyanazine/MCPB	1.00 + 0.56	7.3	9.1	7.3	8.5
Cyanazine/MCPB	2.00 + 1.12	9.0	9.9	7.3	8.5
Bentazone/MCPB	1.50 + 1.50	7.3	9.6	5.5	8.0
Bentazone/MCPB	3.00 + 3.00	7.8	9.9	6.3	9.5
Dinoseb-amine	1.87	6.5	9.3	7.5	7.5
Dinoseb-amine	3.74	7.8	9.4	7.5	8.5
Untreated	-	0.0	0.0	0.0	0.0

Table 4

Percentage control of individual weed species 1975-76

Weed species	Material: Cyanazine		Cyanazine/ MCPB		Bentazone/ MCPB		Dinoseb-amine	
	Rate: 1.10		1.00+0.56		1.50+1.50		1.87	
	Site: A&B	C&D	A&B	C&D	A&B	C&D	A&B	C&D
Stellaria media	87	80	82	95	100	65	84	100
Polygonum aviculare	33	37	53	65	68	47	30	67
Polygonum convolvulus	100	92	100	82	100	37	100	70
Veronica spp.	100	85	100	100	25	42	68	100
Chenopodium album	63	55	100	90	100	85	99	100
Fumaria officinalis	-	35	-	92	-	95	-	100
Capsella bursa-pastoris	100	87	100	100	100	35	100	100
Aethusa cynapium	65	-	45	-	100	-	33	-
Papaver rhoeas	53	-	70	-	100	-	50	-
Sinapis arvensis	65	-	83	-	90	-	100	-
Tripleurospermum maritimum	75	-	73	-	100	-	100	-

The addition of MCPB to cyanazine improved control of Sinapis arvensis, P. rhoeas, F. officialis and C. album to acceptable levels but control of P. aviculare was only slightly better and still not acceptable. Overall weed control by cyanazine/MCPB was always acceptable and equal to or better than the other materials. The mixture gave better control of P. rhoeas and Veronica spp. than dinoseb-amine but it was inferior against Tripleurospermum maritimum and S. avensis. Compared with bentazone/MCPB the cyanazine/MCPB mixture gave better control of Veronica spp. and C. bursa-pastoris but was weaker on A. cynapium P. rhoeas and T. maritimum. Bentazone/MCPB gave good control at sites A, B & D but poor control at site C, of normally susceptible weeds such as S. media, P. convolvulus and C. bursa-pastoris. A light shower of rain after treatment may explain this result. It may also explain the increased effects on crop and weeds from dinoseb-amine at this site in comparison to the other materials.

Control of weeds by dinoseb-amine was acceptable at site B where more susceptible weeds were present, but where P. aviculare, P. convolvulus and Veronica spp. predominated, especially when they were at an advanced growth stage, control was only just acceptable. It was not acceptable at site A, where crop competition was also poor.

Yield data is presented in Table 5 as a percentage of the untreated control.

Table 5

Yield data 1975-76

Material	Rate kg/ha	Yield (% of untreated control) Site			
		A	B	C	D
Cyanazine	1.10	127**	102	136	101
Cyanazine	2.20	-	-	144	118
Cyanazine/MCPB	1.00 + 0.56	138***	96	137	106
Cyanazine/MCPB	2.00 + 1.12	133***	91*	125	99
Bentazone/MCPB	1.50 + 1.50	96	83**	118	102
Bentazone/MCPB	3.00 + 3.00	76**	38***	123	86
Dinoseb-amine	1.87	128**	94	153	119
Dinoseb-amine	3.74	127**	90*	135	103
Untreated	-	100	100	100	100
S.E.D mean ±		o	4	16	14
Yield of untreated (tonnes/ha)		3.9	9.1	1.6	1.9

* Significantly different from the untreated at the 5% level.
** " " " " " " " 1% "
*** " " " " " " " 0.1% "

Yields obtained from plots treated with cyanazine alone, cyanazine/MCPB and dinoseb-amine were comparable at all sites. Bentazone/MCPB gave low yields at sites A and B where marked crop injury had been recorded, particularly at twice the normal rate. At site A all the treatments, with the exception of bentazone/MCPB, significantly increased the yield compared to the untreated control while the twice normal rate of the latter material gave a significantly lower yield. At site B, where good crop competition suppressed weed development on the untreated control, the double rates of dinoseb-amine and cyanazine/MCPB and both rates of bentazone/MCPB gave significantly lower yields than the control. At this site the normal rates of cyanazine, cyanazine/MCPB and dinoseb-amine gave significantly higher yields than the normal rate of bentazone/MCPB. At sites C and D there were no statistically significant differences in yield between treatments or with the control.

Maturity data is presented in Table 6. The effects on maturity were generally small but both rates of bentazone/MCPB and the single rate of cyanazine/MCPB significantly delayed maturity at site A, while the double rate of bentazone/MCPB delayed crop maturity at site B.

Table 6

Maturity data 1975-76

Material	Rate kg/ha	Tenderometer reading Site			
		A	B	C	D
Cyanazine	1.10	117	105	169	105
Cyanazine	2.20	-	-	167	106
Cyanazine/MCPB	1.00 + 0.56	113*	109	165	105
Cyanazine/MCPB	2.00 + 1.12	115	106	164	101
Bentazone/MCPB	1.50 + 1.50	113*	108	162	108
Bentazone/MCPB	3.00 + 3.00	99**	92	162	110
Dinoseb-amine	1.87	120	107	162	106
Dinoseb-amine	3.74	121	104	164	103
Untreated	-	121	103	169	102
S.E.D mean ±		4	4	5	3

* Significantly different from the untreated @ the 5% level
** " " " " " " " 1% "

DISCUSSION

Although dinoseb-amine can on occasion cause serious crop damage, especially to crops with poor leaf wax or to sensitive varieties, under the conditions prevailing in these experiments only the double rates caused serious crop damage and then only at two of the sites. Crop injury from the cyanazine or cyanazine/MCPB treatments was generally less than that resulting from a single rate of dinoseb-amine. However, bentazone/MCPB caused injury at two sites even at the normal rate.

These results are contrary to those previously obtained with this mixture and are presumed to be due to the crops being under moisture stress. Under these conditions cyanazine alone caused slight temporary chlorosis, while in addition the cyanazine/MCPB mixture caused slight distortion which was very quickly outgrown. Considerably more distortion was caused by the bentazone/MCPB, particularly at the double rate.

These experiments and other work with cyanazine as a post-emergence herbicide for peas have shown that the material can be safely used over a wide range of varieties and weather conditions, but that it has a limited weed spectrum. The addition of MCPB at 0.56 kg/ha to cyanazine greatly enhanced the overall weed control and gave acceptable control of C. album, F. officinalis, P. rhoeas and S. arvensis, but although the effect on P. aviculare was improved control was still not quite acceptable. The addition of MCPB to cyanazine gave similar levels of overall weed control to those achieved with dinoseb-amine and bentazone/MCPB. Unfortunately complete control of P. aviculare was not achieved. The addition of higher rates of MCPB might improve control of this species but could reduce selectivity.

Under the conditions of these experiments bentazone/MCPB gave acceptable control of T. maritimum, S. arvensis P. rhoeas, F. officinalis and C. album, variable control of C. bursa-pastoris whilst control of Veronica spp was poor. This mixture did not satisfactorily control P. aviculare but gave control equivalent to cyanazine/MCPB.

Cyanazine/MCPB and bentazone/MCPB are safe and convenient to handle and their performance appears to be relatively less affected by weather conditions than that of dinoseb-amine. The cyanazine/MCPB mixture had less adverse affect on the crop in these experiments at sites where the plants were under moisture stress than did the bentazone/MCPB mixture. Preliminary work has shown that cyanazine/MCPB can be used on a wide range of varieties although cyanazine-sensitive varieties such as Vedette should not be treated. Previous work has shown that bentazone/MCPB mixtures can also be used on a wide range of varieties. Further work is planned on this aspect. However, cyanazine is an active residual herbicide and this should be borne in mind when choice of post-emergence treatments for sandy soils is being considered. The soil action, however, can be a valuable asset in preventing late weed germination on more suitable soils.

Acknowledgements

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EXPERIMENTS IN PEAS WITH A MIXTURE OF CHLORTHAL-DIMETHYL AND METHAZOLE FOR RESIDUAL WEED CONTROL ON SANDY SOILS

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Summary: S1445, a mixture of chlorthal-dimethyl and methazole, proved to be a useful residual herbicide for peas, being effective against a wide range of weeds when compared to prometryne, trietazine + simazine and terbutryne + terbuthylazine. Control of Polygonum convolvulus, Stellaria media, Veronica spp., Viola arvensis, Chenopodium album and Descurania sophia was better than the standards used, but control of Fumaria officinalis was poor. The high level of crop safety with S1445 was demonstrated on the sandy soils used for the experiments in comparison to the triazine materials, which at several sites caused extensive crop injury. No adverse effect on yield or maturity was recorded for S1445, but further work to assess its usefulness on other soil types and with triazine-sensitive varieties will be necessary.

INTRODUCTION

Since their introduction, residual herbicides for peas have proved a valuable means of controlling annual weeds to the extent of approximately 60% of the total hectarage being treated. Unfortunately some of the available herbicides are not recommended or 'Approved' for use on light soils whilst others must be used at reduced rates or at 'growers risk'.

Materials such as prometryne, trietazine + simazine, cyanazine and terbutryne + terbuthylazine can be damaging to peas under adverse conditions on light soils. Under conditions of high precipitation leaching occurs carrying the materials to the root zone of the peas. It is estimated that approximately 4,000 ha of vining and dried peas are on soils for which no consistently safe residual herbicide is available. In addition many thousands of hectares fall into marginally safe soil classifications where damage can occur under difficult conditions. S1445, a mixture of chlorthal-dimethyl and methazole was reported by Meyer (1972) Bosch et al (1974) as having a high level of crop safety in peas. Preliminary trials at PGRO (unpublished) suggested that this mixture might be very useful in these difficult soil situations and this paper reports results of seven field trials carried out over the past three seasons on light sandy soils in East Anglia, where the present range of residual herbicides would normally prove of doubtful safety.

METHOD AND MATERIALS

The experiments were of a randomized block design with three- or four-fold replication, the plots being 10 sq. m in area. The experiments, with the exception of those at Thornhaugh, were carried out in commercial crops. Applications were made with a van der Weij sprayer fitted with Birchmeier cone nozzles at a volume of 560 l/ha. The materials used were S1445 as a 75% w.p. containing 66% active chlorthal-dimethyl and 9% active methazole, prometryne, trietazine plus simazine and terbutryne plus terbuthylazine as 50% w.p. formulations, prometryne containing 50%

active prometryne while the trietazine simazine mixture contained approximately 87% active trietazine and 13% active simazine and the terbutryne terbuthylazine mixture contained 70% and 30% active material respectively. Dose rates are given as active ingredient. The rates of the standard materials were not varied on the different soil types, being equivalent to those recommended for medium soils applied at normal and twice normal doses. In practice, the use of these rates meant that higher than recommended doses were used at site G whilst the very sandy soils at sites B and E were outside the present recommendations for the standard materials. Since the object of the work was to compare relative crop tolerance and weed control, this was considered to be acceptable.

Crop assessments and overall and individual weed scores were made between seven to ten weeks after treatments and again at harvest. The scoring system used was 0-10 where 10 was no crop effect or complete weed control. The peas were cut by hand and threshed with a plot viner. Yield of shelled peas was recorded and maturity was measured by means of a tenderometer.

Canned and frozen samples were taken in 1975 and 76 for possible taint testing by the Campden Food Preservation Research Association.

Site details are shown in Table 1 below.

Table 1

Site details

Year	Code	Location	Soil type	Variety	Date of sowing	Date of application	Depth of drilling (cm)
1974	A	Thornhaugh	FSL	Hurst Greenshaft	4/4	10/4	1-3
	B	Marston	CSL	Hurst Beagle	14/2	27/2	5-7
	C	Grimston	Org.CSL	Sprite	15/3	29/3	3-5
1975	D	Thornhaugh	SL	Scout	18/3	27/3	4-5
	E	Little Massingham	FS	Charger	10/4	18/4	2-2.5
1976	F	Thornhaugh	FSL	Scout	11/3	1/4	4-5
	G	Snettisham	CAL.FSL	Superfection	20/4	30/4	4-7

RESULTS

In 1974 none of the treatments affected the crop at site A, but at sites B & C S1445 proved to be safer than prometryne (Table 2). The effects of prometryne were severe chlorosis, some reduction in plant vigour and occasional loss of plant, especially at site B, where these effects persisted until harvest. The crop effect effects recorded on plots treated with S1445 were a general reduction in vigour, which was outgrown by harvest but there was no serious chlorosis, necrosis or loss of plants. The crop injury scores for S 1445 were good at sites B and C for both the normal and twice normal rates, but only just acceptable at site C and unacceptable at site B for twice the normal rate of prometryne. These results were confirmed in 1975 at sites D and E.

In 1976, at sites F and G, slightly more crop damage was recorded at normal rates of S1445 in comparison to prometryne, but at each site it was always acceptable and outgrown by harvest.

In 1975 heavy rainfall after application at site E illustrated the susceptibility of peas to trietazine + simazine and terbutryne + terbuthylazine in situations where leaching of chemical occurs on light sandy soils. Severe necrosis and loss of plant at normal and twice normal rates resulted in unacceptable levels of crop damage. At site D the scores for these materials were again lower than for S1445, but little different from those with prometryne.

Due to the very dry conditions in 1976, very few serious crop effects were recorded for any treatment and those effects recorded were soon outgrown.

Table 2

Crop assessments 1974-76 seven to ten weeks after treatment

Material	Rate kg/ha Sites		Crop damage (0-10) Site						
	A-C	D-G	A	B	C	D	E	F	G
S1445	4.77	5.25	10.0	9.8	9.0	9.3	10.0	9.5	8.7
S1445	9.55	10.50	10.0	9.3	8.5	9.3	8.0	9.0	8.4
Prometryne	1.25	1.38	10.0	7.0	8.4	8.8	8.9	10.0	9.4
Prometryne	2.51	2.76	10.0	5.3	7.5	7.6	4.4	9.3	7.4
Trietazine + simazine	-	1.10	-	-	-	8.6	4.1	9.3	9.4
Trietazine + simazine	-	2.20	-	-	-	7.4	1.9	10.0	9.4
Terbutryne + terbuthylazine	-	1.10	-	-	-	9.1	5.5	10.0	9.4
Terbutryne + terbuthylazine	-	2.20	-	-	-	7.4	2.0	9.5	9.4
Untreated	-	-	10.0	10.0	10.0	10.0	10.0	10.0	10.0

Table 3 includes data of weed assessment scores made seven to ten weeks after treatment. In Table 4 weed assessment scores at or near harvest are shown and in Table 5 the percentage control of individual weed species. No pre-harvest scores were made at site A and no weeds emerged at site E.

Table 3

Overall weed assessments 1974-76 seven to ten weeks after treatment

Material	Rate kg/ha Sites		Weed score (0-10) Site					
	A-C	D-G	A	B	C	D	E	G
S1445	4.77	5.25	7.3	7.6	7.8	8.3	5.0	4.7
S1445	9.55	10.50	8.0	7.8	9.1	9.0	6.0	7.4
Prometryne	1.25	1.38	7.5	9.3	6.8	6.8	5.0	4.7
Prometryne	2.51	2.76	8.3	9.3	8.5	8.9	8.3	5.7
Trietazine + simazine	-	1.10	-	-	-	8.9	5.3	4.4
Trietazine + simazine	-	2.20	-	-	-	9.8	7.8	6.0
Terbutryne + terbuthylazine	-	1.10	-	-	-	8.4	4.8	5.0
Terbutryne + terbuthylazine	-	2.20	-	-	-	9.3	8.5	6.0
Untreated	-	-	0.0	0.0	0.0	0.0	0.0	0.0

Table 4

Overall weed assessments 1974-76 (at or near harvest)

Material	Rate kg/ha Sites		Weed score (0-10)				
	B-C	D,F,G	B	C	D	F	G
S1445	4.77	5.25	7.0	8.5	6.8	5.3	5.0
S1445	9.55	10.50	8.3	9.5	8.0	7.3	8.3
Prometryne	1.25	1.38	6.9	6.8	6.6	4.0	4.0
Prometryne	2.51	2.76	7.8	8.3	7.3	5.3	5.7
Trietazine + simazine	-	1.10	-	-	9.1	4.5	5.3
Trietazine + simazine	-	2.20	-	-	9.6	8.5	8.3
Terbutryne + terbuthylazine	-	1.10	-	-	7.9	4.5	4.7
Terbutryne + terbuthylazine	-	2.20	-	-	9.0	8.0	6.7
Untreated	-	-	0.0	0.0	0.0	0.0	0.0

At the early assessments, at site B, S1445 compared favourably with all materials except prometryne, but was equal to it by harvest. At site D, the persistence of trietazine + simazine and terbutryne + terbuthylazine was illustrated by better weed control near to harvest than from either prometryne or S1445.

In 1976, at sites F & G, S1445 compared well to all materials although overall weed control was below acceptable levels for all materials at the normal rates.

In 1974 S1445 proved to be more persistent than prometryne and subsequently gave better control of Polygonum convolvulus, Veronica spp., Descurania sophia and Viola arvensis, but was slightly weaker against Tripleurospermum maritimum, Polygonum persicaria and Polygonum aviculare; this latter weed was the only one not satisfactorily controlled by S1445.

In 1976, S1445 gave better control of all weeds when compared to prometryne, with the exception of Fumaria officinalis, a species resistant to S1445. Control of P. convolvulus, P. aviculare, Stellaria media and Chenopodium album in 1976 was better with S1445 than from any of the other materials, while it gave similar control of Viola arvensis. In all cases, however, the control of F. officinalis was inferior. In 1976, S1445 seemed to be less affected by the dry conditions than the other materials.

Yields obtained from plots treated with S1445 compared favourably to those treated with prometryne at sites A and G, but were not significantly better than on the untreated plots. At site B, on a very sandy free-draining soil, where marked crop injury was recorded during the season on prometryne treated plots the yields for the normal and twice normal rates of S1445 were significantly higher than the untreated plots, but the yields from the prometryne treated plots were not. At site D the normal rate of S1445 significantly outyielded the normal rate of trietazine plus simazine while the twice normal rate gave significantly higher yields than plots treated with twice normal rates of trietazine plus simazine and terbutryne plus terbuthylazine. At site E the two rates of S1445 and the normal rate of prometryne were the only treatments not to show a significant loss of crop compared to the untreated control.

At both sites F and G the herbicide treatments gave significantly higher yields than the untreated control but differences between treatments were not significant.

Maturity data is presented in Table 7. At site D the produce from all the herbicide treatments was significantly delayed compared to the untreated control

Table 5

Per cent control of weed species 1974 & 1976

Weed species	No. of sites		S1445 5.25 kg/ha		Prometryne 1.38 kg/ha		Trietazine+simazine 1.10 kg/ha	Terbutryne + terbuthylazine 1.10 kg/ha
	1974	1976	1974	1976	1974	1976	1976	1976
Polygonum convolvulus	3	2	92	56	80	49	44	42
Polygonum aviculare	3	1	64	68	72	43	48	43
Stellaria media	3	2	85	71	83	54	46	53
Veronica spp.	3	-	84	-	75	-	-	-
Chenopodium album	3	1	83	67	80	47	54	64
Urtica urens	2	-	93	-	93	-	-	-
Tripleurospermum maritimum	2	-	82	-	96	-	-	-
Polygonum persicaria	1	-	75	-	90	-	-	-
Fumaria officinalis	-	1	-	33	-	53	65	45
Viola arvensis	1	1	73	50	65	34	50	47
Descurania sophia	1	-	88	-	48	-	-	-

and the same trend appeared at site E. These effects were presumably due to greater weed competition on the untreated controls. At site G the maturity of the herbicide mean was significantly delayed compared to the untreated. At site E the produce from plots treated with both rates of S1445 and the normal rate of prometryne was significantly more mature than produce from other treatments which had caused crop injury.

Table 6

Yield data 1974-76

Material	Rate kg/ha Site A-C	Rate kg/ha Site D-G	Yield as % of untreated control Site A	B	C	D	E	F	G
S 1445	4.77	5.25	90	124*	99	110	98	147*	126
S 1445	9.55	10.50	97	126*	101	108	94	181***	142
Prometryne	1.25	1.38	90	108	96	89	98	150**	118
Prometryne	2.51	2.76	95	113	106	87	67***	134*	130
Trietazine + simazine	-	1.10	-	-	-	83*	60***	154**	133
Trietazine + simazine	-	2.20	-	-	-	59***	13***	149**	118
Terbutryne + terbuthylazine	-	1.10	-	-	-	104	76***	151**	127
Terbutryne + terbuthylazine	-	2.20	-	-	-	72**	37***	163**	137
Herbicides mean			93	118	101	89	68	154***	129**
Untreated	-	-	100	100	100	100	100	100	100
S.E. D mean ±			11	10	10	10	6	15	13
S.E.D herbicide mean & untreated ±			-	-	-	-	-	9	10
Yield untreated (tonnes/ha)			8.3	5.2	3.7	3.9	5.2	1.5	2.3

* Significantly different from untreated at the 5% level.
** " " " " " " 1% "
*** " " " " " " 0.1% "

Table 7

Maturity data 1974-76

Material	Rate kg/ha Site A-C	Rate kg/ha Site D-G	Mean tenderometer reading Site A	B	C	D	E	F	G
S 1445	4.77	5.25	116	101	98	109*	148	161	116
S 1445	9.55	10.50	112	101	100	112*	136***	161	116
Prometryne	1.25	1.38	112	101	101	109*	135***	156	113
Prometryne	2.51	2.76	111	100	99	104*	113***	154	114
Trietazine + simazine	-	1.10	-	-	-	111*	118***	156	118
Trietazine + simazine	-	2.20	-	-	-	107*	107***	157	117
Terbutryne + terbuthylazine	-	1.10	-	-	-	109*	123***	162	116
Terbutryne + terbuthylazine	-	2.20	-	-	-	111*	109***	148	118
Herbicide mean			113	101	100	109	124	156	116*
Untreated	-	-	122	103	101	121	148	165	120
S.E. D mean ±			5	2	2	3	4	6	3
S.E.D herbicide mean & untreated ±			-	-	-	-	-	5	2

* Significantly different from untreated at the 5% level.
*** " " " " " " 0.1% "

DISCUSSION

The results of the experiments reported in this paper together with unpublished data, suggest that S1445 may be a safer residual herbicide for use on those sandy soils where a reduced rate or 'growers risk' recommendation is made for existing commercial products. Crop tolerance on medium-textured soils has also been better with S1445 than with commercial products used for comparison. At none of the sites, under the conditions of the experiments, was unacceptable crop damage recorded for either the normal or twice normal rates of S1445.

Other than at one site, weed control by S1445 was comparable to or better than that by prometryne seven to ten weeks after treatment and was in all cases at least as good as it at harvest. S1445 also compared favourably with trietazine + simazine and terbutryne + terbuthylazine, both under suitable conditions for pre-emergence herbicide use and in very dry conditions.

A good range of annual broad-leaved weeds was controlled by S1445 whilst control of P. convolvulus, S. media, Veronica spp and C. album was consistently better than the other materials, but control of P. aviculare was variable, and control of F. officinalis was poor.

No detrimental yield of maturity effects were recorded from the use of S1445 and any difference in maturity was less than that needed to affect harvesting by one day.

Further development work with S1445 is planned on heavier soils where many varieties sensitive to triazine materials are grown.

Comprehensive varietal sensitivity screening will also be undertaken.

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EXPERIMENTS WITH METAMITRON FOR WEED CONTROL IN RED BEET

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Summary Field tests with fifteen drilled vegetable crops demonstrated an outstanding tolerance of red beet to pre- and post-emergence applications of metamitron. This did not extend to spinach, and pea was the only other crop in which there was any indication of potentially useful tolerance. In four experiments with red beet on a sandy loam, metamitron gave good control of a range of weed species when incorporated pre-drilling or applied pre-emergence at 2.8 or 4.2 kg a.i./ha. Good results were also obtained from applications at the early 2-leaf stage of the crop but certain weed species, notably *Polygonum aviculare*, were able to recover unless sprayed at a very early stage. Addition of an adjuvant oil increased effectiveness with negligible damage to the crop foliage. Pre-emergence treatment with 2.8 kg/ha followed by a second application post-emergence gave excellent weed control. The results suggest that in view of the high degree of safety to the crop, wide spectrum of activity and flexibility in time of application, metamitron could prove a valuable addition to the range of herbicides for use in red beet.

INTRODUCTION

Metamitron (4-amino-4,5-dihydro-3-methyl-6-phenyl-1,2,4-triazin-5-one) is a triazinone herbicide which has shown considerable promise for selective weed control in sugar beet crops and which is being developed commercially for that purpose (Hack, 1975a,b; Schmidt et al., 1975). In 1974 and 1975 it was included in a standard field test with fifteen crops at the National Vegetable Research Station to determine its potential usefulness in vegetable production. These tests showed a high degree of tolerance by red beet to both pre- and post-emergence application. This was followed up in 1975 and 1976 when experiments were conducted in which metamitron was applied to red beet in various ways, and the results are summarized in this report.

MATERIALS AND METHODS

The formulation of metamitron used was a 70% w.p., and all doses are given as kg a.i./ha. The sprays were applied in a volume of 1100 l/ha (pre-emergence) and either 1100 or 440 l/ha (post-emergence). The soil was a sandy loam with approximately 2% o.m. To determine relative crop tolerance, single rows of crops (Table 1) were drilled at appropriate depths and metamitron applied across them either immediately afterwards or post-emergence at different growth stages. Treatments in individual tests were not replicated but two separate tests were made in 1974 and two in 1975. Irrigation was given in dry periods. Crop injury and overall weed control were assessed visually on a scale of 0 (no effect) to 10 (complete kill), and the response of individual species in the naturally-occurring weed population was determined.

The experiments with red beet were of randomized block design with three replicates and a plot size of approximately 5 m^2 with four rows 30 cm apart of which the centre two were recorded. The weathered furrow was ring-rolled and the treatments to be incorporated then applied. A single pass with a rotary power harrow working to a depth of 10 cm prepared the seebed and achieved incorporation into the top 5 cm of soil. The seed (cv. Improved Detroit Globe or Boltardy) was then drilled, a single pass made with a wooden roll, and the pre-emergence treatments applied.

The treated plots were not weeded and comparisons were made with both unweeded and hand-weeded controls. The effect on weeds was assessed by counting survivors in a number of random quadrats on each plot to obtain percentage kills, and by recording the fresh weight of weeds on each plot at harvest to obtain the percentage reduction from that on the unweeded controls. Effects on the crop were assessed by recording the numbers and fresh weights of beet roots per plot. These data are expressed in the Tables as percentages of the values for the hand-weeded controls, and those significantly less are indicated by single (P = 0.05) or double (P = 0.01) asterisks.

RESULTS

Crop tolerance tests

Although there were some differences between tests in the level of response to pre-emergence application of metamitron, associated with the distribution of rainfall and irrigation, the relative responses of the crops were consistent and mean values from the four tests are shown in Table 1.

Table 1

Response of vegetable crops to pre-emergence applications of metamitron

Crop	Injury 0-10 (means of four tests)			
	1.4	2.8	4.2	5.6 kg/ha
Cabbage	5.8	7.8	7.5	9.5
Radish	7.3	9.0	9.0	10
Turnip	4.8	6.8	6.0	9.5
Leek	5.0	7.3	8.5	9.5
Onion	7.0	8.5	9.0	10
Carrot	7.5	8.8	10	10
Parsley	8.3	9.0	9.5	9.5
Parsnip	6.3	7.5	8.0	10
Red beet	0.0	0.0	3.0	3.0
Spinach	4.8	6.8	9.0	8.5
Lettuce	8.3	9.5	9.5	10
Pea	0.7	1.3	3.0	5.0
Dwarf bean	3.0	5.8	8.0	9.5
Runner bean	2.5	5.0	7.5	9.0
Broad bean	0.0	2.3	4.0	5.0
Weeds - initial	7.8	8.9	9.8	9.5
- final	7.8	8.6	9.5	9.8

The most striking feature of these results was the outstanding tolerance of red beet. With the two highest doses there was a slight initial reduction in vigour, but this was soon overcome and no other injury was apparent. All the other small-seeded crops proved highly susceptible, with unacceptable injury at the lowest rate of

.4 kg/ha. Of the four large-seeded crops, dwarf bean and runner bean were the most usceptible, and there was usually some injury even with 1.4 kg/ha. Pea and broad ean were more tolerant, with only slight injury from 1.4 or 2.8 kg/ha.

Weed control was consistently good, and the mean scores for the final assessment n each test showed little change from those made earlier (Table 1). Species killed y the lowest rate of 1.4 kg/ha included Capsella bursa-pastoris, Chenopodium album, atricaria matricarioides, Poa annua, Senecio vulgaris, Solanum nigrum, Stellaria edia, Trifolium repens, Tripleurospermum maritimum ssp. inodorum and Urtica urens. amium amplexicaule, Veronica persica and Viola arvensis appeared to be slightly ore tolerant, and a few small plants of these survived at 2.8 kg/ha. The most olerant of the species present were Fumaria officinalis and Polygonum aviculare, ut there was almost complete kill of these also at the two highest rates.

Red beet showed no injury from applications of up to 5.6 kg/ha of metamitron ade from the late cotyledon stage onwards. Pea was also relatively tolerant to post-mergence application, and there was only slight injury in the form of stunting and arginal necrosis of the lower leaves. In striking contrast was the susceptibility f dwarf, runner and broad bean, all of which were severely injured by post-emergence pplications. The remaining crops all proved susceptible, but there was some indication f the development of tolerance on the part of onion, and more especially leek, once hey had passed the 1-leaf stage, Weed control was again good, and species consistently illed in the early seedling stages included Capsella bursa-pastoris, Chenopodium lbum, Poa annua, Senecio vulgaris, Veronica persica, Viola arvensis and Urtica urens. amium amplexicaule appeared to be slightly more tolerant, and the least-affected pecies were Fumaria officinalis and Polygonum aviculare. At later growth stages the ffects were less pronounced, especially with C. album, L. amplexicaule and P. annua.

xperiments with red beet in 1975

In the first of the two 1975 experiments there was a high weed density, with . annua, T. maritimum ssp. inodorum, C. bursa-pastoris, S. media and P. aviculare as he main components. Rainfall in the first 3 weeks after drilling amounted to 29 mm, nd one irrigation of 6 mm was given. Metamitron at 2.8 and 4.2 kg/ha incorporated efore drilling or applied immediately afterwards gave almost complete weed kill, and he few small plants of F. officinalis and P. aviculare that survived were suppressed y the crop. A combined treatment of 2.8 kg/ha pre-emergence followed by 2.8 kg/ha t the early 2-leaf stage gave complete kill (Table 2). The combination of 1.4 kg/ha ith propham at 2.2 kg/ha was included because of the susceptibility of P. aviculare o propham. This treatment gave complete weed kill except for a few plants of F. fficinalis. Lenacil at 0.9 kg/ha, included as a standard, was less effective but he survivors, mainly Lamium purpureum, Veronica persica and T. maritimum ssp. inodorum, ere largely suppressed by the crop.

By the time of the early post-emergence application the weeds ranged from the 1-o 4-leaf stages and the level of kill was not so high as that achieved with pre-mergence treatment. Both rates killed S. media, C. bursa-pastoris, T. repens and . amplexicaule, but F. officinalis, P. aviculare and the larger plants of T. maritimum sp. inodorum and P. annua recovered from the initial injury. Addition of the adjuvant il Actipron (BP Trading Ltd) increased effectiveness; weed kill with 1.4 kg/ha + ctipron was better than that with 2.8 kg/ha alone and the surviving weeds were injured o a greater extent. At the later stage, 4.2 kg/ha + Actipron completely killed lants of S. media, L. purpureum, S. vulgaris, C. bursa-pastoris and T. maritimum ssp. nodorum which were 5 cm in diameter. Plants of P. aviculare and larger plants of . maritimum ssp. inodorum were only scorched, and these accounted for most of the eed vegetation present at harvest. The Actipron treatments caused only minor ecrotic spotting or scorch of the beet foliage, and did not appear to have any adverse ffect on growth.

Table 2

Response of weeds and red beet to metamitron applied in various ways in 1975

Metamitron (kg/ha)	Exp. 1 Weeds Kill (%)	Exp. 1 Weeds Red. in fr. wt (%)	Exp. 1 Beet No. (%)	Exp. 1 Beet Wt roots (%)	Exp. 2 Weeds Kill (%)	Exp. 2 Weeds Red. in fr. wt (%)	Exp. 2 Beet No. (%)	Exp. 2 Beet Wt roots (%)
2.8 inc.	97	99	96	98	96	100	95	98
4.2 inc.	98	100	86	102	97	99	101	98
2.8 pre-em.	98	100	90	97	90	88	75	96
4.2 pre-em.	100	100	100	97	99	100	105	89
2.8 early 2-leaf	80	77	93	85	60	82	106	101
4.2 early 2-leaf	87	77	103	85	71	87	96	111
2.8 pre-em. + 2.8 early 2-leaf	100	100	99	94	97	100	104	93
1.4 + propham 2.2 pre-em.	98	100	91	94	94	99	103	97
1.4 + Actipron 5.6 l/ha e. 2-lf	85	83	103	91	73	72	110	99
2.8 + Actipron 5.6 l/ha e. 2-lf	91	93	92	92	89	88	103	97
2.8 + Actipron 5.6 l/ha 4-leaf	60	51	92	76**	68	96	103	95
4.2 + Actipron 5.6 l/ha 4-leaf	80	83	96	78*	39	87	107	94
Lenacil 0.9 pre-em.	81	91	98	92	91	99	121	109
Control, weeded	-	-	100	100	-	-	100	100
Control, unweeded	($236/m^2$)		97	43**	($7/m^2$)		107	94

All the incorporated and pre-emergence treatments were sufficiently effective to produce beet yields which did not differ significantly from those of the weeded controls. This was also true for treatments applied when the crop was in the early 2-leaf stage. Where metamitron was applied alone at this stage, however, there was visual evidence that some competition from surviving weeds had taken place. Delaying application until the 4-leaf stage resulted in significant yield loss (Table 2) attributable to competition. On the unweeded controls competition was severe, and yield was reduced by more than half.

The second experiment was drilled in late May during a dry period; only 4.8 mm of rain fell during the first 3 weeks and two irrigations totalling 15 mm were given. The main weed species present were Polygonum aviculare, Poa annua and Tripleurospermum maritimum ssp. inodorum, but the overall denisty was low. All the incorporated and pre-emergence treatments gave a high degree of weed kill, but as in the earlier experiment, application when the crop was in the 2-leaf stage was less successful (Table 2). Plants of P. aviculare survived and constituted the main bulk of the weed vegetation present at harvest. Addition of Actipron again improved weed kill, but some plants of P. aviculare survived. When applied at the 4-leaf stage, some plants of T. maritimum ssp. inodorum and P. annua also survived, but were later suppressed by the crop. None of the treatments caused any apparent crop injury, other than slight leaf damage where Actipron was used, and there were no significant differences in yield from that of the weeded controls. In this experiment the presence of weeds on the unweeded controls did not result in any significant yield loss.

Experiments with red beet in 1976

The same treatments were examined in two further experiments in 1976 except that applications at the 4-leaf stage were omitted. The first was drilled in March and received only 6.4 mm rain in the first 3 weeks; no irrigation was given until May. The weed population was lower than usual for early spring, comprising mainly P. annua, S. media, P. aviculare and Matricaria recutita. Despite the dry weather, both incorporated and pre-emergence applications of metamitron gave good weed control (Table 3), although some plants of P. aviculare and occasional S. media survived. Applications at the early 2-leaf stage also gave good control; whether Actipron was included or not P. aviculare was the main survivor, but where only 1.4 kg/ha of metamitron was applied some S. media also remained. The combined pre- and post-emergence treatment resulted in plots which were very clean, but pre-emergence treatment with metamitron at 1.4 kg/ha + propham was not effective and plants of P. aviculare, P. annua, S. media and some other species became established. Lenacil also failed to perform effectively, and at harvest there were large plants of P. aviculare and M. recutita.

Table 3

Response of weeds and red beet to metamitron applied in various ways in 1976

Metamitron (kg/ha)	Experiment 1 Weeds Kill (%)	Experiment 1 Weeds Red. in fr. wt (%)	Experiment 1 Beet No. (%)	Experiment 1 Beet Wt roots (%)	Experiment 2 Weeds Kill (%)	Experiment 2 Weeds Red. in fr. wt (%)	Experiment 2 Beet No. (%)	Experiment 2 Beet Wt roots (%)
2.8 inc.	83	99	88	87*	76	98	110	105
4.2 inc.	91	96	97	95	88	100	110	100
2.8 pre-em.	83	77	103	95	90	98	108	101
4.2 pre-em.	94	96	95	91	98	100	103	94
2.8 early 2-leaf	91	82	81	87*	65	0	88	69**
4.2 early 2-leaf	92	98	96	93	89	63	101	94
2.8 pre-em. + 2.8 early 2-leaf	96	98	88	90	100	99	99	102
1.4 + propham 2.2 pre-em.	54	65	86	80**	85	95	106	89
1.4 + Actipron 5.6 l/ha e.2-lf	85	77	88	92	76	90	105	92
2.8 + Actipron 5.6 l/ha e.2-lf	97	91	78	91	92	96	97	93
Lenacil 0.9 pre-em.	75	11	88	82**	88	89	102	92
Control, weeded	-	-	100	100	-	-	100	100
Control, unweeded	($120/m^2$)		78	81**	($224/m^2$)		113	81*

Because of the dry weather, germination of the beet was uneven and the stand was variable with no significant effects attributable to treatment. On the unweeded control plots and those which received lenacil or metamitron + propham pre-emergence, there was significant loss of yield from weed competition. Metamitron incorporated or applied post-emergence at 2.8 kg/ha also gave yields just significantly less ($P = 0.05$) than that of the weeded controls; this may have been fortuitous, since there was little weed present yet the comparable higher rates had no significant adverse effect.

The second experiment was drilled in late April and received 7.0 mm rain and two irrigations of about 6 mm each during the first 3 weeks. Main weed species present included P. annua, S. media, V. persica and C. album. In this experiment the initial weed kill was somewhat higher with pre-emergence application of metamitron as compared with incorporation, but surviving weeds were suppressed by the crop and the plots were clean at harvest (Table 3). The combined treatments of 2.8 kg/ha pre-emergence with propham also gave good control.

Post-emergence application of metamitron at 2.8 kg/ha gave only partial weed kill and survival of C. album and P. aviculare led to weed weights at harvest greater than those on the unweeded controls, with consequent yield loss as a result of competition. Addition of Actipron improved weed kill, and even where only 1.4 kg/ha was applied there was less weed vegetation at harvest than with 4.2 kg/ha applied alone. Actipron again caused only slight leaf damage. None of the treatments had any significant effect on crop stand, and with the exception already referred to, the yields of roots did not differ significantly from that of the weeded controls.

DISCUSSION

The results of the tests in which metamitron was applied to a range of vegetable crops drilled on a light soil showed a high degree of tolerance by red beet to pre-emergence applications (Table 1) and to those made at different post-emergence stages. This was confirmed in the subsequent experiments; in none was there any evidence of adverse effects on yield attributable to phytotoxicity from incorporated, pre- or post-emergence treatments (Tables 2 and 3). As pointed out by Hack (1975a) in relation to sugar and fodder beet, such flexibility is valuable.

At the rates used, metamitron incorporated or applied pre-emergence consistently killed a range of common weeds which included Capsella bursa-pastoris, Chenopodium album, Matricaria matricarioides, Poa annua, Senecio vulgaris, Solanum nigrum, Stellaria media, Tripleurospermum maritimum ssp. inodorum and Urtica urens. The most tolerant of the species encountered were Polygonum aviculare and Fumaria officinalis; this is in accord with their responses as tabulated by Hack (1975a). On the light soil at Wellesbourne there was no consistent difference in the activity of metamitron incorporated before drilling as compared with surface application after drilling, and even when there was little rainfall good weed control was obtained. The period of persistence of activity in the soil appeared to be adequate for effective weed control in these experiments. At the same time, it seems unlikely that problems of damage to following crops will arise. Bioassays of soil from the 1975 experiments showed that even in an abnormally dry summer no more than 20% of the initial activity remained in the top 7 cm by the time the beet were harvested (Bond & Roberts, 1976).

From trials with sugar and fodder beet, it has been concluded that early post-emergence treatment controls the widest spectrum of weeds (Hack, 1975b). However, it does appear that tolerance develops quite rapidly in certain species. When applied to red beet at the early 2-leaf stage, some weeds had already become too large and metamitron was less effective than when applied pre-emergence. Competition resulted in yield loss in one experiment (Table 3). Application of 2.8 kg/ha at this stage following 2.8 kg/ha pre-emergence gave excellent results (Table 2 and 3), and under conditions leading to an extended period of weed emergence such a sequential treatment would have obvious advantages.

Post-emergence activity of metamitron was considerably increased when an adjuvant oil was present. In all four experiments 2.8 kg/ha + Actipron gave weed control similar to or better than that with 4.2 kg/ha alone. The low rate of 1.4 kg/ha + Actipron gave a degree of control which in three experiments was better and in the other only slightly worse than that with 2.8 kg/ha alone. The slight leaf injury that occurred did not affect crop growth, and the results suggest that the adjuvant could be useful in situations where for one reason or another the weeds have passed the optimum stage of growth for control by metamitron.

It is concluded that because of the high degree of crop safety and the wide spectrum of weeds killed by both soil and early foliar applications, metamitron could be a valuable addition to the range of herbicides for use in red beet. Further work is required to establish optimum rates and timing of applications on different soil types, and to examine possible combinations with other herbicides which might give improved control of Polygonum spp.

The tolerance shown by red beet did not extend to spinach (Table 1), and pea was the only other crop of those examined which showed a potentially useful degree of tolerance to both pre- and post-emergence applications of metamitron. This finding supports results obtained in France (Pourcharesse et al., 1975).

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WEED CONTROL IN OVERWINTERED BULB ONIONS

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Summary In field experiments on a sandy loam in three successive years, effective weed control in crops of bulb onions drilled in late summer for overwintering was obtained with appropriate herbicide programmes. One of the most successful of these was propachlor 4.37 kg a.i./ha pre-emergence followed by pyrazone/chlorbufam (1.12/0.91 kg a.i./ha) at the post-crook stage and methazole 2.09 kg a.i./ha in late winter. It appeared essential to prevent weed establishment during autumn and early winter, and attempts were made to extend the spectrum and period of activity of propachlor. A combination of propachlor 4.37 kg and chlorthal-dimethyl 6.72 kg a.i./ha gave excellent weed control without crop injury, and in three experiments resulted in yields no different from those of the weeded controls even when no follow-up treatments were applied. A combination of propachlor with penoxalin at 1.12 kg a.i./ha also gave excellent control but caused crop injury under conditions of high rainfall. Results obtained with herbicides for control of volunteer cereals and as 'clean-up' treatments are briefly discussed.

INTRODUCTION

It has been shown that by drilling seed of suitable cultivars during late summer it is possible to obtain good yields of bulb onions during the period May - July, well before those derived from conventional spring drillings in the United Kingdom (Tucker & Hough, 1973; Salter, 1975). In 1975 more than 1000 ha of bulb onions for overwintering were drilled. Weed problems in this crop are particularly severe. Emergence occurs at a time of year which is highly favourable for germination of Stellaria media, Poa annua and many other annual weeds. Weed emergence may continue throughout the autumn, and such species as Tripleurospermum maritimum ssp. inodorum grow during winter so that the crop becomes smothered. Spring-germinating species such as Polygonum aviculare may also, in some seasons, compete with the crop and interfere with harvesting. Where the crop is grown in a rotation which includes cereals, volunteers emerging early in autumn and growing through the winter can be a serious problem.

A herbicide programme is essential if the overwintered onion crop is to be profitable. In practice, various sequences are employed, usually involving a pre-emergence treatment selected in accordance with the soil type and followed by one or more post-emergence treatments. The present experiments compared some of the sequences that might be used on a light soil and also examined possibilities of improving the performance of the pre-emergence treatment. More limited tests were also made with herbicides for control of volunteer cereals and for eliminating weeds which had escaped previous treatments.

METHODS AND MATERIALS

The soil was a sandy loam with approximately 2% o.m. The experiments were of randomized block design with three or four replicates. Plot size was 6 m^2, with four rows 30 cm apart of which the centre two were harvested. Seed of cv. Presto was drilled on three occasions in 1973, two in 1974 and two in 1975; irrigation was given when necessary to secure establishment. Before emergence, all plots received a high-volume application of propachlor at 4.37 kg/ha (all doses are given as a.i.). Some plots were then kept clean by hand-weeding to serve as controls; the remaining plots received sequences of herbicides, and these plots were not weeded. Numbers of surviving weeds were assessed by counts of a number of random quadrats on each plot and weed control assessed visually on a scale in which 7 represented the minimum acceptable level and 10 complete kill.

When the onion tops had died down, the bulbs were lifted, allowed to dry and the numbers and weights of sound bulbs per plot recorded. The numbers and weights per plot of plants which had produced flowering stems were recorded separately. In the Tables, numbers and weights significantly less than those for the weeded controls are indicated by single (P = 0.05) and double (P = 0.01) asterisks.

RESULTS

1973/74 experiments

Major weed species in these experiments included *Veronica persica*, *Stellaria media*, *Poa annua*, *Capsella bursa-pastoris* and *Senecio vulgaris*, with *Urtica urens*, *Chenopodium album* and *Thlaspi arvense* present in smaller numbers. Pre-emergence treatment with propachlor alone gave a high level of initial weed kill but further seedlings appeared during autumn, especially in the third sowing, and a mixed stand of weed species was present in winter where no further treatment had been applied.

Where chlorthal-dimethyl at 6.7 kg/ha was added to propachlor, the numbers of surviving weeds were considerably less (Table 1). Besides improving the control of *Chenopodium album* and other species which emerged with the crop, weed establishment during autumn was prevented and the plots remained very clean throughout winter. Methazole at 2.09 kg/ha applied in late winter killed most of the survivors and prevented the establishment of *Polygonum aviculare* and other spring-germinating weeds. At harvest, the only survivors were a few plants of *Senecio vulgaris* and *Matricaria matricarioides*. Penoxalin at 1.12 kg/ha added to propachlor pre-emergence also gave excellent results closely similar to those with chlorthal-dimethyl. Neither herbicide caused any visible crop injury, and the numbers and weights of bulbs did not differ significantly from those of the weeded controls.

Plots which received a sequence of propachlor pre-emergence, pyrazone/chlorbufam (1.12/0.91 kg/ha) at the post-crook stage and methazole 2.09 kg/ha in February were particularly clean at harvest. However, all treatments were successful in that (with one exception in the second sowing) the yields did not differ significantly from those of the weeded controls (Table 1). Yields of sound bulbs from the first two sowings were low because of the high levels of bolting, 53% and 43% respectively compared with 8% for the third sowing. Most treatments had no effect on the level of bolting but where pyrazone/chlorbufam was applied there was a check to growth which was especially apparent when followed by methazole at the 2½-leaf stage. This was reflected in lower bolting percentages of 45, 29 and 1 respectively for the three sowings. In the third sowing this treatment also caused significant reduction in the onion stand.

Table 1

Weed control in overwintered bulb onions 1973/74

Treatment			Weeds/m^2 early autumn	Weed control 0-10		Bulbs	
Pre-em.	Autumn	Late winter		Feb	Apr	/m^2	t/ha
First sowing, 31 July 1973							
Propachlor	py./chl.+	methazole	9	7.5	8.0	64	27
Propachlor	methazole	-	10	7.3	7.0	51	19
Propachlor	py./chl.; methazole	-	7	8.8	8.0	58	24
Propachlor	-	methazole	18	7.0	7.8	55	23
Prop. + chl.-dim.+	-	methazole	7	9.1	8.9	55	21
Prop. + penoxalin	-	methazole	5	9.3	9.3	55	21
Propachlor	weeded	weeded	18	-	-	53	19
S.E. diff. between one treatment mean and weeded control mean (34d.f.)						±6.1	±3.2
Second sowing, 14 August 1973							
Propachlor	py./chl.	methazole	16	9.1	8.4	69	25
Propachlor	methazole	-	47	8.9	9.0	57	22
Propachlor	py./chl.; methazole	-	9	7.6	9.6	50	25
Propachlor	-	methazole	57	8.3	8.3	50	20*
Prop. + chl.-dim.	-	methazole	2	9.0	9.4	50	21
Prop. + penoxalin	-	methazole	2	9.2	9.1	48	23
Propachlor	weeded	weeded	57	-	-	57	25
S.E. diff. between one treatment mean and weeded control mean (34d.f.)						±6.4	±1.8
Third sowing, 29 August 1973							
Propachlor	py./chl.	methazole	5	9.9	10.0	120	48
Propachlor	methazole	-	130	8.3	7.5	118	43
Propachlor	py./chl.; methazole	-	7	9.8	9.9	95*	42
Propachlor	-	methazole	138	5.8	8.0	125	41
Prop. + chl.-dim.	-	methazole	14	9.3	9.3	126	47
Prop. + penoxalin	-	methazole	5	9.4	9.6	109	45
Propachlor	weeded	weeded	138	-	-	118	43
S.E. diff. between one treatment mean and weeded control mean (34d.f.)						±7.4	±2.6

+ Py./chl. = pyrazone/chlorbufam; chl.-dim. = chlorthal-dimethyl.

1974/75 experiments

The main weeds present initially were Poa annua and Stellaria media together with a range of minor species, at densities of 500 and 385/m^2 respectively in the first and second sowings. Propachlor alone gave 85% reduction in numbers in the first sowing and 98% in the second, but there was further emergence during autumn of seedlings of P. annua and Tripleurospermum maritimum ssp. inodorum especially.

Addition of chlorthal-dimethyl at 6.72 kg/ha appreciably improved control compared with propachlor alone, and by the end of April only a few P. annua, Fumaria officinalis and T. maritumum ssp. inodorum were present, even though no follow-up treatment had been applied. In the first sowing, the yield did not differ significantly from that of the weeded controls, but in the second where the crop plants were smaller, competition from T. maritimum ssp. inodorum in particular resulted in a significant yield reduction.

Where penoxalin at 1.12 kg/ha was added to propachlor there was also excellent weed control, with only a few plants of P. annua and T. maritimum ssp. inodorum surviving. Injury to the first sowing was only slight, even though the rainfall during September was twice the average and the crop was waterlogged for much of the autumn. In the second sowing, however, penoxalin killed more than half the onion plants. In a supplementary experiment, penoxalin at 0.84 kg/ha also seriously reduced the stand, and there was a slight reduction with 0.56 kg/ha under these severe conditions.

Table 2

Weed control in overwintered bulb onions 1974/75

Treatment			Weeds/m^2 February	Weed control 0-10 April	Bulbs	
Pre-em.	Autumn	Late winter			/m^2	t/ha
First sowing, 15 August 1974						
Propachlor	py./chl.+	methazole	11	9.7	103	45
Propachlor	methazole	-	27	7.3	111	45
Propachlor	py./chl.; methazole	-	21	8.2	99	46
Propachlor	-	methazole	80	5.3	-	-
Prop. + chl.-dim.+	-	-	4	8.5	96	45
Prop. + penoxalin	-	-	2	9.0	94	44
Propachlor	-	weeded	71	-	111	47
S.E. diff. between one treatment mean and weeded control mean				(17 d.f.)	±8.4	±4.9
Second sowing, 28 August 1974						
Propachlor	py./chl.	methazole	1	9.7	81	36
Propachlor	methazole	-	2	9.7	75	33
Propachlor	py./chl.; methazole	-	0	10.0	62*	35
Propachlor	-	methazole	22	8.3	79	34
Prop. + chl.-dim.	-	-	2	8.5	68	31*
Prop. + penoxalin	-	-	2	8.3	41**	23**
Propachlor	-	weeded	21	-	88	39
S.E. diff. between one treatment mean and weeded control mean				(17 d.f.)	±11.2	±3.4

+ Py./chl. = pyrazone/chlorbufam; chl.-dim. = chlorthal-dimethyl.

Where propachlor alone was applied pre-emergence, appreciable numbers of Poa annua established during autumn and these had become too large to be killed by methazole applied in February. In the first sowing P. annua carpeted the plots receiving these two applications only, and they were not harvested; in the second the numbers were lower and the plants smaller, so that yield was not affected. The remaining treatments gave satisfactory weed control in both sowings, although some P. annua and T. maritimum ssp. inodorum survived in the first sowing. Again, however, where pyrazone/chlorbufam was applied post-crook and followed by methazole at the 2½-leaf stage there was some crop injury and a significant reduction in the number of bulbs in the second sowing. Few onions bolted in these experiments, only 6% in the first sowing and isolated plants in the second.

1975/76 experiments

The main weeds were again Poa annua and Stellaria media, together with Capsella bursa-pastoris and various other species, at a density in the range 200 - 700/m^2. Propachlor pre-emergence gave excellent initial kill, and counts in September/October showed that the weed density had been reduced to 21 and 11/m^2 respectively on the two sowings, with S. media and Lamium amplexicaule the main survivors. During autumn fresh seedlings appeared, including S. media, Veronica persica and Tripleurospermum maritimum ssp. inodorum; nevertheless plots receiving propachlor pre-emergence and methazole in late winter gave yields no different from those of the weeded controls (Table 3).

Table 3

Weed control in overwintered bulb onions 1975/76

Treatment: Pre-em.	Autumn	Late winter	Weeds/m^2 January	Weed control 0-10 February	Bulbs /m^2	t/ha
First sowing, 14 August 1975						
Propachlor	py./chl.+	methazole	33	8.2	80	41
Propachlor	methazole	-	13	8.7	72	34
Propachlor	py./chl.; methazole	-	0	10.0	87	46
Propachlor	-	methazole	-	5.3	68	34
Propachlor	half methazole	half methazole	31	8.7	75	37
Prop. + chl./dim.+	-	-	49	7.3	75	36
Prop. + chl./dim.	-	methazole	42	8.0	88	40
Prop. + chl./dim.	half methazole	half methazole	3	9.5	81	41
Prop. + penoxalin	-	methazole	31	8.0	72	35
Prop. + penoxalin	half methazole	half methazole	3	9.5	81	42
Propachlor	weeded	weeded	-	-	72	35
S.E. diff. between one treatment mean and weeded control mean				(23 d.f.)	±9.8	±3.1
Second sowing, 27 August 1975						
Propachlor	py./chl.+	methazole	1	9.7	104	52
Propachlor	methazole	-	8	7.3	102	48
Propachlor	py./chl.; methazole	-	0	10.0	95	46
Propachlor	-	methazole	87	5.7	110	49
Propachlor	half methazole	half methazole	4	9.7	108	53
Prop. + chl./dim.	-	-	3	9.5	103	49
Prop. + chl./dim.	-	methazole	11	8.3	100	48
Prop. + chl./dim.	half methazole	half methazole	0	9.5	104	52
Prop. + penoxalin	-	methazole	8	7.8	95	48
Prop. + penoxalin	half methazole	half methazole	0	9.8	85*	47
Propachlor	weeded	weeded	-	-	103	52
S.E. diff. between one treatment mean and weeded control mean				(23 d.f.)	±7.3	±3.4

+ Py./chl. = pyrazone/chlorbufam; chl.-dim. = chlorthal-dimethyl.

Addition of chlorthal-dimethyl at 6.72 kg/ha to the pre-emergence propachlor application improved weed control, with no crop injury; even where no follow-up treatment was applied the yield did not differ from that of the weeded controls. When followed by a split application of methazole, 1.05 kg/ha at the 1½-leaf stage and 1.05 kg/ha in February, the plots were extremely clean (Table 3). The weed control obtained with penoxalin as an additive to propachlor was very similar to that with chlorthal-dimethyl. In this experiment only 0.56 kg/ha of penoxalin was used, yet there was still some initial check to crop growth and in the second sowing a significant reduction in stand when followed by methazole 1.05 kg/ha at the 1½-leaf stage.

The remaining treatments all resulted in plots which were fairly clean in winter, and gave yields not significantly less than those of the weeded controls. Where pyrazone/chlorbufam was applied post-crook, and especially when followed by methazole at the 2½-leaf stage, there was an initial check to crop growth which was reflected in some reduction in the number of bolters from the 31% and 3% recorded for the weeded plots of the first and second sowings.

DISCUSSION

In these experiments, propachlor pre-emergence followed by either one or two post-emergence treatments generally gave acceptable weed control, both from the point of view of yield and of ease of harvesting. It is clear that an autumn post-emergence treatment is essential to control weeds which survive the initial application and those which appear subsequently. Where this was not given, weed control was sometimes poor (Table 2). Pyrazone/chlorbufam post-crook gave good weed control but sometimes checked the crop when followed by rainfall. Methazole at the 2½-leaf stage appreciably reduced the numbers of weeds present in winter, and in none of the experiments was there any yield loss as a result of weed competition where this was applied. A split dose of methazole, half in autumn at the 1½-leaf stage and half in late winter, also gave good results in the only year in which it was tried (Table 3). Where pyrazone/chlorbufam was followed by methazole at the 2½-leaf stage, weed control was excellent but there was sometimes a reduction in crop stand.

In 1976 the spring was exceptionally dry and spring-germinating weeds were no problem. In the other years, some Polygonum aviculare and P. convolvulus emerged in March and although they exerted no measurable competition, they could have interfered with mechanised harvesting. Their occurrence was too sporadic to permit comparisons of the various treatments, but certainly methazole applied in spring gave good control. However, because of the risk of persistence of residues in the soil in dry weather (Bond & Roberts, 1976), application of the full dose might not be desirable if it is intended to drill a susceptible crop soon after onion harvest.

The choice of pre-emergence herbicide depends largely on the soil type; on heavier soils pyrazone/chlorbufam is used commercially, while on both heavy and organic soils appropriate amounts of chlorpropham are added to propachlor. In the overwintered onion crop it is vital that the pre-emergence herbicide should be effective, otherwise rapid growth of survivors occurs and by the time the crop has reached a safe stage for post-emergence treatment these weeds may be too large to be killed. Propachlor has a high safety factor on light soils, but some weed species are not killed and the persistence is not sufficiently great. Chlorpropham as an additive is not safe enough on light soils, nor is its persistence adequate when applied in August. Possible additives to propachlor were therefore examined.

A preliminary examination of penoxalin suggested that it was worthy of further evaluation for this purpose (Roberts & Bond, 1974). The results obtained in 1973/74 were encouraging (Table 1), but in 1974/75 there was heavy rainfall not long after application and 1.12 kg/ha caused severe injury to the second sowing (Table 2). Conditions were not as severe in autumn 1975, yet in a supplementary experiment at the second sowing, 1.12 kg/ha reduced crop stand by 52%. In none of the experiments was there any significant adverse effect on the first sowings, but when a more protracted period in the germinating and early seedling stages coincided with wet conditions, damage resulted. The rate of 0.56 kg/ha used in 1975/76 (Table 3) did not cause severe injury even in 1974/75, when it was examined in a supplementary test, and the control of weeds was little different from that with 1.12 kg/ha. However, it does appear that the selectivity is not quite adequate.

A combination of propachlor with chlorthal-dimethyl seems much more promising. hlorthal-dimethyl has been widely used as a pre-emergence treatment for drilled nions in various parts of the world and a high degree of inherent crop tolerance has een recorded (Janýška, 1974). The two herbicides complement each other to a large xtent in terms of weed species controlled, and the combination with propachlor has een found valuable in Australia (Toth, Kaine & Swaine, 1973). In all the present xperiments the initial weed control and suppression of weed establishment during autumn as appreciably better with propachlor 4.37 kg/ha + chlorthal-dimethyl 6.72 kg/ha than ith propachlor alone. There was no crop injury with this mixture, and in three xperiments the control of weeds was such that there was no reduction in yield compared ith the weeded controls, even when no follow-up treatment was applied. The results uggest that application of this combination could eliminate the need for any post-rook treatment.

Certain weeds were particularly troublesome in these experiments. Plants of _ripleurospermum maritimum_ ssp. _inodorum_ that established in autumn and survived reatment continued to grow throughout the winter and ultimately reached sizes of up o 1 m across. _Fumaria officinalis_, though present only in small numbers, also formed lants 1 m across which had a serious suppressing effect on the crop; this species olerates propachlor, chlorthal-dimethly and methazole.

Commercial experience indicates a need for suitable 'clean-up' treatments for use rom late autumn to late winter against weeds which have escaped previous treatments. n 1973/74 ioxynil/linuron (0.28 + 0.28 kg/ha) applied either at the 2½-leaf stage or n late winter gave good results with no adverse effect on yield. In 1975/76 several erbicides were applied at the 3-4-leaf stage or in late winter to plots which had eceived propachlor pre-emergence. Bentazone at 1.4 kg/ha did not harm the crop and illed large plants of _Stellaria media_, _Thlaspi arvense_ and _Tripleurospermum maritimum_ ssp. _inodorum_. Bromofenoxim/terbuthylazine (0.69 + 0.43 kg/ha) also killed large _amium amplexicaule_, _Veronica persica_ and _Fumaria officinalis_ on the treated plots, hich were clean except for _Poa annua_ and some _Matricaria matricarioides_. This treat-ent did cause some injury to the crop foliage, but there was good recovery and further ests are proposed.

The overwintered onion crop may be grown in a rotation which includes cereals, and t has been found that volunteers can present serious problems. In 1974/75, tests were ade on the two sowings to determine whether carbetamide could be used selectively in his crop. The plots received a pre-emergence herbicide and then carbetamide at 2.10 g/ha - the rate used for cereal and grass control in spring cabbage - applied either n mid-November or mid-February. Both treatments completely killed barley which had een sown between the crop rows, and also killed all _Poa annua_. There was no visible rop damage, and no apparent effect on crop stand or yield. In 1975/76 applications ere made in October, November or February. Barley was completely killed by the two ater applications, but there was only a partial kill with the October treatment. In ontrast with the previous result, some crop injury became apparent; this was greatest ith the November application on the first sowing. Although there was no ultimate ignificant effect on bulb yield, plants on some plots were observed to die back rogressively and the extent of injury was considered unacceptable. These results uggest that although there is a considerable degree of selectivity with carbetamide, t may prove too unreliable to be used safely in the overwintered onion crop.

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HERBICIDE PROGRAMMES FOR DRILLED LEEKS

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Summary Various herbicide programmes were examined in an attempt to obtain effective season-long weed control in leeks without soil cultivation or hand weeding. Propachlor was applied pre-emergence, followed by pyrazone/chlorbufam at the post-crook stage as standard treatments. A range of post-emergence herbicides was applied thereafter, supplemented where necessary by further treatment. In one experiment the standard treatments achieved complete weed control. In a second they were initially effective but two further treatments were needed to avoid crop loss due to late-germinating weeds. In the third experiment, the standards were ineffective because of dry soil conditions. Despite herbicide treatment as soon as the appropriate crop stage had been reached and further treatment to control resistant species, severe loss of crop occurred due to weed competition. It was concluded that restrictions imposed by crop tolerance on herbicide timing and efficacy still make it necessary to retain the options of soil cultivation or hand weeding in this crop.

INTRODUCTION

Leeks germinate slowly and their growth during the seedling stage is also slow. The young crop is therefore very susceptible to suppression by weeds and the use of pre-emergence herbicides has become standard commercial practice. These have limited residual effects, however, although the relatively non-competitive growth habit of the established crop and its long growing season necessitate effective protection from weeds until harvest. Post-emergence herbicides can give excellent weed control under optimum conditions, but due to restrictions on earliness of application because of crop tolerance, or to inherently resistant species, no single post-emergence herbicide treatment can be relied upon to keep the crop free from weeds. Soil cultivation and hand-weeding are still important aspects of commercial weed control programmes for leeks. However, when the crop is grown at high populations for the production of small leeks for the pre-pack trade, access for soil cultivation is restricted. Also, increased labour costs have made hand-weeding relatively less economic compared with the cost of herbicide treatment. The experiments reported in this paper were carried out to examine various methods of achieving weed control throughout the life of the crop by means of herbicides alone.

MATERIALS & METHODS

The experiments were situated at Invergowrie on sandy loam or sandy clay loam soils with between 6% and 8% organic matter (by loss on ignition). Leeks, cv. Malabar, were sown using a Stanhay Precision drill, at seed rates designed to produce 10-12 plants per 30 cm of row. Rows were 4.8 m long and 30 cm apart in beds 180 cm wide, giving five rows per bed. Plots were arranged in randomized blocks with four replicates. In each experiment propachlor was applied to all plots shortly before crop emergence, together with paraquat at 1.12 kg a.i./ha if seedling weeds were present. This was followed by pyrazone/chlorbufam when the crop reached the post-crook stage. Experimental treatments (A) were imposed thereafter, followed where necessary by an appropriate supplementary treatment (B) to control resistant weeds. Details of dosage and timing are shown below:

Herbicide	Dosage kg a.i. /ha	Date of application Expt I	Expt II	Expt III
Standard treatments				
Propachlor	4.4	19 April	1 May	8 May
Pyrazone/ chlorbufam	2.0	29 May	9 June	5 June
Experimental treatments (A)				
Unweeded	-	-	-	-
Aziprotryne	1.8	15 June	6 July	8 August
Methazole	1.9	15 June	6 July	8 August
Cyanazine	1.5	15 June	6 July	8 August
Ioxynil	0.6	22 June	6 July	8 August
Ioxynil/linuron	0.7	22 June	6 July	8 August
Bentazone	1.5	7 June	6 July	8 August
Weed-free	-	-	-	-
Supplementary treatments (B)				
Methazole	1.9	3 July	27 July	-
Ioxynil/linuron	0.7	3 July	-	-
Ioxynil	0.6	-	27 July	-

All herbicide applications were made overall by Oxford Precision Sprayer in a water volume of 730 l/ha. Dosages were those recommended by manufacturers for commercial or experimental use in leeks. Regular visual assessments of percentage ground covered by weeds were made throughout the season. Crops were scored for effects of herbicide treatment on a 0-10 scale (0 = no injury, 10 = dead). At harvest, leeks were lifted from the centre three rows of each plot leaving a discard area at each end. They were trimmed, weighed and graded. Leeks of stem diameter less than 1 cm or with visible injury or discoloration to stem or foliage were considered unmarketable.

RESULTS

Expt I (1973) The crop was sown on 5 April. Propachlor was ineffective because of dry soil conditions after application and a dense population of weeds emerged with the leeks. Treatment with pyrazone/chlorbufam at the post-crook stage of the crop checked weed growth, but only temporarily. The major weed species surviving the standard treatments were *Polygonum aviculare*, *Polygonum convolvulus* and *Fumaria officinalis*. Percentage ground cover by weeds was 11% on 7 June when bentazone was applied to one set of plots at the 1-2 leaf stage of crop growth. This treatment controlled *P. convolvulus* and *F. officinalis*, but had no effect on *P. aviculare* which spread rapidly thereafter, the expansion of ground cover keeping pace with

Table 1

Experiment I - Percentage ground cover by weeds at various dates

Experimental treatments A	B	7 June	15 June	22 June	3 July+	27 July	27 Aug.	29 Oct.
Unweeded	-	11	27	46	84	95	91	78
Aziprotryne	Methazole	-	-	40	58	15	43	25
Methazole	Ioxynil/linuron	-	-	35	23	37	36	7
Cyanazine	Methazole	-	-	40	53	18	39	23
Ioxynil/linuron	Methazole	-	-	-	20	5	10	2
Ioxynil	Methazole	-	-	-	59	13	33	8
Bentazone	Methazole	-	21	43	81	34	62	41

+Date of application of B treatments

Table 2

Experiment I - Crop records

Experimental treatments A	B	Herbicide injury Score (0-10) 3 July+	Harvest records Yield t/ha Total	Marketable	Number/4m^2 Total	Marketable
Unweeded	-	0	2.7***	1.3***	215**	43***
Aziprotryne	Methazole	0.2	14.8***	13.8***	342	246*
Methazole	Ioxynil/linuron	2.2	14.5***	14.0***	204**	159***
Cyanazine	Methazole	7.2	4.4***	4.0***	88***	51***
Ioxynil/linuron	Methazole	5.0	14.1***	13.6***	167***	130***
Ioxynil	Methazole	2.0	17.7***	16.6***	320	227**
Bentazone	Methazole	0.2	9.7***	8.4***	300	160***
Weed-free	-	0	39.3	38.7	365	327
S.E. mean ±		-	1.88	1.87	31.2	20.8

*, **, *** Significantly different from Weed-free at the 5%, 1% or 0.1% level

+before B treatments applied

that on untreated plots (Table 1). A further series of plots was treated with aziprotryne, methazole or cyanazine on 15 June when the crop was at the 2-3 leaf stage and weed cover on untreated plots had reached 27%. By this time weeds were at the young plant stage. Methazole worked very slowly but gave excellent control of P. aviculare and P. convolvulus. It had no effect on F. officinalis, which spread very rapidly. Aziprotryne and cyanazine had relatively little effect on weeds of this size, merely delaying the further expansion of weed cover. The final two treatments, ioxynil and ioxynil/linuron, were applied on 22 June at the 3 leaf stage of crop growth when weed cover had reached 52% on untreated plots and the weeds were coming into flower. Ioxynil controlled F. officinalis although not completely, but had no effect on Polygonum spp; the overall effect on weed cover was small. Ioxynil plus linuron, on the other hand, effected a considerable reduction in P. aviculare and virtually eliminated the other two species, the overall effect by 3 July being as good as that with methazole.

Since no individual experimental herbicide treatment had achieved adequate control of all three major weed species, supplementary treatments were applied on 3 July, except on weed-free and unweeded controls. Because of the predominance of P. aviculare on most plots, methazole was applied in all cases other than on plots initially treated with this herbicide. These were re-treated with ioxynil/linuron, which had earlier given the best control of F. officinalis, but at this stage was not very effective (Table 1). Polygonum spp were eventually killed on all plots treated with methazole at this date but, due mainly to further germination, F. officinalis again became a problem, especially on plots originally treated with bentazone. This was the only weed species present on treated plots thereafter, achieving substantial ground cover on all plots except those treated with ioxynil/linuron followed by methazole (Table 1). In most cases the weed cover during late summer was unacceptable, though it declined rapidly in late October as F. officinalis seeded and senesced.

Neither propachlor nor pyrazone/chlorbufam had any visible effect on germination or early growth of the crop. However, several of the experimental herbicide treatments caused crop injury (Table 2). Bentazone and aziprotryne had little effect, but methazole and ioxynil caused quite severe scorch of treated foliage, which was eventually outgrown. Ioxynil/linuron caused severe crop injury, from which the crop gradually recovered, but cyanazine killed a high percentage of the crop. Later treatments with methazole or ioxynil/linuron had no visible adverse effect on crop growth, even on those showing initial injury. The crop was harvested on 6 November. Total and marketable yields on all herbicide-treated plots were severely reduced, the best of them giving a marketable yield only 43% of that on weed-free plots (Table 2). However, all herbicide programmes except those involving cyanazine significantly out-yielded unweeded plots. Plots initially treated with bentazone gave the next lowest yields, due largely to poor weed control, but there was little difference between the other herbicide programmes in either total or marketable yield. Unweeded plots lost over 40% of plant numbers due to competition, but the effect of weeds on plant size was such that marketable weight was only 3% of that on weed-free plots. Significant losses in total numbers of plants were avoided on plots initially treated with aziprotryne, ioxynil and bentazone, despite relatively poor weed control. Since methazole and ioxynil/linuron gave better weed control, reductions in total numbers of plants on these plots must be attributed to effects of herbicide injury. However, adverse effects of weeds and/or herbicide injury reduced numbers of marketable leeks significantly on all treatments in comparison with the weed-free control.

Expt II (1974) The crop was drilled on 17 April. Treatment with propachlor/paraquat, followed by pyrazone/chlorbufam was most effective, and the crop reached the 1 leaf stage by late May, without weed emergence. Ground cover by weeds was only 8% by 24 June, but a dense stand of Chenopodium album emerged and it was decided to

Table 3

Experiment II - Percentage ground cover by weeds at various dates

Experimental treatments A	B	24 June	8 July	19 July	30 July+	16 Aug.	27 Sept.
Unweeded	-	8	16	38	51	63	43
Aziprotryne	Ioxynil	-	-	18	15	9	6
Methazole	Ioxynil	-	-	18	9	3	4
Cyanazine	Ioxynil	-	-	35	16	6	8
Ioxynil/linuron	Methazole	-	-	16	10	5	5
Ioxynil	Methazole	-	-	10	5	2	4
Bentazone	Methazole	-	-	12	18	7	3

+B treatments applied 27 July

Table 4

Experiment II - Crop records

Experimental treatments A	B	Herbicide injury Score (0-10) 25 July+	Harvest records Yield t/ha Total	Marketable	Number/4m² Total	Marketable
Unweeded	-	0	17.9***	14.3***	328	172***
Aziprotryne	Ioxynil	0	40.4	37.8	405	319
Methazole	Ioxynil	2.0	38.3	35.3	378	272
Cyanazine	Ioxynil	1.2	28.5**	26.3**	335	210**
Ioxynil/linuron	Methazole	0.3	33.6	30.8*	357	255
Ioxynil	Methazole	1.6	36.7	34.2	363	273
Bentazone	Methazole	4.5	17.6***	17.0***	150***	118***
Weed-free	-	0	41.3	39.9	345	291
S.E. mean ±		-	2.85	2.96	24.4	17.5

*,**,*** Significantly different from Weed-free at the 5%, 1% or 0.1% level

+before B treatments applied

apply the experimental treatments on 8 July. At this time the crop was at the 3 leaf stage and ground cover by weeds was 16% (Table 3). Other weed species included Stellaria media, F. officinalis, P. aviculare and P. convolvulus. All herbicide treatments controlled S. media. Cyanazine had little effect on the other species and overall ground cover by 19 July was similar to that on untreated plots. Ioxynil and bentazone killed C. album and F. officinalis completely, leaving only the Polygonum spp uncontrolled. These two treatments gave the best overall weed control. Ioxynil /linuron and aziprotryne were fairly effective on C. album and F. officinalis, but gave limited control of Polygonum spp. Methazole killed both P. aviculare and P. convolvulus, partly controlled C. album and had no effect on F. officinalis.

Since no treatment gave complete control of all species, supplementary treatment was applied on 27 July. Plots originally treated with aziprotryne, methazole and cyanazine were re-treated with ioxynil, primarily to control C. album, while those originally treated with ioxynil/linuron, ioxynil or bentazone were re-treated with methazole, to control P. aviculare. Supplementary treatments were successful, the only surviving species again being F. officinalis on plots treated with methazole and P. aviculare on those treated with ioxynil. At no time thereafter did either species achieve sufficient ground cover to merit further treatments.

The plant stand achieved in this experiment was variable but reached acceptable density on all plots. Neither propachlor nor pyrazone/chlorbufam had any visible adverse effect on germination or early growth of the crop. Several of the experimental herbicide treatments, particularly methazole and ioxynil scorched the crop initially, but this was rapidly outgrown. Bentazone, however, severely injured the crop (Table 4). Supplementary treatments had no additional adverse effects on crop growth. The crop was harvested on 10 December. Weeds on untreated plots did not reduce total numbers of leeks, but their effects on plant size severely reduced total and marketable yields (down 57% and 64% respectively). Yield of leeks was significantly reduced on plots originally treated with cyanazine, again due to smaller rather than fewer leeks than on weed-free plots. There was also a reduction in marketable yield on plots treated with ioxynil/linuron. Otherwise, with the exception of plots injured by bentazone, herbicide programmes prevented significant loss of crop due to competition from weeds.

Expt III (1975) The crop was sown on 25 April. Treatment with propachlor followed by pyrazone/chlorbufam gave virtually 100% weed control. Dry early summer weather did not encourage late weed emergence and plots remained clean. The experimental treatments were however applied on 8 August when the crop had 6 leaves, purely to examine crop tolerance. Injury scores taken one week later showed minor scorch of leaf tips by cyanazine, ioxynil, ioxynil/linuron and bentazone, which was rapidly outgrown. Since there were no weeds, the experiment was not taken to yield.

DISCUSSION

The weed control situations encountered in these three experiments are typical of commercial experience with this crop. In Expt I, failure of the standard herbicides allowed weeds to develop before the crop was large enough to be treated safely. Not only did this expose the crop to competition from the weeds, it also meant that weed plants were often past their most sensitive growth stages before herbicide treatment could be applied. In addition the range of species present was beyond the ability of single herbicide treatments to control. Supplementary treatment was effective, but still allowed F. officinalis to become a problem on many plots. Despite the use of four separate herbicide treatments, the crop on all plots suffered severely from weed competition, the best marketable yield being less than half that on weed-free plots. Where only the standard herbicides had been applied, the marketable yield was negligible.

In Expt II, the standard herbicides worked well and late-germinating C. album was the major problem. Weeds allowed to grow without further treatment reduced marketable yield to just over one-third of that on weed-free plots. Several of the herbicides applied at the 3 leaf stage of crop growth gave effective control of C. album, but P. aviculare and F. officinalis required further treatment. In this experiment it was possible to grow the crop without loss due to weed competition because the standard treatments prevented the development of dense weed cover between the post-crook stage and the 3-leaf stage of crop growth. In Expt III, the basic treatments worked so well that no further treatment was required.

Hewson & Roberts (1970), attempting to achieve complete weed control by combinations of pre-emergence and post-emergence treatment, encountered similar problems. Although a wider range of herbicides is now available, pyrazone/chlorbufam remains the only one which can be used shortly after emergence. The wider range of species which can be controlled with more recent materials is, however, valuable. Methazole was particularly useful in these experiments because of its ability to control large plants of P. aviculare. This herbicide in conjunction with ioxynil or ioxynil/linuron to control F. officinalis gave the best overall results in Expts I & II. All three can on occasion, however, injure the crop, even at the recommended growth stage, as in Expt. I. Aziprotryne and cyanazine were relatively ineffective on large weeds, but could not be used earlier than the 2-3 leaf stage of the crop. This restricts their usefulness. The severity of crop injury by cyanazine in Expt I suggests that further investigations into its tolerance by drilled leeks are required. Bentazone, on the other hand, severely affected crop growth in Expt II when applied at the 3-leaf stage although having no such effect when applied at the 1-2 leaf stage in Expt I. This also requires further examination, before the herbicide can be included in herbicide programmes for leeks. None of the herbicides caused more than transient injury when applied to established plants in Expt III.

The vulnerability of leeks to competition from weeds and the restrictions still imposed by crop tolerance on herbicide timing and efficacy suggest that it would be unwise for growers to adopt systems of production which exclude soil cultivation or handweeding as options in their weed control programmes for this crop.

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GLASSHOUSE EXPERIMENTS ON WEED CONTROL BY CARBETAMIDE/ DIMEFURON MIXTURES FOR SELECTED LEGUMINOUS AND CRUCIFEROUS CROPS

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Summary In a glasshouse experiment, the effects on emergence and early shoot growth in one variety each of pea and field bean (at four sowing depths), and in radish, mustard, cabbage and three weeds (*Poa annua*, *Avena fatua* and *Solanum nigrum*) of pre-emergence applications of carbetamide, dimefuron and three mixtures of these herbicides were examined. With the exception of mustard, to which dimefuron was phytotoxic, the crop seedlings tolerated all treatments. *Solanum nigrum* was killed by dimefuron, alone and in mixtures, even at the lowest rate applied (0.25 kg/ha). *Poa annua* was effectively controlled by carbetamide at 1 kg/ha, applied alone or in mixtures. In a separate test, carbetamide at 2 ppm completely inhibited seed germination of *Poa annua*. Kill, and reduction of shoot height and dry weight of survivors, of *Avena fatua* by carbetamide appeared to be enhanced in treatments also containing dimefuron. However, in a second experiment, in which *Avena fatua* was subjected to a wider range of treatments, enhancement was not observed.

INTRODUCTION

Carbetamide is recommended for control of annual grasses and some broad-leaved weeds, principally in cruciferous and leguminous crops (Anon., 1970). Dimefuron shows potential, principally for broad-leaved weed control, in a similar range of crops (Desmoras *et al*., 1974; Burgaud *et al*., 1974; Glasgow *et al*., 1976). Trials on weed susceptibility to, and on weed control in lucerne and winter rapeseed by, mixtures of these two herbicides have been reported (Burgaud *et al*., 1974). Subsequently, the potential use of mixtures to provide selective, wide-spectrum weed control in other crucifers has been examined (G. Ingram, personal communication). The latter work, undertaken in the field, has been complemented by investigations in the glasshouse, the results of which are reported here.

METHOD AND MATERIALS

Two glasshouse experiments were undertaken; one in February and March, the other in August, 1976. Both employed an unsterilized sandy loam (57% sand, 14% silt, 22% clay by pipette method; 7% organic matter by Walkley-Black method; pH 6.8). All herbicide treatments were pre-emergence, applications being made immediately after sowing, using a Shandon Laboratory Spray Gun (operating at 5 bars) at a volume rate of 1000 l/ha (Experiment 1) and 2000 l/ha (Experiment 2). Carbetamide was applied as 'Carbetamex' (70% w.p.) and dimefuron as 'Vt 2809' (50% w.p.).

Experiment 1. Seeds (25) of each of the following crops and weeds were sown in rows in trays (32 x 42 x 9.5 cm) at the depths shown:

Crops:	Pea, 'Kelvedon Wonder' Field bean, 'Maris Bead'	0, 1.5, 3.0, 4.5 cm
	Radish, 'Cherry Belle' Cabbage, 'Early Durham' Mustard, 'English White'	1 cm
Weeds:	*Avena fatua* *Poa annua*	1 cm
	Solanum nigrum	0 cm

Dimefuron was applied alone at three rates (equivalent to 0.25, 0.33 and 0.5 kg a.i./ha); carbetamide was applied at 1.0 kg a.i./ha, alone and in combination with dimefuron at the above rates giving carbetamide/dimefuron ratios at 4:1, 3:1 and 2:1 (w/w). All crop/herbicide and weed/herbicide combinations, including the untreated control, were replicated twice. Trays were watered using a fine rose at an average rate of 1.4 mm/day. Seedling emergence and phytotoxicity were assessed daily; shoot dry weights were determined four weeks after sowing.

In conjunction with this experiment, the effect of carbetamide (2 ppm), dimefuron (0.5, 0.67 and 1.0 ppm) and carbetamide/dimefuron mixtures at 4:1, 3:1 and 2:1, employing the above concentrations, on seed germination of these crops and weeds was determined. The tests were conducted with batches of 20 seeds in petri dishes lined with filter paper, at ambient temperature in the laboratory.

Experiment 2. Seeds (20) of *Avena fatua* were sown at a soil depth of 1 cm in each of 72 pots (14-cm half-pots). Carbetamide was applied at 0.2, 0.4, 0.6, 0.8 and 1.0 kg a.i./ha, both alone and in combination with dimefuron to give carbetamide/dimefuron mixtures of 2:1 and 1:1 (w/w). Dimefuron was also applied alone at all rates at which it was employed in mixtures (i.e. 0.1, 0.2, 0.3, 0.4, 0.5, 0.6, 0.8 and 1.0 kg a.i./ha). The 24 treatments, including an untreated control, were replicated three times in a randomized block design. Pots were watered at an average rate of 3.0 mm/day. Emergence and phytotoxicity were assessed daily; shoot fresh weight/pot and individual shoot lengths were determined at harvest, three weeks after sowing.

RESULTS

Experiment 1

Weeds

(a) *Poa annua* (Table 1). In seed germination tests, carbetamide at 2 ppm, alone and in mixtures with dimefuron, completely inhibited germination, as judged by failure of radicles to emerge. Shoot emergence (as % sown) from the soil was low in all treatments, and was clearly reduced by carbetamide, particularly alone, but also in mixtures with dimefuron. Comparison of counts at 2 and 4 weeks after sowing shows that death of emerged seedlings, which occurred from 18 days onwards, was induced by the mixtures. The dry weights of plants surviving at harvest were decreased in particular by treatment with 2:1 and 3:1 mixtures.

Table 1

Response of *Poa annua* to herbicides

Treatment	Rate (kg/ha)	Rate (ppm)	Germination Test (% germination)	Live seedlings (% sown) at: 2 wk	Live seedlings (% sown) at: 4 wk	Shoot dry wt at 4 wk (mg/plant)
Control	0	0	65	28	44	5.0
Carbetamide	1.0			12	14	3.2
		2.0	0			
Dimefuron	0.25			40	34	8.1
		0.5	60			
	0.33			34	24	4.4
		0.67	45			
	0.50			24	24	5.0
		1.0	50			
Carb./dim.	1.0/0.25			20	8	3.5
		2.0/0.5	0			
	1.0/0.33			16	10	0.7
		2.0/0.67	0			
	1.0/0.5			14	4	2.0
		2.0/1.0	0			

(b) *Avena fatua* (Table 2). With the exception of dimefuron at 1 ppm, which appeared to be stimulatory, no effects on % germination were noted. However, in all carbetamide treatments, only the radicle emerged and its growth was soon inhibited. Kill of emerged seedlings began after 18 days in all treatments containing carbetamide. This herbicide substantially reduced growth (in terms of both shoot height and dry weight), and whilst dimefuron did not, mixtures in all combinations were more effective than carbetamide alone.

(c) *Solanum nigrum* (Table 3). Even at the lowest rate of application, dimefuron, alone and in mixtures, caused early post-germination damage and subsequent effective control of this weed.

Crops

There were no obvious treatment effects on beans, peas (except those surface-sown), cabbage and radish. The tolerance of these crop seedlings is illustrated by data for peas, sown at 1.5 cm (Table 4), and radish (Table 5).

Table 2

Response of *Avena fatua* to herbicides

Treatment	Rate (kg/ha)	Rate (ppm)	Germination (%)	Live seedlings (% sown): 2 wk	Live seedlings (% sown): 4 wk	Shoot dry wt at 4 wk (mg/plant)	Mean plant height at 11 days (cm)
Control	0	0	40	76	80	128	12.4
Carbetamide	1.0			62	54	49	6.2
		2.0	45*				
Dimefuron	0.25			62	62	110	11.3
		0.5	55				
	0.33			80	80	105	11.9
		0.67	50				
	0.50			54	50	157	10.6
		1.0	85				
Carb./dim.	1/0.25			56	38	32	2.8
		2/0.5	55*				
	1/0.33			64	50	28	2.7
		2/0.67	25*				
	1/0.5			68	32	24	3.6
		2/1.0	35*				

* Radicle emergence only

Table 3

Response of *Solanum nigrum* to herbicides

Treatment	Rate (kg/ha)	Rate (ppm)	Germination Test (% germination)	Live seedlings (% sown) max. recorded	Live seedlings (% sown) 4 wk	Shoot dry wt at 4 wk (mg/plant)
Control	0	0	40	64	64	16.0
Carbetamide	1.0			52	48	9.2
		2.0	24			
Dimefuron	0.25			52	8	1.4
		0.5	32			
	0.33			36	4	1.8
		0.67	28			
	0.50			48	4	0.9
		1.0	44			
Carb./dim.	1/0.25			48	4	0.4
		2/0.5	24			
	1/0.33			60	4	0.8
		2/0.67	28			
	1/0.5			48	8	1.0
		2/1.0	24			

Table 4

Response of pea 'Kelvedon Wonder', sown at depth of 1.5 cm, to herbicides

Treatment	Rate (kg/ha)	(ppm)	Germination Test (% germination)	Emergence (% sown) after 10 days	Shoot dry weight at 4 wk (mg/plant)
Control	0	0	100	84	162
Carbetamide	1.0			82	171
		2.0	100		
Dimefuron	0.25			72	211
		0.5	100		
	0.33			90	148
		0.67	100		
	0.50			94	194
		1.0	85		
Carb./dim.	1/0.25			86	168
		2/0.5	90		
	1/0.33			78	175
		2/0.67	100		
	1/0.5			88	192
		2/1.0	100		

Table 5

Response of radish 'Cherry Belle' to herbicides

Treatment	Rate (kg/ha)	(ppm)	Germination Test (% germination)	Emergence (% sown) after 11 days	Shoot dry weight at 4 wk (mg/plant)
Control	0	0	48	72	69
Carbetamide	1.0			82	70
		2.0	64		
Dimefuron	0.25			88	64
		0.5	56		
	0.33			86	91
		0.67	68		
	0.50			90	62
		1.0	60		
Carb./dim.	1/0.25			84	67
		2/0.5	60		
	1/0.33			88	102
		2/0.67	56		
	1/0.50			88	53
		2/1.0	56		

Effects on surface-sown peas and on mustard are described below.

(a) Surface-sown pea. Early shoot growth (assessed by visual observations on leaf expansion) appeared to be promoted by dimefuron alone, particularly at the highest rate, but was reduced by all carbetamide treatments, especially by the mixtures. This effect of the mixtures could be correlated with early side-shoot development. These effects were not noted in peas sown at other depths.

(b) Mustard. All herbicide treatments caused a slight reduction in early shoot growth. Dimefuron at the two higher rates caused leaf chlorosis and eventual death of some plants.

Experiment 2

Dimefuron alone did not significantly affect shoot fresh weight of *A. fatua* on a 'per pot' basis at any of the rates at which it was applied (Table 6). Lower rates (up to 0.4 kg/ha) appeared to promote growth slightly; higher rates (0.8 and 1.0 kg/ha) killed a few plants within 3 weeks of treatment. Carbetamide alone at 1.0 kg/ha significantly reduced fresh weight (by 59%), and under this treatment, most plants exhibited severe stunting and their development was arrested at the 1-leaf stage. Similar effects were observed in mixtures only where carbetamide was present at the highest rates (0.8 and 1.0 kg/ha). Both the 1:1 and 2:1 mixtures in which carbetamide was applied at 1.0 kg/ha reduced shoot fresh weight to a similar level to that obtained with carbetamide applied alone at this rate (Table 6); phytotoxic symptoms appeared to be those of carbetamide.

Table 6

Effect of pre-emergence applications of carbetamide and dimefuron, alone and as 1:1 and 2:1 (w/v) mixtures, on shoot fresh weight (g/pot) of *Avena fatua*

Dimefuron rate (kg/ha)	Carbetamide rate (kg/ha) 0	0.2	0.4	0.6	0.8	1.0
0	5.26	5.21	5.80	4.46	4.71	2.14*
0.1	5.46	5.52				
0.2	5.56	5.47	5.50			
0.3	6.11			5.96		
0.4	5.70		4.94		4.11	
0.5	4.77					2.42*
0.6	5.37			5.18		
0.8	3.90				3.46	
1.0	4.32					2.12*

* indicates a significant difference from the untreated control (L.S.D. = 1.96, at P = 0.05)

DISCUSSION

The main purpose of investigating mixtures of herbicides is to provide a wider spectrum of weed control, at economic rates of application, than may be obtained with the individual compounds. There is always a possibility, however, that interactions may occur between two or more herbicides on an individual plant species. The glasshouse experiments reported here were not aimed, therefore, at a coverage of a comprehensive range of crops and weeds, but at revealing any such interactions which may occur in studies of short duration with a few selected crops and weeds.

Four of the five crops investigated exhibited tolerance to mixtures which was as high as that to the separate herbicide components. Of the weeds, the effects of mixtures on Solanum nigrum were a manifestation of susceptibility to dimefuron. The control of Poa annua by mixtures may have had two components, but the major contribution was clearly made by carbetamide. The observation that carbetamide at 2 ppm completely inhibited seed germination of Poa annua promoted further tests; concentrations of 0.3 ppm and below were ineffective (Dicks, unpublished). In the field, therefore, the extent to which inhibition of seed germination, as opposed to inhibition of seedling growth, contributes to control of Poa annua by carbetamide will depend upon the herbicide concentration attained in the soil solution at the seed surface before germination occurs.

The response of Avena fatua to mixtures was principally a response to carbetamide. However, the data in Table 2 did suggest that the two herbicides interacted to provide better control than carbetamide alone. For this reason, a closer examination was made of the response of Avena fatua to carbetamide/dimefuron mixtures over a wider range of application rates. The results of experiment 2 showed that whilst the action of carbetamide was not antagonized by dimefuron at the ratios employed, nor was it promoted.

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THE INHERITANCE OF METOXURON SUSCEPTIBILITY IN WINTER WHEAT

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Summary Metoxuron tolerance is simply inherited in the progeny of crosses between resistant and susceptible winter wheat varieties. In some crosses susceptibility is apparently determined by a single recessive gene while in others two genes appear to be involved. The expression of one of these two genes was evident only in certain of the experiments and an environmental influence is suspected.

Selection for metoxuron tolerance would be possible in a breeding programme but is probably unjustified in view of the recent introduction of the related substituted urea, isoproturon, with similar herbicidal activity but without problems of varietal sensitivity. The need for the plant breeder to be familiar with the reaction of his selections to herbicide treatments is emphasised.

Sommaire La tolérance à métoxuron est herité simplement dans les hybrides entre variétés de blé d'hiver sensibles et résistents. Il se montre que la sensibilité en quelques hybrides est determiné par un seul gène, cependant que dans autres hybrides deux gènes sont impliqué. L'expression d'un de ces gènes était demontré seulement en certains esperiènces, et une influence de l'environnement est supposé.

La selection pour la tolérance à métoxuron peut être possible dans une programme d'amélioration des plantes mais n'est pas probablement justifié en consideration de l'introduction récente de l'urée substituée alliée, isoproturon. Celle ci montre une activité similaire, mais sans les problèmes de la sensibilité variétale. La necessité que le selectionneur des plantes soi familier avec la sensibilité de ces selections aux traitements herbicidales est accentué.

INTRODUCTION

Varietal differences in susceptibility of wheat varieties to the substituted urea herbicides metoxuron and chlortoluron have been reported by a number of workers (e.g. Tottman et al 1975; Fryer and Makepeace 1972; van Heile et al 1970). Such differences are frequently very clearly defined, suggesting that susceptibility may be determined by a simple genetic mechanism. The present paper describes experiments designed to determine this mechanism in crosses involving the susceptible varieties Hobbit and Maris Huntsman.

METHOD AND MATERIALS

The inheritance of metoxuron susceptibility was determined in material derived from the following crosses:

TJB 660 - Maris Widgeon (resistant - R) x Hobbit (susceptible - S)

TJB 683 - TJB 54/224 (Maris Widgeon sib x Viking, R) x Hobbit (S)

TJB 987 - TJB 268/175 (Maris Beacon x (Maris Ranger x Maris Durin sib), R) x Hobbit

TJB 1001 - TJB 268/175 x Maris Huntsman (S)

TJB 1030 - TJB 269/378 (Maris Beacon x (Maris Envoy x Maris Durin sib), R) x Hobbit

TJB 1060 - TJB 269/378 x Maris Huntsman.

In each experiment the seed from single plants of the previous generation were sown in two-row plots 120 cm long with plant spacing 5 x 15 cm. Resistant and control varieties were sown after each set of 25 plots. Half of each plot was sprayed with metoxuron at a rate of 13.45 kg a.i./ha, that is at three times the manufacturer's recommended dose, when the plants had two fully expanded leaves (growth stage 12, Zadoks, Chang and Konzak, 1974). Symptoms of damage were first apparent on susceptible plants approximately six weeks after spraying and the plots were scored during February and March when plants killed by the herbicide could be distinguished from those which had failed to germinate.

<u>Experiment 1</u> 1973/4 - F_3 generation. Seed from each of 200 random F_2 plants from each cross were sown on 11 October 1973, sprayed on 18 December and scored on 26 February and again on 7 March 1974.

<u>Experiment 2</u> 1974/5 - F_4 generation. The progeny of ten single plants, harvested from the unsprayed halves of twenty representative families from the crosses TJB 660 and 683 and twelve families from TJB 987, 1001, 1030 and 1060 in Experiment 1, were sown on 9 October 1974, sprayed on 20 December and scored on 7 and 17 February 1975.

<u>Experiment 3</u> 1975/6 - F_4 generation. Experiment 2 was repeated with seed remaining from the harvest of Experiment 1. The seed was sufficient to sow only 1 row of each single plant progeny. Plots were sown on 20 October 1975, sprayed on 8 December and scored on 1 March 1976.

<u>Experiment 4</u> 1975/6 - F_5 generation. The unsprayed halves of five representative F_4 families from the crosses TJB 660 and 683 and of two families from TJB 987, 1001, 1030 and 1060 were harvested from Experiment 2. The progeny of five single plants from each plot (ten per family and each the progeny of a single F_3 plant) were sown on 24 October 1975. Subsequent growth was much slower than in Experiment 3 and spraying was delayed until the plants had two fully-expanded leaves on 13 January 1976. Damage to the plants was scored on 3 March.

RESULTS

Observations made in Experiment 1 showed a very clear cut segregation for metoxuron susceptibility (Table 1). Data from the crosses TJB 660 and 683 suggest that two recessive genes are involved, but results from the other crosses suggest that resistance in them is determined by a single gene. It was possible to distinguish in TJB 660 and 683 between progenies segregating 3:1 or 9:7 of resistant to susceptible plants, but in TJB 987, 1001, 1030 and 1060 it was not always possible to distinguish with certainty between fully resistant and segregating progenies. These have therefore been grouped for genetic analysis and goodness of fit to a 3:1 ratio determined.

The results obtained in subsequent experiments in all cases confirmed the susceptibility of progenies showing full susceptibility to metoxuron spray in Experiment 1, though the number of susceptible lines included in the samples grown was rather small. The subsequent experiments also confirmed the hypothesis that susceptibility in the crosses TJB 987, 1001, 1030 and 1060 was determined by a single recessive gene (Table 2). Some of the progenies classified as segregating in Experiment 1 showed no further segregation in subsequent experiments.

Table 1 Segregation for metoxuron susceptibility in F_2 plant progenies of wheat crosses (Experiment 1)

	Resistant	Segregating 3:1	Segregating 9:7	Susceptible
TJB 660	14	38	49	99
TJB 683	11	50	59	80
Crosses combined				
Observed	25	88	108	179
Expected	25	100	100	175
χ^2 2.17 P 0.5-0.7				
TJB 987	22	131		47
TJB 1001	41	107		52
TJB 1030	28	123		49
TJB 1060	27	115		58
Crosses combined				
Observed	594 (Resistant + Segregating)			206
Expected	600 (Resistant + Segregating)			200
χ^2 0.24 P 0.5-0.7				

This indicates that these lines were probably mis-classified in Experiment 1 and accounts for the considerable excess of segregating lines observed in this experiment. It was, however, found that lines recorded as fully resistant in F_3 were nearly all fully resistant in subsequent experiments. Exceptional cases would be expected because the size of the sample of plants sprayed in Experiment 1 might sometimes exclude susceptible plants in a segregating progeny. Detailed results for one of these crosses are given in Table 3.

Table 2 (a) F_4 segregation in plots derived from representative F_3 families (Experiment 2)

(a) F_4 segregation	Resistant	Segregating	Susceptible
TJB 660	6	9	5
TJB 683	3	13	4
TJB 987	4	5	3
TJB 1001	1	7	3
TJB 1030	4	6	2
TJB 1060	4	5	3
Total	22	45	20
Expected (1:2:1)	21.75	43.5	21.75

χ^2 0.220 P 0.8-0.9

(b) F$_5$ segregation in plots derived from ten F$_4$ lines in selected F$_3$ families (Experiment 4)

		Resistant	Segregating	Susceptible
TJB 987	Family 1	0	6	4
	" 4	2	7	1
TJB 1001	" 2	2	5	2
	9	2	4	4
TJB 1030	" 3	0	10	0
	7	1	6	3
TJB 1060	" 5	2	7	1
	7	4	6	0
Total		13	51	15
Expected (1:2:1)		19.75	39.5	19.75

χ^2 6.87 P 0.02-0.05

Table 3 Segregation for metoxuron susceptibility in selected plant progenies of TJB 1030

Family	1	2	3	4	5	6	7	8	9	10	11	12
F$_3$ Observation (Experiment 1)	3:1	S	3:1	3:1	R	R	3:1	3:1	R	3:1	S	3:1
F$_4$ Observations												
Experiment 2, 1975	3:1	S	3:1	R	R	3:1	3:1	R	3:1	3:1	S	R
Experiment 3, 1976	3:1		3:1	R	R	R	3:1	R	R	3:1		R

Segregation of F$_4$ plant progenies in F$_5$ (Experiment 4)

Family	3	7
Resistant	0	1
Segregating	10	6
Susceptible	0	3

The suggestion that susceptibility to metoxuron was determined by two recessive genes in the crosses TJB 660 or 683 was not confirmed by results obtained in Experiments 2 and 3. Indeed, the results obtained in these experiments suggests that susceptibility was determined by a single recessive gene as in the other crosses, and the observations obtained have been combined with those for the other crosses in the data presented in Table 2(a). The results obtained from Experiment 4, however, again suggest that two genes may be involved in determining susceptibility in TJB 660 and 683. The results from these two crosses, given in detail in Table 4, show that the F$_5$ segregation follows closely the pattern expected from observations made in F$_3$. Exceptions occur in the cases of family 2 in TJB 660 and family 10 in TJB 683 which should probably have been scored as 3:1 in F$_3$.

Table 4 Segregation for metoxuron susceptibility in selected plant progenies of TJB 660 (a) and TJB 683 (b)

(a) TJB 660

Family	1	2	3	4	5	6	7	8	9	10
F$_3$ Observation (Experiment 1)	S	9:7	9:7	S	9:7	S	3:1	9:7	S	3:1
F$_4$ Observations										
Experiment 2, 1975	S	3:1	3:1	S	3:1	S	3:1	R	S	R
Experiment 3, 1976		R	3:1		R			R		R

Family	11	12	13	14	15	16	17	18	19	20
F_3 Observation (Experiment 1)	9:7	9:7	S	R	3:1	R	3:1	9:7	R	R
F_4 Observations										
Experiment 2, 1975	3:1	3:1	S	R	R	R	R	3:1	3:1	3:1
Experiment 3, 1976	3:1	3:1		R	R	R	R	3:1	R	R

Segregation of F_4 plant progenies in F_5 (Experiment 4)

Family	2	10	12	17	18
Resistant	5	7	0	7	2
Segregating	5	3	5	3	4
Susceptible	0	0	5	0	4

(b) TJB 683

Family	1	2	3	4	5	6	7	8	9	10
F_3 Observation (Experiment 1)	9:7	9:7	9:7	3:1	S	3:1	9:7	3:1	9:7	9:7
F_4 Observations										
Experiment 2, 1975	3:1	3:1	3:1	3:1	S	3:1	3:1	R	3:1	3:1
Experiment 3, 1976	R	3:1	3:1	R	S	R	R	R	3:1	R

Family	11	12	13	14	15	16	17	18	19	20
F_3 Observation (Experiment 1)	S	9:7	9:7	3:1	9:7	9:7	S	R	S	9:7
F_4 Observations										
Experiment 2, 1975	S	3:1	3:1	R	3:1	3:1	S	R	S	3:1
Experiment 3, 1976		R	R	R	3:1	3:1		R		3:1

Segregation of F_4 plant progenies in F_5 (Experiment 4)

Family	1	4	6	9	10
Resistant	2	7	2	0	1
Segregating	7	2	8	6	9
Susceptible	1	0	0	4	0

DISCUSSION

Although the inheritance of metoxuron susceptibility appears to be simply inherited, the switch between one gene and two gene segregation in TJB 660 and 683 calls for further comment. It should first be noted that these crosses are of similar parentage, both involving the resistant variety Maris Widgeon and the susceptible variety Hobbit. This suggests that Maris Widgeon may carry a normally non effective gene which may in certain circumstances augment the gene determining susceptibility in Hobbit. The plants in Experiments 1 and 4, when a two gene segregation took place, may have been growing under somewhat less favourable circumstances than those in Experiments 2 and 3. The slow early growth of the plants in Experiment 4 has already been mentioned and may have been caused by the low soil water content prevailing during the very dry weather in late summer and autumn 1975. As a result these plants did not reach the two expanded leaf stage, at which metoxuron was applied in all experiments, until mid January 1976. The plants were therefore recovering from spray application under colder and less favourable conditions than those obtaining in Experiments 2 and 3. No simple explanation of the behaviour of plants in Experiment 1 is possible though there was on this occasion a sharp cold spell shortly after metoxuron application.

Our experience with routine observations of reactions of wheat varieties and advanced breeders' selections to metoxuron has been that varietal patterns of behaviour have been very consistent between sites and seasons. Levels of crop damage have frequently varied between tests, but the relative levels of damage have remained constant. Such observations are consistent with the hypothesis that susceptibility to metoxuron damage is determined by a simple genetic mechanism such as the single gene in the crosses TJB 987, 1001, 1030 and 1060. The more complex mechanism, involving the occasional action of a second gene, as suggested for TJB 660 and 683, would give rise to a situation in which the reactions of selections homozygous for the second gene, supposedly derived from Maris Widgeon, would vary according to the environment in which the crop was grown. This situation is not observed in Maris Widgeon itself, which is consistently tolerant of metoxuron, but should be seen in derivatives of the susceptible plants in families 12 and 18 of TJB 660 or of family 9 of TJB 683. This hypothesis will be tested in subsequent experiments.

The clear cut segregation and apparently simple inheritance of varietal susceptibility to metoxuron show that selection for herbicide tolerance would present little difficulty to the plant breeder. Such a programme would however add another factor to the many characters which the breeder must consider and must be considered in relation to the total effort available for his programme as a whole. It must also be considered in relation to the continuing release of more selective and effective herbicides by the chemical manufacturing industry. Indeed, during the time while the investigations described in this paper were being carried out, a series of new and highly selective herbicides has been developed, one of which, isoproturon, serves much the same function as metoxuron with markedly reduced damage to wheat (Tottman et al, 1975). We therefore suggest that work to incorporate herbicide tolerance into a wheat breeding programme is not justified, though it is important that the breeder should be familiar with the herbicide reactions of his material. This would enable him to select herbicide tolerant lines for release if a choice of otherwise similar lines comes up for consideration. It would also enable him to issue warnings of the possibility of herbicide damage if a susceptible variety is released.

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Proceedings 1976 British Crop Protection Conference - Weeds

FACTORS CONTRIBUTING TO THE IMPROVED SIMAZINE RESISTANCE OBSERVED IN OILSEED RAPE VARIETY RIGO AFTER THREE CYCLES OF SELECTION

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Summary Resistance to simazine was correlated with an increase in vigour, especially evident during early growth, in the selected (S3) material. Although mean seed size and weight were greater in the S3, seedlings from small S3 seeds were more resistant than seedlings from large unselected (S0) seed. S3 plants tolerated sustained contact with 0.05 ppm simazine in nutrient solution whereas S0 plants, of similar size and from seeds of the same size, died. The rate of inhibition of photosynthesis in plants exposed to 0.2 ppm simazine was more rapid in S0 plants.

Résumé La résistance à la simazine est liée avec une augmentation de la vigueur spécialement en dèbut de végétation dans le materiel sélectionné (S3). Bienque le calibre moyen et le poids moyen furent plus important dans la population S3, les semis venant des petits grains S3 furent plus résistants que les semis des gros grains non-sélectionnés (S0). Les plantes S3 tolèrent en permanence une solution titrant 0,05 ppm de simazine tandisque les S0, d'une taille similaire et venant des grains de taille similaire, sont détruites. Le taux d'inhibition de photosynthèse dans des plantes d'une taille similaire exposées à 0,2 ppm de simazine fut plus rapide dans les S0.

INTRODUCTION

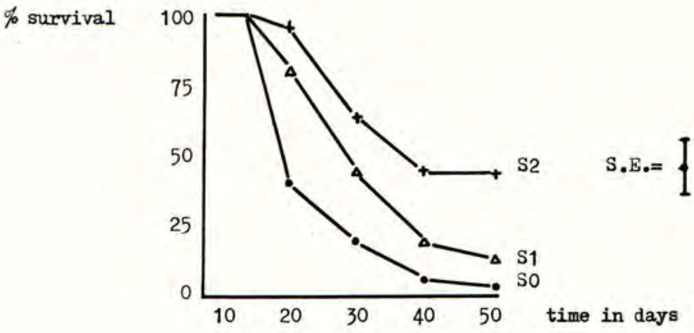
The search for more selective herbicides is both laborious and expensive, and in recent years an alternative approach has been suggested: to utilise the natural variability exhibited by crops in response to herbicides and to breed for resistance to existing chemicals that are efficient in controlling weeds (COMSTOCK & ANDERSEN 1968, HAYES et al 1965, KARIM & BRADSHAW, 1968). Oilseed rape and simazine were chosen for study. Rape: because its most competitive weeds are closely related and herbicides may lack adequate security. Simazine: because although its low cost and high effectiveness make it a superior herbicide, its selectivity is low and its range of usefulness limited to those crops showing natural resistance.

I. PRODUCTION OF RAPE EXHIBITING INCREASED RESISTANCE TO SIMAZINE

Although the time taken for seedlings to die varies considerably between varieties, the ability to survive exposure to soil treated with 0.56 kg a.i./ha simazine for longer than 5 weeks seems to be a characteristic of individuals (KARIM & BRADSHAW 1968, WARWICK 1973), so screening was confined to a single variety: Rigo. Seeds were sown in sieved soil mixed with 0.56 kg a.i./ha simazine (50% w.p.). After 6 weeks survivors were transferred to untreated soil and allowed to set seed in a polycross (WARWICK 1973). Seed from this polycross (designated Selection 1 or S1) was rescreened in the same way and survivors polycrossed to produce the S2. The response of the unselected variety (S0), the S1 and S2 to simazine treatment was compared in soil treated with 0.56 kg a.i./ha simazine (Fig. 1). There were 5 replicates and the experiment was performed in a glasshouse.

The S2 was rescreened to produce the S3, in which some of the factors contributing to the increased resistance observed were studied.

Fig. 1. Comparison of survival of oilseed rape selected for simazine resistance and grown in 0.56 kg a.i./ha simazine



II. EXPERIMENTS TO DETERMINE SOME OF THE FACTORS CONTRIBUTING TO RESISTANCE

Species susceptibility to simazine depends on the extent to which the herbicide remains in a toxic concentration at the site of action in the leaf tissue, (SHEETS 1961). In plants that are able to survive simazine treatment a toxic concentration is in some way prevented from accumulating with the result that inhibition of photosynthesis and subsequent growth either does not occur, or occurs at an insufficient rate to kill the plant.

There were 4 replicates in each experiment unless otherwise stated. All data were subjected to analyses of variance and to Duncan's New Multiple Range Test.

1. General Vigour

Method Partitioning of dry weight into roots, stems and leaves, the leaf areas, the relative growth rates, and the root/shoot ratios in the S0 and S3 grown in untreated soil were compared. 20 comparable seedlings were transferred to individual pots of soil 4 days after germination and harvested after 8, 12, 16, 20, 24, or 28 days. Dry weights of roots, stems and leaves were measured for each plant (WARWICK 1973).

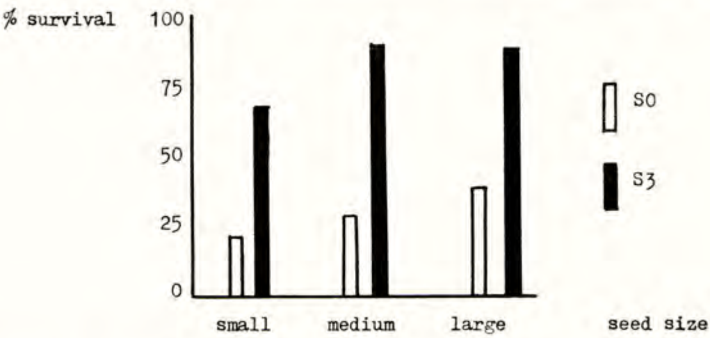
Results Total dry weight production, leaf dry weight and leaf area were significantly greater (P = 1%) in the S3 than in the SO especially at the earliest harvest dates. Relative growth rates were not significantly different. Although root/shoot ratios did not differ significantly between the SO and S3 at all harvests, a significantly higher proportion of seed reserve was put into root production (P = 5%) in the S3 during the first 8 days after germination. Thus it was possible that repeated screening in simazine-treated soil had selected out those seedlings with large food reserves, seed size being known to influence the tolerance of certain plants to soil-applied herbicides (ANDERSEN 1970, SCHROEDER & WARREN 1971, WETTASINGHE 1968).

2. Seed size

Method 20 SO and 20 S3 seedlings from small, medium or large seeds, graded by sieving and controlled by weighing a known sample size, were allowed to emerge in soil treated with 0.28 or o.56 kg a.i./ha simazine, (WARWICK 1973).

Results Seedlings from large seeds were taller and larger than those from small seeds. This was most marked in untreated soil and in the SO. In simazine-treated soil, although seedlings from large seeds were more vigorous in both the SO and S3, all S3 seedlings were healthier than the SO in each seed size category. Although no seedling survived the higher treatment (possibly due to some very hot days at the time of emergence), the time to death varied considerably between the SO and S3. There were clear differences in ultimate survival at the lower simazine level that were not related to seed size in the S3 (Fig. 2). The slower rates of appearance of symptoms and time to death observed in the S3 could be due to slightly different rates of translocation or detoxification of the absorbed simazine (HAMILTON & MORELAND 1962, SHEETS 1961, SHONE & WOOD 1972).

Fig. 2. The effect of seed size on survival of oilseed rape selected for simazine resistance and grown in soil treated with 0.28 kg/ha simazine



D.N.M.R. test (P=1%) Seed size: small medium large

Selections: SO S3

3. Tolerance of simazine in nutrient solution

Methods a) Tolerance of a low concentration of simazine over a long period.

The experimental unit was a plastic beaker containing nutrient solution and 10 seedlings. Each beaker was covered by a plastic tile perforated by 10 open-ended plastic tubes, each containing a single 6 day old seedling from medium-sized S0 or S3 seed: its roots being in nutrient solution and its cotyledons projecting from the top. There were 5 S0 and 5 S3 seedlings per beaker. Similar beakers containing 0.025, 0.05, 0.1 or 0.2 ppm simazine in nutrient solution were also prepared. The experiment was performed in a growth chamber. When the seedlings were 10 days old, the tiles complete with tubes and seedlings were transferred to the beakers containing simazine. Subsequent growth and development was observed.

b) Recovery from a brief exposure to a high concentration of simazine.

Beakers were prepared as in a) but in the second set the simazine concentration was always 0.2 ppm. The roots of similar-sized seedlings were exposed to this for 0, 1½, 3, 6, 12, or 24 hours before being rinsed and returned to untreated nutrient solution (WARWICK 1973).

Results a) Symptoms were apparent in the 0.025 ppm treatment after 8 days in the S0 and 10 days in the S3. At high simazine levels, where necrosis was severe, there was also a difference between S0 and S3 seedlings in the rate of development of symptoms and time to death. The S3 grew more vigorously than the S0 in all treatments. S3 development, although obviously retarded by the constant contact with simazine, continued for several weeks in 0.05 ppm simazine whereas all S0 seedlings were dead by day 12.

b) No symptoms developed in seedlings exposed to simazine for 1½ or 3 hours. Leaves of seedlings exposed for 12 or 24 hours developed chlorosis 5 days later but this damage did not increase. In seedlings exposed for 6 hours, 80% of the S0 compared with 20% of the S3 turned chlorotic after 5 days (yellowing of the latter being confined to the leaf margins). Three days later, although the damage to the S0 had spread, the S3 had completely recovered.

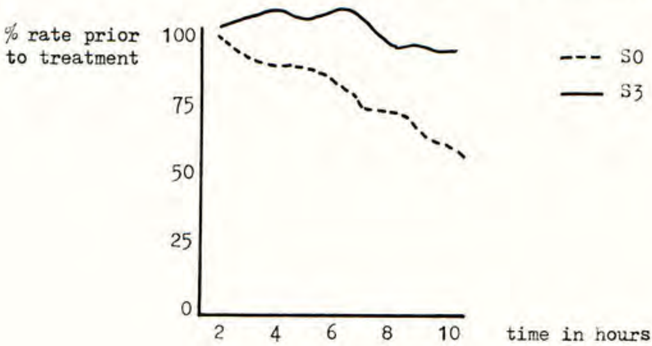
4. Photosynthetic rate

A positive correlation exists between photosynthetic rate, in terms of CO_2 uptake and inactivation of a given inhibitor of photosynthesis such as simazine. The effect of simazine on the photosynthetic rates of the S0 and S3 was therefore tested using a technique developed by VAN OORSCHOT,1968.

Method Groups of 20 S0 or S3 seedlings, selected for comparable size, were grown in containers of nutrient solution under controlled environmental conditions (WARWICK 1973). When the seedlings were 12 days old the containers were transferred to plexiglass cuvettes, each of the 16 cuvettes containing either 20 S0 or 20 S3 seedlings. It was possible to remove the solution from a given container by means of a tube and suction pump and then to replace it with another solution without disturbing conditions within the cuvette. CO_2 uptake from each of the cuvettes was measured automatically (WARWICK 1973). When the rate of uptake was steady for each group of plants, the solutions were replaced with nutrient solution containing simazine. Concentrations of 0.2, 0.4, or 0.8 ppm simazine were used and there were 2 replicates of each treatment. Plants were left until 50% inhibition of CO_2 uptake, calculated from the initial rate of uptake and related to the rate observed in control plants (no simazine) was obtained.

Results Photosynthetic rate did not differ significantly between the S0 and S3. In S0 and S3 plants exposed to 0.4 or 0.8 ppm simazine it was inhibited at a similar rate: 50% inhibition occurring after 9-10 hours with 0.4 ppm and after 7 hours with 0.8 ppm simazine. 50% inhibition of photosynthesis was not obtained during the first day in plants exposed to 0.2 ppm simazine and it was not possible to complete the experiment. However there were clear differences in the initial decline of photosynthesis in S0 and S3 plants (Fig. 3).

Fig. 3. The effect of 0.2 ppm simazine on the rate of CO_2 uptake in oilseed rape selected for simazine resistance.



DISCUSSION

As in flax resistance to atrazine (COMSTOCK & ANDERSEN 1968), the increased resistance of rape to simazine appears to be quantitatively controlled.

Vigour is clearly an important factor especially at the earliest growth stages. Germinated S3 radicles and plumules weighed slightly more than those of the S0, the cotyledons were larger and the seedlings altogether more vigorous than those of the S0.

Seed size also influences the ability of rape to survive simazine treatment, seedlings from large seeds surviving longer than those from small seeds. Mean seed size and weight of the S3 population was greater than that of the S0 although S3 seedlings from all three seed sizes were more resistant, in terms of the rate of development of symptoms and subsequent survival, than seedlings from the largest S0 seed.

If seedling vigour and seed size were the only factors contributing to the increased resistance of the S3, treated plants should eventually die under the conditions of Experiment 3 where the roots were unable to avoid uptake of the herbicide and the seeds used were standardised for both size and weight. However S3 seedlings were able to tolerate constant contact with 0.05 ppm simazine, a concentration that killed the S0. The results of Experiments 3 and 4 suggest that there are also minor differences in the rate of simazine translocation or detoxification between the S0 and S3.

Thus a significant change in resistance was achieved within 3 cycles of selection. The differences observed between S0 and S3 plants in glasshouse experiments were both a reality at the physiological level and also apparent in field-trials (WARWICK 1973) although the results obtained after only 3 cycles of selection were not sufficient to be of direct commercial significance. Nevertheless the results do confirm the feasibility of manipulating the genetics of crop plants, rather than the chemistry of herbicides, in the search for improved selectivity, and of breeding for resistance to efficient herbicides already in existence.

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A PARAQUAT RESISTANT VARIETY OF *Lolium perenne* UNDER FIELD CONDITIONS

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Summary The effects of paraquat on young sward plots of a paraquat-resistant variety of *Lolium perenne*, PRP VII, infested with deliberately sown weed grasses were compared with the effects of the same treatments on a control variety, Aberystwyth S.101. In plots with PRP VII, paraquat applied at 0.3 kg a.i./ha almost eliminated the weed grasses, leaving an even sward of PRP VII, and leading to a much increased yield of the *L. perenne* component and higher digestibility of herbage cut in June; the total yield of herbage was reduced at this cut but increased in a second cut. In plots with S.101, the same treatment left a less even sward and had a smaller beneficial effect on botanical composition, a somewhat greater effect on digestibility, and a much more severe effect on total herbage yield. It is concluded that this new paraquat-resistant variety of *L. perenne* opens up new possibilities in grassland weed control which are precluded for normal varieties of *L. perenne* by their susceptibility to paraquat.

Résumé L'action de paraquat sur jeunes terrains de pelouse d'une variété de *Lolium perenne*, PRP VII, résistant à paraquat, infesté de mauvais herbes graminées semé avec intention, étaiént comparés avec l'action du même traitement sur une variété de réference, Aberystwyth S.101. Dans les terrains avec PRP VII, paraquat appliqué à 0.3 kg/ha a presque eliminé les mauvais herbes graminées laissant une pelouse uniforme de PRP VII et aboutant à un rendement augmenté de *L. perenne* et une digestibilité plus grande d'herbage coupé en Juin; le rendement total d'herbage fut réduit à cette coupe mais augmenté dans une seconde coupe. Dans les terrains avec S.101 le même traitement a laissé une pelouse moins uniforme et avait un effet moins salutaire sur la composition botanique, un effet un peu plus grand sur digestibilité et un effet plus sévère sur le rendement total d'herbage. Nous avons conclu que cette nouvelle variété de *L. perenne* résistant à paraquat offre des possibilités dans la domaine de la lutte contre les mauvais herbes en herbages, qui sont privés des variétés normales à cause de leur susceptibilité à paraquat.

INTRODUCTION

Reseeding of grassland is a costly, and sometimes wasted operation. It can only be done by a farmer who can afford the time to do the necessary cultivations, the money for fuel, seed and fertilisers, and the temporary loss of production from the old sward. And even for the best farmers, reseeds sometimes fail. Any innovations which reduce the frequency with which reseeding is required, or which increase the reliability of establishing a good sward must therefore be welcome.

The deterioration of leys sown with *Lolium perenne* L. is associated with invasion by less productive grasses, such as *Holcus lanatus* L. and *Poa trivialis* L..

Removal of these competing grasses by herbicides should help to prolong the useful life of a ley.

Studies on the selective effect of low levels of paraquat on grass swards have been summarised by Leonard (1973) and Elliott and Allen (1964). Generally it has been found that Trifolium repens L. is much less susceptible than grasses. The proportion of Lolium perenne in a mixed sward is often increased by paraquat treatment, but this effect is not reliable. Because of the potential value of paraquat in suppressing the less desirable species in grassland, resistance to this herbicide is one of the objectives in breeding L. perenne at Loughgall. This paper reports some preliminary field results with sown sward plots of a new paraquat-resistant variety.

METHOD AND MATERIALS

An experiment consisting of 48 plots, each 5.5 x 1.5 m, was broadcast sown on a neutral medium-heavy soil on 23 September 1975 after conventional cultivations. Fertiliser amounting to 100 kg N/ha, 30 kg P/ha and 60 kg K/ha was applied at sowing to encourage establishment. A further application of 60 kg N/ha, 20 kg P/ha and 40 kg K/ha was given in March 1976. The seeds mixture was as follows:

Lolium perenne cv. PRP VII or Aberystwyth S.101	10.9 kg/ha
Trifolium repens cv. Aberystwyth S.100	2.4 kg/ha
Poa trivialis Danish commercial	2.4 kg/ha
Agrostis stolonifera cv. Prominent	1.2 kg/ha
Holcus lanatus Local Irish collection	0.5 kg/ha

The plots were grouped into 6 replicate blocks, each comprising 4 plots of the paraquat-resistant variety PRP VII and 4 plots of the paraquat susceptible control variety Aberystwyth S.101. These two varieties are similar in growth habit and maturity type. Three of the four plots of each variety in each replicate were reserved for paraquat treatment on three dates, the fourth being an unsprayed plot. One application of a commercial preparation containing 200 g paraquat per litre with a wetting system was made on 15 April 1976, when the herbage was 100-150 mm high; the second and third paraquat treatments will be applied at later dates. The herbicide was sprayed at 0.3 kg active ingredient in 280 litres water per hectare at 1.4 bars using a knapsack sprayer fitted with Allman 00 nozzles. The spraying took place in dry weather during a period of rapid grass growth.

The herbage on all plots was cut and weighed on 4 June and 21 July. Samples for determination of dry matter percentage and botanical analysis were taken from both cuts, and for determination of in vitro digestibility by the method of Tilley and Terry (1963) from the first cut only.

RESULTS

A sward with a uniform distribution of L. perenne, P. trivialis and T. repens was established in all plots. H. lanatus and A. stolonifera formed only a small fraction of the young sward.

Shortly after spraying it was apparent that, while all foliage in the S.101 plots was affected, in the plots of PRP VII the L. perenne foliage had only small necrotic spots. By the end of two weeks, there was little superficial damage to the PRP VII plots, although close inspection revealed dead foliage of P. trivialis. At the same time, the S.101 plots still had a brownish appearance although there were signs of recovery in T. repens and some tillers of L. perenne.

Ear emergence occurred in the second half of May. In the unsprayed plots heads of *P. trivialis* dominated the sward, while in the sprayed plots of PRP VII heads of *P. trivialis* were absent. The sprayed plots of S.101 clearly consisted mainly of *L. perenne*, though a few heads of other grasses were present and the sward had a thinner patchy appearance because of variation in degree of recovery by individual plants.

Botanical analysis of the herbage cut on 4 June (Table 2) confirmed that the weed grasses had been virtually eliminated from the sprayed plots of PRP VII.

Table 1

Dry matter yield (t/ha) of herbage cut on 4 June and 21 July, and digestible dry matter as a percentage of total dry matter in herbage cut on 4 June

Variety	Paraquat kg/ha	4 June t/ha	4 June Digestibility	21 July t/ha
PRP VII	0.3	6.69	71.6%	3.99
	0	8.65	68.9%	2.98
S.101	0.3	3.80	72.9%	4.38
	0	9.54	69.4%	2.80
s.e.		0.29	0.5%	0.13
probability		<0.001	<0.001	<0.001

Table 2

Percentage botanical composition of herbage cut on 4 June 1976 on unsprayed plots and plots sprayed with paraquat on 15 April 1976

Variety	Paraquat kg/ha	*L. perenne*	Grass weeds	*T. repens*	Dicot. weeds
PRP VII	0.3	98.4	1.1	0.5	0.0
	0	33.8	64.1	0.7	1.4
S.101	0.3	85.3	12.2	2.1	0.5
	0	31.7	65.4	1.7	1.2
s.e.		4.3	4.3	0.4	0.6
probability		<0.001	<0.001	0.04	NS

The paraquat treatment had reduced the bulk herbage yield of these plots (Table 1) by 23% (1.96 t/ha) relative to the untreated plots, but the yield of the *L. perenne* component was increased by 121% (from 33.8% of 8.65 t/ha = 2.98 t/ha, to 98.4% of 6.69 t/ha = 6.59 t/ha). Presumably because of the higher proportion of *L. perenne* digestibility was increased by 2.7% (Table 1). In the sprayed plots of S.101, the proportion of weed grasses was also reduced but to a lesser degree (Table 2), and the loss of bulk herbage yield (5.74 t/ha, 60%) was much greater. The yield of *L. perenne* herbage was approximately the same in sprayed and unsprayed plots of S.101, but the digestibility of the sprayed plots was 3.5% higher (Table 1), probably because of the higher proportions of *L. perenne* and of young regrowth foliage.

After this cut, regrowth in the plots which had been sprayed was obviously superior to that in the unsprayed plots, because of the higher density of tillers of L. perenne in the former, particularly in the PRP VII plots. Regrowth of P. trivialis was very slow. It appeared that the amount of T. repens was lower in the sprayed plots of PRP VII than in all other plots. Some gaps were present in the sprayed plots of S.101, but the individual plants of L. perenne in these plots grew more rapidly than in the sprayed plots of PRP VII, presumably because of the greater availability of nitrogen derived from clover. These visual observations were confirmed in the botanical analysis (Table 3) and yield records (Table 1) of the cut taken on 21 July. The gain in yield in the PRP VII plots resulting from

Table 3

Percentage botanical composition of herbage cut on 21 July 1976 on unsprayed plots and plots sprayed on 15 April 1976

Variety	Paraquat kg/ha	L. perenne	Grass weeds	T. repens	Dicot. weeds
PRP VII	0.3	96.0	1.4	2.5	0.1
	0	45.1	32.5	20.6	1.8
S.101	0.3	81.4	3.4	14.4	0.8
	0	34.6	46.0	18.7	0.7
s.e.		3.8	2.8	2.2	0.6
probability		<0.001	<0.001	<0.001	NS

paraquat treatment (1.01 t/ha, 34%) represents a recovery of slightly over half the loss incurred at the first cut. The S.101 plots showed a somewhat greater gain at this cut.

After the second cut, the swards had different appearances owing to their different compositions. The plots of PRP VII sprayed in April had an even mid-green cover of L. perenne with only fairly small amounts of T. repens. The sprayed plots of S.101 had larger dark green tufts of L. perenne with T. repens occupying most of the intervening spaces. The unsprayed plots of both varieties also had tufts of L. perenne, but these were rather fewer in number and some of the intervening spaces were occupied by P. trivialis showing very little regrowth. Small amounts of H. lanatus were in evidence in all these unsprayed plots and traces of A. stolonifera were present in a few plots.

DISCUSSION

A shift in the balance of a mixed sward in favour of L. perenne has also been recorded in some, but not all, previous experiments with paraquat. Williams and Palmer (1969) made 16 comparisons between control plots and plots sprayed with paraquat at rates from 0.07 to 0.28 kg a.i. per hectare: in 11 instances, spraying increased the proportion of L. perenne, sometimes markedly so; in 4 instances it reduced the proportion by trivial amounts, and in one instance from 41% to 17%. Jones and David (1964) reported that in one experiment rates of paraquat from 0.14 to 0.56 kg a.i. per hectare applied in April suppressed P. trivialis and benefited L. perenne, but in another experiment L. perenne recovered less well from paraquat treatment than did Agrostis spp.. Allen (1965) applied paraquat at 0.84, 1.68 and 3.36 kg a.i. per hectare to a mixed sward in July, October and April: only the

July application of 0.84 kg/ha led to an increase in the proportion of L. perenne present; the April applications decreased the proportion of L. perenne and the October applications virtually eliminated it.

None of the reports of the experiments cited above give indications of the statistical significance of the effects observed. It is scarcely possible therefore, to form a reliable impression of the effect of paraquat on sward composition under any particular set of circumstances. Furthermore, since these experiments were on permanent grassland in which the origin of L. perenne was unknown, it is impossible to judge whether genetic variation was responsible for any of the variation in results. However, it is reasonably clear that the margin of selectivity of paraquat for most varieties of L. perenne is not reliable enough to form the basis of a generally practical technique of sward improvement. The initial suppression of growth and the risk of permanent damage to the L. perenne would both weigh heavily against such a technique.

The adverse effect of the April paraquat application on clover in the PRP VII plots (Tables 4 & 5) was contrary to expectations, since this species is normally regarded as resistant to paraquat, which can be used for suppressing grass weeds including L. perenne in clover seed crops (Blood, 1962; Leonard, 1964) and for increasing the clover content of swards (Taylor and Arnst, 1968; Williams and Palmer, 1969). Two reasons probably contributed to the reduction of clover in this instance. Firstly the resistant L. perenne variety would have provided more vigorous competition than normal grasses after paraquat treatment. The importance of this competition is revealed by comparison with plots of the susceptible L. perenne variety, S.101; in these plots paraquat treatment in April did not result in a significant reduction in the amount of clover in the sward (Table 4). The second reason was the age of the clover plants. There is evidence (e.g. Bramley, 1961) that young plants of clover are rather susceptible to paraquat although mature plants are resistant. At the time of the April spraying, the clover plants were seedlings each with only a few leaves and were perhaps physiologically juvenile with respect to paraquat tolerance.

Although the paraquat treatment resulted in a slight reduction in dicotyledonous weeds (Tables 2 & 3), the majority of these weeds at this early stage in sward development were annuals of little long-term consequence in grassland.

In other experiments in which a paraquat-resistant line closely related to PRP VII was grown in boxes or as spaced plants in field plots, it has been shown that herbicidal treatment can successfully control a wide range of annual dicotyledonous weeds and perennial grasses including Agropyron repens in competition with L. perenne (Faulkner, 1975). In a seed crop of PRP VII on a commercial scale sown in September 1975 (Faulkner, unpublished), control of a range of weeds was obtained by spraying with paraquat at 0.28 kg a.i. per hectare in December 1975 or 0.42 kg a.i. per hectare in April 1976. An exceptionally weed-free seed crop yielding approximately 1.25 t/ha resulted. In two small portions of the field left unsprayed, however, there was a moderate weed infestation, with Poa annual L., P. trivialis, Cynosurus cristatus L., Holcus lanatus, Anthoxanthum odoratum L., and several dicotyledons all present. The experiment reported in this paper has shown that very successful control of P. trivialis can be achieved in a field sward situation, with a highly beneficial effect on the yield of L. perenne 7 weeks after treatment.

Further research is required to find the optimal conditions for paraquat treatment of swards containing PRP VII, especially with regard to maintaining the balance of L. perenne and clover, and to the possibility of oversowing with seed of PRP VII if the density of paraquat-resistant L. perenne plants has fallen too low to permit recolonisation of gaps in the sward by tillering. However the existing evidence suggests that this paraquat-resistant variety represents a unique advance in grassland weed control. The variety has been entered for National List Trials and could be available in commercial quantities in 1980. Further varieties covering the range of maturity types in L. perenne are being developed.

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INVESTIGATIONS INTO THE EFFECT OF VARIETY ON THE SUSCEPTIBILITY OF POTATOES TO METOXURON

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Summary Four pot experiments carried out in 1975 and 1976 have shown that some varieties of potato are more susceptible to foliar applications of metoxuron (w.p.) than others. Nine varieties were studied; Arran Pilot, King Edward, Majestic, Maris Peer, Maris Piper, Pentland Crown, Pentland Dell, Record and Red Craigs Royal. Majestic, Pentland Crown and Record were found to be the most resistant and in general Maris Peer, Maris Piper and Arran Pilot were the most susceptible. However, there was considerable variability between experiments, indicating that other factors were also affecting metoxuron's performance. Overall, control was poorer than that often achieved in the field.

The results of these experiments are discussed in relation to the use of metoxuron to control volunteer potatoes.

Résumé Quatre expériences en pots en 1975 et 1976 montrèrent que certaines variétés de pomme de terre sont plus sensibles que d'autres aux applications foliaires du métoxuron (p.m.). Les neuf variétés étudiées étaient: Arran Pilot, King Edward, Majestic, Maris Peer, Maris Piper, Pentland Crown, Pentland Dell, Record et Red Craigs Royal. Majestic, Pentland Crown et Record se montrèrent les plus résistentes, et en général Maris Peer, Maris Piper et Arran Pilot furent les plus sensibles. Cependant des variations importantes se furent remarquer entre les expériences, ce qui indique que d'autres facteurs influaient également sur le comportement du métoxuron. En général le désherbage se montra inférieur à celui obtenu normalement en plein champ.

On considère ces résultats par rapport à l'emploi du métoxuron dans la lutte contre les pommes de terre adventices.

INTRODUCTION

Metoxuron, a substituted urea herbicide, shows some activity against volunteer potato plants. Field control of potatoes in carrot crops with this herbicide is sometimes excellent but often poor. The reasons for this variability are not understood but it has been suggested that variety may be a contributory factor. Information collated by Griffiths and Lake (1974) indicated that the varieties Arran Pilot and Record were more susceptible to this herbicide than were Maris Peer and Pentland Crown.

Varietal differences in the susceptibility of potatoes to a number of herbicides have been reported by several authors. Experiments carried out by Graf and Ogg (1976) showed that some North American varieties were more tolerant of metribuzin than others. Glasshouse experiments and a field trial reported by Zimdahl (1976)

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demonstrated that the variety White Rose was more susceptible to pre-emergence treatments of metribuzin, metobromuron, linuron and oxadiazon than were 5 other varieties. In the United Kingdom the variety Maris Piper has been shown to be less tolerant of metribuzin than King Edward (May & Smith, 1974).

In order to obtain more information about the tolerance of different potato varieties to metoxuron four pot experiments were carried out in 1975 and 1976 at the Weed Research Organization.

METHOD AND MATERIALS

General

In all 4 experiments good quality seed tubers were used. The nine varieties studied in the three experiments carried out in 1975 were; Arran Pilot (AP), King Edward (KE), Majestic (M), Maris Peer (MPe), Maris Piper (MPi), Pentland Crown (PC), Pentland Dell (PD), Record (R) and Red Craigs Royal (RCR). Only four were used in 1976; Majestic (M), Maris Peer (MPe), Maris Piper (MPi) and Pentland Crown (PC).

Some weeks before planting, the tubers were placed in trays in an illuminated store to encourage the production of small strong sprouts. In the experiment carried out in 1976 they were kept under these conditions for 3 weeks, in the first two experiments of 1975 for 4 weeks and in the third experiment in 1975 for 7 weeks.

All the potatoes were planted in pots 25 cm in diameter filled with sandy loam soil to which DDT and fertilizer had been added (6.7 kg/m^3 John Innes fertilizer; 1.7 kg/m^3 $MgSO_4$; 0.8 kg/m^3 DDT). Four tubers were buried approximately 3 cm below the soil surface in each pot. In most cases the number of sprouts/tuber was reduced to two before planting. The pots were placed outdoors and were watered when necessary.

All the herbicide treatments were applied with a laboratory pot sprayer using a single Teejet nozzle. The three 1975 experiments were sprayed with an 8001 nozzle which had an output of 197 l/ha at a pressure of 2.1 bars, whilst in 1976 a 80015E nozzle with an output of 277 l/ha at the same pressure was used.

The damage caused by the metoxuron treatments was assessed subjectively at intervals after spraying using a 1 - 7 scale (Table 1). Eventually the plants were harvested and the dry weight of haulm per pot was determined. All the experiments were set out in randomised blocks with either 3 or 4 replications.

Table 1

Scoring system used to assess metoxuron damage

Score	Description
1	All plants dead
2	Some stems still alive; occasional green leaf
3	Most stems alive; quite a number of green leaves but many dead
4	Extensive chlorosis and necrosis of plants
5	Moderate chlorosis and some necrosis
6	Some chlorosis
7	Healthy green plants

Experiment 1 (1975)

In this experiment, when the plants had reached a height of about 25 cm they were either sprayed with metoxuron (w.p.) at 2,4 and 8 kg/ha a.i., or were left untreated. As the nine varieties grew at different rates they were sprayed in three groups; group A (varieties AP, MPe and RCR) was treated 33 days after planting; group B (varieties M, MPi, PD and R) after 41 days and group C (varieties PC and KE) after 43 days. All plants were harvested 78 days after planting.

Experiment 2 (1975)

All the plants in this experiment were treated with metoxuron (w.p.) at 4 kg/ha a.i. 43 days after planting irrespective of their size at the time of spraying and were harvested 82 days after planting.

Experiment 3 (1975)

As in the first experiment the plants were sprayed when they reached a height of 25 cm. Thus five of the varieties (AP, MPe, M, PD and RCR) were sprayed 28 days after planting and the remaining four (PC, KE, R and MPi) 5 days later. All the plants were sprayed with metoxuron (w.p.) at 4 kg/ha a.i. and were harvested 68 days after planting.

Experiment 4 (1976)

This experiment examined the effect of application date as well as variety on the susceptibility of the potatoes to metoxuron (w.p.) at 2, 4 and 8 kg/ha a.i. Consequently the four varieties were sprayed at four dates after planting (26, 29, 32 and 35 days). All the plants were harvested 77 days after planting. Immediately prior to the first two applications the diameter of the notional circle of foliage produced by each emerged sprout was recorded. As the number and size of sprouts were much greater at the third and fourth application it was impossible to continue these measurements and so the diameter of each of the four plants was measured instead.

RESULTS

Experiment 1

Within 7 days of treatment nearly all the plants were showing signs of damage; yellowing of the leaves and slight scorch on the margins. Representative data from 6 varieties recorded at this and subsequent assessments are presented in Fig. 1. Those plants treated with the highest dose developed more severe symptoms. The damage scores recorded 35 days after treatment showed that Arran Pilot, Maris Peer and King Edward were particularly severely injured by the 8 kg/ha dose (Table 2), but no plants were killed completely. Conversely Majestic, Record, Pentland Crown and Red Craigs Royal were much less severely damaged. The lower doses caused little damage. In general the dry weight data collected at the final harvest confirmed these results, those plants showing the least damage also having the highest dry weights (Table 3). There were a few exceptions; the dry weights of Arran Pilot following the 8 kg/ha dose were somewhat higher than those expected from the visual scores and those of Maris Piper and Pentland were lower. The difference between the weights of the unsprayed plants and the treated ones, particularly with Maris Peer and Arran Pilot, were not as large as expected as the control plants had started to senesce before they were harvested.

Experiment 2

In this experiment the visual assessments of damage suggested that Majestic and Record were the most resistant to metoxuron (4 kg/ha), whilst Arran Pilot and Maris

Fig. 1

Visual assessments of the chlorosis and scorch damage caused by 3 doses of metoxuron applied to 6 potato varieties (Expt 1)

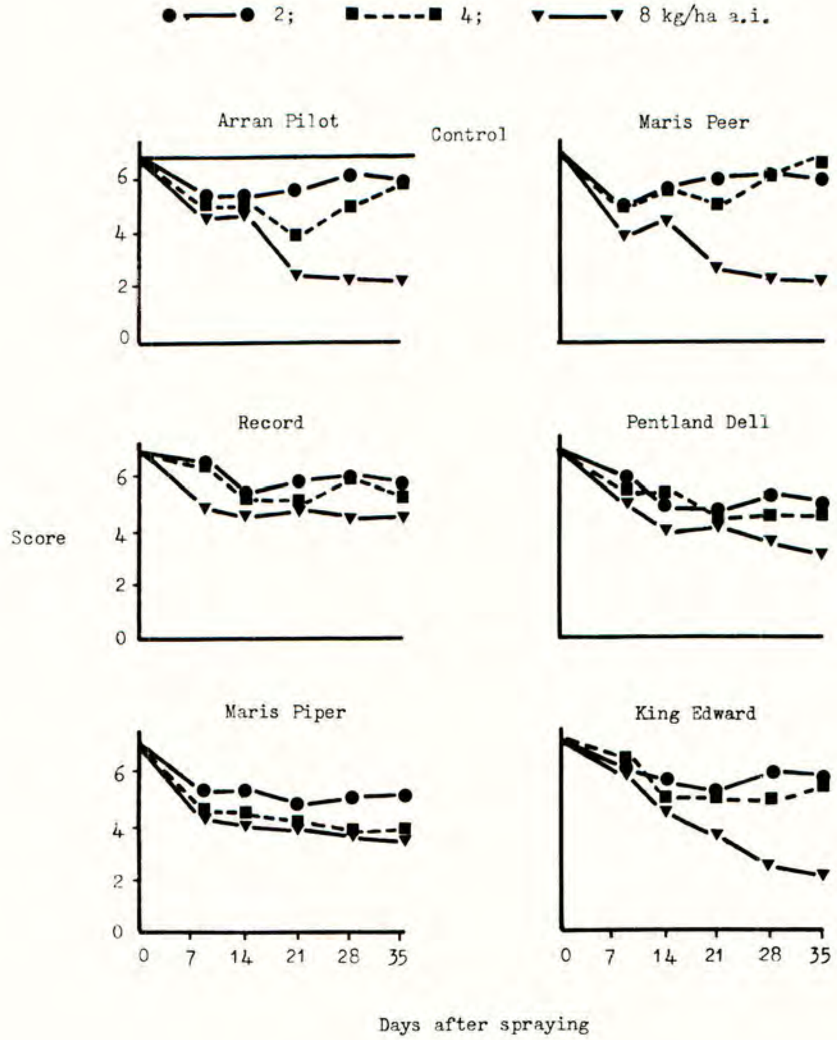

Table 2

Visual assessments of the damage caused by metoxuron (1-7 scale) to the 9 potato varieties

Score+	1975 EXPT 1 4 kg/ha a.i. 35 days after spraying	EXPT 1 8 kg/ha a.i. 35 days after spraying	EXPT 2 4 kg/ha a.i. 28 days after spraying	EXPT 3 4 kg/ha a.i. 35 days after spraying
1-2			AP MPe	MPi
2-3		AP MPe KE	RCR	
3-4		PD MPi	MPi	AP PD
4-5	PD* MPi	RCR M R PC	PD KE PC	MPe RCR KE
5-6	R M KE		R M	PC
6-7	AP MPe RCR PC			R M

*Full names of varieties are given in the text.
+Scores - see Table 1.

Table 3

The effect of metoxuron on the dry weight of haulm (g) produced by the potato plants (Expts 1-3)

Variety	Experiment 1 Metoxuron dose (kg/ha a.i.)				Expt 2 Dose (kg/ha a.i.)	Expt 3 Dose (kg/ha a.i.)
	0	2	4	8	4	4
Arran Pilot	16.5	18.0	19.4	11.8	3.7	11.3
King Edward	26.1	27.8	23.9	4.8	15.0	13.8
Majestic	30.1	34.3	28.5	15.7	32.8	33.4
Maris Peer	13.8	15.0	18.2	8.8	0	14.7
Maris Piper	28.2	25.8	17.3	9.5	10.3	3.9
Pentland Crown	27.4	25.7	26.5	14.4	19.4	17.9
Pentland Dell	27.8	23.9	19.5	9.2	9.2	12.4
Record	30.3	30.6	27.4	19.6	28.0	30.4
Red Craigs Royal	22.3	25.1	23.8	18.9	5.0	15.6
Standard error		2.18			2.14	1.47

Peer were the most susceptible (Table 2). The plants of the latter variety were killed completely. Dry weight data collected at the final harvest largely confirmed the visual scores (Table 3).

Experiment 3

The scores 35 days after spraying showed that Record and Majestic were damaged the least and Maris Piper, Arran Pilot and Pentland Dell the most (Table 2). The dry weight data collected at the final harvest supported these results (Table 3).

Experiment 4

The treatments applied 26 days after planting, when most of the emerged sprouts

Table 4

The effect of 3 doses of metoxuron applied at 4 dates on 4 varieties of potato

	Days from planting to spraying												
	26 Dose (kg/ha a.i.)			29 Dose (kg/ha a.i.)			32 Dose (kg/ha a.i.)			35 Dose (kg/ha a.i.)			Control
	2	4	8	2	4	8	2	4	8	2	4	8	
A) Assessment of the damage 20 days after treatment (1-7 scale)													
Majestic	6.9	6.8	6.2	6.9	6.7	6.2	6.7	6.7	4.3	6.6	5.8	5.2	7.0
Maris Peer	6.7	6.6	5.3	6.9	6.6	3.6	6.8	6.2	3.8	6.8	6.3	5.2	7.0
Maris Piper	6.6	6.4	4.9	6.6	6.0	4.6	6.5	4.0	4.0	5.8	5.6	4.9	7.0
Pentland Crown	6.5	6.0	5.0	6.6	5.7	5.2	6.6	5.9	5.6	6.3	5.6	5.1	7.0
B) Dry weight of haulm/pot (g) 77 days after planting													
Majestic	36.2	39.6	37.6	32.6	38.8	35.7	37.8	39.2	21.9	38.8	39.7	38.9	32.1
Maris Peer	21.9	23.6	22.5	20.3	24.3	11.4	23.3	22.3	18.1	20.8	21.0	19.8	16.5
Maris Piper	27.5	28.3	17.6	26.6	27.3	21.1	29.2	25.4	14.6	29.1	28.8	25.9	22.6
Pentland Crown	31.7	29.1	27.2	32.3	27.3	29.0	26.5	28.3	29.4	29.0	30.9	31.0	27.0
Standard error 3.15													

Results underlined are those where appreciable damage occurred.

were less than 6 cm in diameter caused little damage to the potato plants. Only the 8 kg/ha dose applied to Maris Peer, Pentland Crown and Maris Piper caused any noticeable damage (Table 4A). The applications 29 and 32 days after planting were more effective, but even so only the 8 kg/ha dose caused appreciable damage, Maris Peer and Maris Piper, being more affected than Majestic and Pentland Crown. At the final application, 35 days after planting the plants were quite large, with much mutual shading, 60% of them being over 24 cm in diameter. The herbicide treatments were less damaging than those applied at the previous 2 dates, the highest dose causing only slight chlorosis (scores 5-6).

The dry weight data reflected the trends shown by the subjective scores, appreciable reductions occurring after applications of the highest dose at the second and third dates (Table 4B). However, by the time of the final harvest many of the controls, particularly of Maris Peer and Maris Piper, had started to senesce. Hence their dry weights were lower than many of those of the treated plants.

DISCUSSION

The results of the 4 experiments indicated that some potato varieties were more susceptible to the metoxuron treatments than others. Despite the variability between the experiments the damage scores presented in Tables 2 and 4A showed that the varieties Majestic, Pentland Crown and Record were consistently more tolerant than the other varieties and that in general Maris Piper, Maris Peer and Arran Pilot were the most susceptible. These results support the conclusions of Griffiths and Lake (1974) that Arran Pilot was susceptible and Pentland Crown resistant, but not their conclusions that Record was susceptible and Maris Peer resistant.

Differences in the rates of growth of the varieties make the dry weight data difficult to interpret. In experiment 1 and 3 the varieties were sprayed in groups, when they had reached a size that was considered to be the optimum for spraying (about 25 cm high). Thus conclusive comparison cannot be made between the varieties in different groups. The sizes and weights of the plants at harvest, recorded as dry weights will have been affected by two separate factors; the intrinsic susceptibility of the plants which was recorded through the damage scores, and the vigour of the plants shown by the dry weights of the unsprayed controls. Thus the variety Majestic grew vigorously, was only slightly damaged by the herbicide and hence had a large dry weight at the end of the experiments. Conversely Maris Piper grew less vigorously, was more susceptible to the herbicide treatments and thus had a lower dry weight. In general the results indicated that the more vigorous varieties were not as susceptible as the less vigorous ones. Probably owing to the somewhat artificial growing conditions and the very dry weather experienced in 1975 and 76, the untreated plants of some varieties, notably Maris Piper, Maris Peer and Arran Pilot, had started to senesce before the final harvest. Conversely, the plants treated with the lower herbicide doses were still regrowing vigorously and consequently sometimes achieved a greater weight at the end of the experiment than the senescent controls. It is unlikely that this situation would arise under field conditions.

The results of experiment 4 showed that the control of plants sprayed when they were very small was poor. Similarly, when the plants were very large control was also poor. In the former, new sprouts emerged following treatment and axillary buds sprouted from the lower parts of the sprayed sprouts. In the latter there was considerable mutual shading and thus the herbicide only affected a proportion of the leaves. Better results were obtained when the plants were between 12 and 24 cm in diameter. This was equivalent to the 25 cm height measurements used in the 1975 experiments.

In general the degree of control achieved was poor, only Maris Peer in Experiment 2 was killed completely. In contrast control of volunteer potatoes in the field although variable has often been satisfactory. The low activity in these experiments may be associated with the quality of the seed tubers used. Most were 4 - 5 cm in diameter whereas the average size of groundkeeper tubers is between 1 and 4 cm in diameter (Lutman, 1977). Hence the experimental plants were much more vigorous than normal groundkeepers and were probably better able to withstand the damage caused by the metoxuron treatments. Further experiments still in progress, have indicated that plants from small tubers are more susceptible than those from large ones.

If it is assumed that the weight of haulm is related to tuber production as is suggested by Moorby and Milthorpe (1975), then the dry weight data collected at the final harvest following metoxuron treatment give an indication of future tuber production. Thus Majestic and Record with the highest dry weights would have the greatest potential for producing tubers, and Maris Peer, Maris Piper and Arran Pilot would have the least.

The experiments described in this paper suggest that variety is one factor contributing to the variability in response of volunteer potatoes to metoxuron. However, there were considerable differences between the experiments indicating that other factors are also involved. These may include physical factors such as the environmental conditions at or after spraying and biological ones like the size of the plants at spraying and the size of the parent tubers.

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WEED MANAGEMENT STUDIES IN RHODESIA

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Summary Weed management investigations started in 1971 when ethephon, applied to a tall grass weed (*Rottboellia exaltata* Lf) in maize, reduced the weed's height and shoot weight. In subsequent studies dalapon and ethephon effectively suppressed monocotyledonous plants while MCPA and chlorflurecol suppressed dicotyledons.

In 1976 an overall (3-4 leaf stage) application of 2 kg/ha dalapon plus 0.4 kg a.e./ha MCPA satisfactorily suppressed mixed weeds and wheat without a noticeable effect on maize.

INTRODUCTION

The concept behind these weed management studies is similar to that in integrated pest control. It accepts that low pest numbers, although they may damage a crop, do not seriously affect its yield. Similarly crop/weed competition studies have shown that weeds that emerge at the same time as the crop, cause the greatest reduction in crop yield and quality (Knake and Slife, 1965; Schwerzel and Thomas, 1971; Thomas and Allison, 1974). If the first weed emergence could be checked in a competitive crop it may be possible to allow subsequent weed growth to compete with the crop. Only limited further weed emergence is likely in undisturbed soil with an existing suppressed weed cover.

If a system of weed management could be perfected it may have interesting possibilities. This system would retain the existing but shortened weed spectrum and a rapid build up of tolerant weeds is unlikely - a major disadvantage of herbicides. The suppressed weed cover would compete for some water and nutrients. This cover will, however, encourage water penetration and reduce erosion (Hudson, 1957).

Although this concept may appear to be impracticable there are many well-known instances of selective suppression of specific weeds in crops. For example, barban, benzoylprop-ethyl and difenzoquat selectively check Wild Oat (*Avena* sp.) in cereal crops. Phenoxyacetic acids and related compounds (2,4-D, MCPA and others) selectively regulate growth of certain weeds. However, no compounds have, to my knowledge, been developed for suppression of all weeds in a crop.

Weed suppressants may have to be applied as a directed spray so as to hit the weeds and not the crop, or it may be possible to spray selective materials "over the top" or overall. On the other hand, seed protectants may be used on crop seeds which may protect the crop against an overall suppressant application. Relatively few herbicide protectants (e.g. 1,8-naphthalic anhydride used to protect corn against EPTC) have been developed but these do not generally protect an established crop against an overall herbicide application.

RESEARCH PROGRESS

Growth regulation studies have been made for several years on various crops in Rhodesia. Investigations at Henderson Research Station have led to the successful use of ethephon to reduce lodging of high-yielding, tall maize (van Lindert, 1970). The applied ethephon reduced plant and cob height and resulted in maize with thicker stems and more vigorous brace roots. At that time the author was studying competition between maize and Rottboellia exaltata, a tall grass weed which may be related to maize. The effect that ethephon had on reducing plant height was of particular interest. Thus ethephon was used in an attempt to suppress R. exaltata in maize.

In 1971, 3 kg/ha ethephon sprayed directly onto R. exaltata reduced its height from 1.65 to 1.25 m. Maize grain and shoot dry weights at final harvest were increased and dry weight of shoot of R. exaltata decreased when the growth regulator was applied to R. exaltata only. For example maize grain yield was increased from 4060 kg/ha where the weed grew normally to 6050 kg/ha when its growth was suppressed. The growth regulator reduced R. exaltata shoot weight from 2960 to 1500 kg/ha (Thomas and Allison, 1974). After these studies an attempt was made to suppress mixed weed populations using ethephon. This was unsuccessful and showed the need to evaluate other compounds.

A number of compounds have been tested since 1974 for their suppressive effect on mixed weed populations of different ages. The initial evaluation of plant growth regulators and certain herbicides is done with a Chesterford mini-logarithmic sprayer. Compounds which effectively stunted monocotyledonous plants were dalapon and ethephon while MCPA and chlorflurecol checked growth of dicotyledonous plants. Mixtures of dalapon with MCPA or chlorflurecol and ethephon with MCPA showed promise. Later investigations concentrated on dalapon and MCPA because they are better known and understood.

Several preliminary investigations showed that the most effective weed suppression is achieved when they are sprayed within three weeks of emergence.

In 1976 an overall application, made at the 3-4 leaf stage, of 2 kg/ha dalapon plus 0.4 kg a.e./ha MCPA satisfactorily suppressed mixed weeds and wheat without noticeably affecting maize. Maize (cv. SR 52) was sown at the same time as the weeds (Acanthospermum hispidum, Amaranthus hybridus, A. spinosus, Bidens pilosa, Leucas martinicensis, Nicandra physalodes, Tagetes minuta, Eleusine indica, Rottboellia exaltata) and wheat cv. Nuanetsi. Maize seed was treated with 0.5% naphthalic anhydride by weight. Preliminary investigations indicated that this antidote may protect young maize plants against dalapon plus MCPA. This aspect is receiving further attention.

Future maize investigations will include additives or wetting agents to speed up penetration of dalapon and MCPA. A small amount of atrazine will be added to this mixture to improve its reliability. Alternatively MCPA may be replaced by atrazine because of drift hazards of MCPA.

Projected weed management studies will include evaluation of promising compounds (with and without wetting agents) for maize and other crops, effects of directed or overall applications on crop and weed attributes, and crop seed protectants.

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