herbicide has shown to be effective when applying propachlor plus chlorthal-dimethyl to overwintering seed beds for early drillings of onions. This gives a warm weedfree seed bed in February that requires no further cultivation before drilling.

Besides preventing downward movement of water, covers raise soil and air temperatures. Overwinter this may work in favour of the herbicide, but after late March the temperature can become too high. Volatile chemicals will disperse before they can work.

The enclosed environment created by crop covers makes crops soft and lush compared to outside conditions. Applying herbicides immediately after cover removal must therefore be treated with caution. Herbicide treatments that are normally safe on crops that have been grown in the open may cause damage to plants before they have had a chance to harden or renew their cuticular coating of wax after uncovering.

Other problems associated with plastics

Timing of herbicide application is a management problem. Residual pre emergence or pre drilling/planting herbicides can be applied before covers or mulches are laid. As described above to make the herbicide work satisfactorily the plastic should not be laid for 1-7 days after application to allow movement into the soil before the soil surface dries or the temperature is raised too much under the cover. The exact timing of laying the plastic after herbicide application depends on soil type, time of year and prevailing weather conditions.

Applying herbicides post emergence also requires considerable management skill. If the covers have to be removed for herbicide application the timing of removal must take into account the growth stage of the weeds and sufficient weaning of the crop to prevent damage. The length of time between removal and application will depend on weather conditions and chemical being used. If these guidelines are followed it could be argued that the recommendations for the use of herbicides are being followed.

Nonwoven materials offer the possibility of applying the herbicide through the cover. However in commercial practice this has not yet been achieved because of the quantity of water required to penetrate the cover, uneven distribution (even with nonwoven covers the spray run off will tend to run to the lowest point before going through the cover), and scorching the crop because of lack of waxing.

Criteria for successful use of herbicides under low level plastics

- Allow time between applying pre emergence residual herbicides and covering with plastics.
- Beware of using herbicides before covering in hot weather.
- If soil surface is dry after application apply 5-8 mm irrigation before covering.
- After removal allow crop to harden and form wax on the leaves before applying herbicides.
- Use the stale seed bed technique whenever possible for use with low level plastics.
- Remember that herbicides that have proved successful under covers take longer to disperse.

HERBICIDES ON NEWLY PLANTED ROOTSTOCKS AND BUDDED TREES

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ABSTRACT

Seven residual herbicide treatments were applied after planting and heading back budded tree crops. The herbicides evaluated were napropamide, napropamide + simazine, atrazine, diphenamid + chlorthal-dimethyl, propyzamide + simazine, chlorthal-dimethyl + metazachlor and oxadiazon. These were applied to a range of genera: Fraxinus, Malus, Prunus, Sorbus and Tilia. A high level of tree selectivity was recorded for all herbicides. Apart from napropamide on S.aria 'Lutescens' no herbicide treatments gave significantly smaller maiden trees than unsprayed controls. No treatment gave complete weed control. The best overall treatment was napropamide + simazine although oxadiazon gave good control of most weeds except Chickweed.

INTRODUCTION

Effective chemical weed control in field grown nursery stock is not easy to achieve. The aim is to apply a chemical or chemical combination which selects against a broad range of weeds but does not adversely affect a range of crop genera. The problem has been aggravated by the appearance of weed species resistant to the triazine group of herbicides. (Moon 1984). The majority of tree producers have relied exclusively on simazine for many years. Over the last five years triazine resistant groundsel (Senecio vulgaris) has become widespread. It has been demonstrated that simazine alone, at rates up to 1 kg/ha seldom damages Prunus 'Ukon'. (Howard 1975). Other work on Acer platanoides 'Crimson King' Betula pendula 'Dalecarlica', Robina pseudoacacia 'Frisia' and Tilia x euchlora has indicated that simazine alone and in combination with pendimethalin probably don't affect bud take but, in the case of Robina and Tilia could affect the rootstock growth (Vasek 1985). Our experiment investigates a range of herbicides as alternatives to simazine alone. The trees trialled are all widely grown on nurseries in the U.K.

MATERIALS AND METHODS

Rootstocks of the following species were planted between 9 and 18 April 1985, Fraxinus excelsior, Malus MM106, Prunus 'Colt' Sorbus intermedia and Tilia platyphyllos. These were budded during the following August with F. excelsior 'Westhof Glory', M. 'Golden Hornet', P. Kanzan S.aria 'Lutescens' and T. x euchlora rspectively. The chip budding technique using degradable latex ties was employed. (Howard 1974) (Skene 1983). All trees were headed back on 24 or 25 February 1986.

The herbicide treatments were napropamide at 4.05 kg/ha a.i. as Banweed, napropamide at 3.5 kg/ha a.i. plus simazine at o.5kg/ha a.i. as Banweed S, atrazine at 0.5kg/ha a.i. as Gesaprim, chlorthal-dimethyl at 7.5kg/ha a.i. as Dacthal diphenamid at 5kg/ha a.i. as Enide, simazine at 0.5kg/ha a.i. plus propyzamide at 0.5kg/ha a.i. as Kerb, chlorthal-dimethyl at 7.5kg/ha a.i.plus metazachlor at 1.25kg/ha a.i. as Butisan S, and oxadiazon at 1.0kg/ha a.i. applied as Ronstar liquid.

The trial was on a randomised block design replicated four times. Control plots were weeded by paraquat sprays, these being replicated eight times. The plot size was 1m x 3m, weed counts being done on the central 0.5 x 2m. There were 10 trees at 0.3m spacings per plot all of which were reduced. All end plants and out rows were guarded with trees of the same species. The field was a well drained snady loam of the Bishampton series with a mean PH of 7.2. Its nutrient status was an index of 1 of N, 4 of P, 3 of K and 4 of Mg using the standards described by the Ministry of Agriculture, Fisheries and Food (1985). The previous crop was a three year grass ley. A dressing of farm yard manure at 120 tonnes/ha was ploughed in during the autumn prior to planting.

The herbicides were applied by precision Knapsack sprayer using an Allman medium fan single nozzle, code 8002. This applied the treatments directly over the rootstocks. All treatments were applied in 1250 l/ha water.

Weeds were counted on 6 June, 30 July and 27 September in the rootstock year and 21 May, 26 June and 19 August in the maiden year. After counting, all plots, including the controls were sprayed with paraquat so that the possibility of recounting at the next assessment was eliminated.

Crop height from ground level was recorded at the end of the rootstock and maiden years. Stem diameter was recorded at the same time, 10cm from the ground for the rootstocks and half height for maiden trees.

RESULTS

Tree Growth

There were no visible differences in maiden tree growth on the different herbicide treatments. Signifcant sensitivity of rootstocks to herbicides, when compared with the untreated control, was only shown by F. excelsior on napropamide and simazine treated plots an the P. 'Colt' treated with oxadiazon. (Tables 1 + 2) Following application of oxadiazon on the P. 'Colt' there was a visible foliar scorch.

Bud take (Table 3) was not significantly affected by any treatment compared with the control. The F. 'Westhof Glory', M 'Profusion', P 'Kanzan' and T. x euchlora maidens did not show any significant treatments on height and diameter at half height compared with controls (Tables 4 + 5). However, the S.aria 'Lutescens' maidens on napropamide treatments were signficantly smaller than untreated controls (Tables 4 + 5).

TABLE 1

Mean rootstock height at 10cm (Nov 1985).

Treatment	g.a.i/ha	Mean rootstock height (cm)				
		A	B	C	D	E
Napropamide	4050	86.5	133.9	125.6	47.0	86.5
Napropamide	3500	76.3	132.1	122.3	57.8	75.8
and simazine	500					
Atrazine	500	94.0	132.8	124.2	49.2	94.0
Chlorthal-dimethyl	7500	87.7	129.0	125.1	55.4	87.7
and diphenamid	5000					
Simazine	500	84.8	131.6	121.3	49.8	84.3
and propyzamide	500					
Chlorthal-dimethyl	7500	92.9	132.2	124.2	50.5	92.1
and metazachlor	1250					
Oxadiazon	1000	92.9	124.6	105.6	49.0	92.7
Control	-	85.6	129.9	125.2	54.0	85.5
LSD.p=0.05		9.3	11.0	6.4	9.1	17.3

A F.excelsior
B MM106
C P.'Colt'
D S. intermedia
E T. platyphyllos

TABLE 2

Mean Rootstock height and diameter at 10cm (Nov 1985)

Treatment	g.a.i/ha	Mean Rootstock diameter (mm)				
		A	B	C	D	E
Napropamide	4050	12.97	13.52	19.50	9.68	9.84
Napropamide	3500	12.82	13.82	17.68	10.40	10.69
and simazine	500					
Atrazine	500	14.42	13.40	19.15	9.93	10.80
Chlorthal-dimethyl	7500	13.63	13.88	19.00	11.07	10.97
and diphenamid	5000					
Simazine	500	13.65	14.07	19.70	10.15	11.21
and propyzamide	500					
Chlorthal-dimethyl	7500	14.57	14.20	17.83	10.45	9.63
and metazachlor	1250					
Oxadiazon	1000	13.72	13.07	15.05	10.02	10.68
Control	-	13.70	13.90	19.46	11.21	10.64
LSD.p=0.5m		1.21	0.89	1.34	1.55	2.03

A F.excelsior
B MM106
C P.'Colt"
D S.aria 'Lutescens'
E T x euchlora

TABLE 3

% bud take

Treatment	g.a.i/ha	A	B	C	D	E
Napropamide	4050	97.3	95.0	92.5	77.5	80.6
Napropamide and simazine	3500 500	88.2	95.0	92.5	79.5	79.5
Atrazine	500	100.0	100.0	95.0	86.8	72.5
Chlorthal-dimethyl an diphenamid	7500 5000	92.5	97.5	90.0	66.7	84.6
Simazine and propyzamide	500 500	94.4	95.0	90.0	90.0	79.5
Chlorthal-dimethyl and metazachlor	7500 1250	97.1	100.0	95.0	80.0	73.7
Oxadiazon	1000	89.7	100.0	100.0	92.5	86.8
Control	-	94.8	96.3	92.5	85.0	76.6
LSD.p=0.5		11.1	7.2	8.7	26.8	14.1

A F.'Westhof Glory'
B M 'Profusion'
C P 'Kanzan'
D S.aria 'Lutescens'
E T x euchlora

TABLE 4

Mean maiden tree height (Nov 86)

Treatment	g.a.i/ha	A	B	C	D	E
Napropamide	4050	109.1	118.2	151.5	129.1	105.7
Napropamide and simazine	3500 500	113.1	114.0	157.1	158.4	104.2
Atrazine	500	113.3	113.3	157.9	142.9	106.1
Chlorthal-dimethyl and diphenamid	7500 5000	109.6	116.8	153.0	154.1	106.2
Simazine and propyzamide	500 500	113.3	117.7	159.9	147.0	107.4
Chlorthal-dimethyl and metazachlor	7500 1250	114.4	119.4	160.6	150.6	97.5
Oxadiazon	1000	114.1	113.8	162.9	142.4	101.5
Control	-	108.2	116.4	150.0	152.4	104.8
LSD.p=0.5m		9.2	7.3	24.7	18.2	12.4

A F. 'Westhof Glory'
B M. 'Profusion'
C P. 'Kanzan'
D S.aria 'Lutescens'
E T x euchlora

TABLE 5

Mean diameter at half height (Nov 86)

Treatment	g.a.i/ha	A	B	C	D	E
Napropamide	4050	14.35	9.05	9.07	11.95	7.81
Napropamide and simazine	3500 500	13.93	9.03	9.57	12.55	7.53
Atrazine	500	14.57	8.70	9.45	12.20	7.59
Chlorthal-dimethyl and diphenamid	7500 5000	14.05	9.03	9.13	13.15	8.02
Simazine and propyzamide	500 500	14.05	9.05	9.75	12.70	7.80
Chlorthal-dimethyl and metazachlor	7500 1250	14.85	9.28	9.68	12.78	7.09
Oxadiazon	1000	13.98	8.73	9.85	12.45	7.67
Control	-	13.20	8.95	8.97	12.93	7.69
LSD.p=0.5		1.40	0.47	1.27	0.84	1.21

A F. 'Westhof Gory'
B M 'Profusion'
C P 'Kanzan'
D S.aria 'Lutescens'
E T x euchlora

TABLE 6

Weed population expressed as percentage of control. (Combined total of all plots at all counts)

Treatment	g.a.i/ha	1	2	3	4	5	6	7	8	9
Napropamide	4050	9.7	15.2	220.6	58.8	69.1	47.8	35.5	78.9	78.9
Napropamide and Simazine	3500 500	7.1	12.7	19.8	42.8	10.1	22.1	22.7	32.9	31.9
Atrazine	500	25.8	28.5	36.0	43.0	10.3	42.5	15.5	72.3	19.2
Chlorthal-dimethyl and diphenamid	7500 5000	13.6	67.6	166.4	83.3	84.1	146.9	18.2	114.5	44.1
Simazine and propyzamide	500 500	23.6	48.6	79.4	43.4	24.5	46.0	20.0	63.2	41.4
Chlorthal-dimethyl and metazachlor	7500 1250	25.8	39.3	126.9	67.3	45.8	31.0	20.0	78.9	24.0
Oxadiazon	1000	20.5	202.3	196.4	77.1	15.6	33.6	42.7	27.6	50.1
Control	-	100	100	100	100	100	100	100	100	100

1 Poa annua
2 Stellaria media
3 Capsella bursa-pastoris
4 Senecio vulgaris
5 Polygonum aviculare
6 Matricaria matricarioides
7 Veronica officinalis
8 Vicia sativa
9 Lamium purpureum

Weed Control

There were large differences in weed number from plot to plot within treatments. All treatments controlled P. annua quite well but overall napropamide and simazine was the best. (Table 6) With the exception of oxadiazon all treatments offered fair control of S. media, napropamide and napropamide and simazine being most effective. Oxadiazon, napropamide and chlorthal-dimethyl and diphenamid were weak on C. bursa-pastoris, the best control of this weed being from napropamide plus simazine and atrazine. Control of S. vulgaris was not good on any treatment but until the final assessment, had been good on napropamide and simazine treated plots. P. aviculare was not effectively controlled by any treatment in the first year although in the second year napropamide and simazine were most effective. M. matricarioides was not an abundant weed on any plot. Reasonable control of V. officinalis was offered by all treatments compared with untreated plots. L. purpureum was not controlled very effectively by any treatment, the napropamide being particularly weak. The best treatment on this weed was atrazine.

DISCUSSION

Herbicide treatments were applied 2-3 weeks after planting. The most rapid leafing P. 'Colt' and S. intermedia were damaged by the contact activity of oxadiazon. No othher species suffered apparant damage. The growth of the P. 'Colt' was reduced on oxadiazon treated plots in the rootstock year. Although S. intermedia also suffered visical damage the plants were not significantly maller than the control at the end of the rootstock year. The damage to the P. 'Colt' rootstocks by the oxadiazon did not affect bud take or subsequent maiden growth. This contact activity would be useful for taking out emerging weed seedlings but could have been very damaging to a less robust crop than P. 'Colt'. The only significant maiden tree growth reduction was from napropamide on S.aria 'Lutescens'. Although growth in the rootstock year was the lowest of all treatments this was not significant compared with the control. By the end of maiden year napropamide treated trees were significantly smaller than control ones. Whilst this would appear to be a strong treatment effect further investigations would be required for confirmation, especially as no such effect is shown by the mixture of napropamide and simazine.

None of the treatments gave anywhere near total weed control and because plot to plot populations were very variable meaningful analysis could not be done. Napropamide gave a good spectrum of control except for C.bursa-pastoris, where it was consistantly the least effective chemical treatment. In combination with simazine its control of C.bursa-pastoris is much improved. Atrazine gave good control of a wide range of weeds. Triazine resistant S.vulgaris was new to Luddington in 1985 and for the duration of this trial atrazine offered reasonable control. Chlorthal-dimethyl and diphenamid and chlorthal-dimethyl and metazachlor did not give as good overall weed control as napropamide plus simazine and atrazine. Both were very weak on S. vulgaris and the chlorthal-dimethyl and diphenamid in particular was letting a very wide spectrum of weed through by the end of the maiden year. Simazine and propyzamide gave a good spectrum of control and retained its comparative effectiveness against S. vulgaris, an indication that triazine resistance is not prevalant on this site.

The main weakness of oxadiazon is its failure to control S.media. Numbers were frequently higher than on control plots, a result probably explained by the oxadiazon excluding competition from other weeds on treated plots.

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WEED CONTROL IN CARROTS AND RELATED CROPS WITH SOME NEWER HERBICIDES

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ABSTRACT

In field trials on a sandy loam soil R-40244 (3-chloro-4-chloromethyl-1-(α,α,α-trifluoro-m-tolyl)-2-pyrrolidone) applied pre-emergence at 0.5 and 1.0 kg a.i./ha gave complete weed control but caused transient bleaching of carrot, parsley and parsnip foliage. Plots treated with SMY 1500 (4-amino-6-(1,1-dimethylethyl)-3-(ethylthio)-1,2,4-triazin-5(4H)-one) were almost weed free but at 0.5 and 1.0 kg a.i./ha parsley and parsnip were damaged. Carrots were more tolerant but there was some loss of stand with 2.0 kg a.i./ha. Pendimethalin and aclonifen were selective in all three crops except under certain weather conditions. Weed control was variable depending on the species present and was improved by the addition of linuron. Diflufenican at a low dose was tolerated by carrots but weed control was again variable except when applied in a mixture with linuron.

INTRODUCTION

In field evaluation trials on a range of vegetables at Wellesbourne, several herbicides have shown selectivity in umbelliferous crops. These chemicals include pendimethalin (Roberts & Bond 1974), R-40244 (3-chloro-4-chloromethyl-1-(α,α,α-trifluoro-m-tolyl)-2- pyrrolidone) (Roberts et al. 1980), aclonifen (Roberts & Bond 1984), diflufenican (Roberts & Bond 1986) and SMY 1500 (4-amino-6-(1,1-dimethylethyl)-3-(ethylthio)-1,2,4-triazin-5(4H)-one) (Bond & Burch 1987). The present report summarises the results from field trials made in the period 1983-86.

EXPERIMENTAL METHOD AND RESULTS

The experiments were of randomised block design with three replicates, and were carried out on a sandy loam soil with 2% o.m. Plot size was 4.5 m2, with four crop rows 30 cm apart of which the centre two were harvested. The pre-emergence treatments were applied in a volume of 1100 l/ha and linuron (Linuron 50WP) at 0.55 kg a.i./ha was included for comparison as appropriate. Weed kill was assessed by counting survivors and by visual scoring of overall weed control on a scale of 0 (no effect) to 10 (complete kill). After assessment, plots were weeded to prevent competition and allow direct effects on yield to be determined. Crop injury was scored on the same 0-10 scale and crop number and weight were recorded at harvest. The yields are presented as percentages of the values for hand-weeded controls. The crop cultivars used were carrot cv. Chantenay red-cored Royal Chantenay, parsley cv. Bravour and parsnip cv. Offenham.

Carrots

In 1983 aclonifen and R-40244 were included in two carrot trials. After the first was drilled and sprayed on 7 April, there was rain almost every day totalling 60 mm in the following three weeks. Weed density was 187/m2 and the main species were Matricaria perforata, Chamomilla recutita, Poa annua, Polygonum aviculare, Bilderdykia convolvulus, Viola arvensis, Senecio vulgaris, Fumaria officinalis and Veronica persica. R-40244 at 0.5

and 1.0 kg a.i./ha gave complete kill of all the weeds present. The only survivors with aclonifen were P. aviculare and Aethusa cynapium. Under the cold, wet conditions prevailing R-40244 caused bleaching of the crop leaves and with 1.0 kg a.i./ha a few seedlings died. The remaining crop recovered and yields were similar to those of the controls (Table 1). Initially, there were no obvious effects with aclonifen but following the continued wet weather the carrots became stunted. However, once the weather improved the crop recovered and final yields were not significantly affected.

A second trial was drilled and sprayed on 14 April. Rainfall in the first three weeks was 82 mm. The seedbed was rougher than in the earlier trial and weed density higher at 277 weeds/m2 with P. aviculare the commonest weed. Again, R-40244 plots were completely weed free. On plots treated with aclonifen P. aviculare was the main survivor with some S. vulgaris and A. cynapium. R-40244 caused initial bleaching of the crop and with 1.0 kg a.i./ha there was a reduction in root numbers at harvest. There was little injury with aclonifen in this trial and no effect on yield (Table 1).

TABLE 1

Response of carrots and weeds to pre-emergence applications of R-40244 and aclonifen, 1983.

Treatments kg a.i./ha		Trial 1 Weeds % kill	Trial 1 Crop score	Trial 1 Crop % no.	Trial 1 Crop % wt	Trial 2 Weeds % kill	Trial 2 Crop score	Trial 2 Crop % no.	Trial 2 Crop % wt
R-40244	0.5	100	0.7	98	105	100	1.7	97	98
R-40244	1.0	100	2.7	87	96	100	5.3	86	100
aclonifen	1.2	96	1.3	97	100	89	0	93	106
aclonifen	1.8	97	2.3	98	92	71	0	93	97
aclonifen	2.4	99	2.3	99	97	100	0.7	97	98
L.S.D. (5%) for comparison with control				20	14			14	4

In 1985, two tests were made to examine the effects of pendimethalin and diflufenican, either alone or in combination with linuron. The first was drilled and sprayed on 2 April during a cold wet spell, with 35 mm rain in the following three weeks. Weed control was assessed on 23 May and weeds counted on 25 May. There were 218 weeds/m2 with P. aviculare, S. vulgaris, P. annua, C. suaveolens, Thlaspi arvense and Stellaria media the main weeds. The standard linuron treatment gave good weed control but results with pendimethalin were poor because of the prevalence of S. vulgaris. Addition of linuron improved control appreciably, killing most S. vulgaris, although some T. arvense and Veronica hederifolia survived the combined treatment. Weed control with diflufenican was good at 50 g a.i./ha, P. aviculare and P. annua being the main survivors. The lower rate of diflufenican gave only moderate control but was improved by the addition of linuron. During the early stages of this trial the soil was cold and wet so that crop emergence and growth were slow. Linuron caused a significant reduction in root numbers (Table 2) but pendimethalin, whether alone or in combination with a low rate of linuron, had no adverse effect on number or weight of roots. Diflufenican caused little visible injury but with 50g a.i./ha there was a

reduction in root weight and, when combined with linuron, both root number and weight were adversely affected.

TABLE 2

Response of carrots and weeds to pre-emergence applications of diflufenican and pendimethalin, alone and in combination with linuron, 1985.

Trial 1

Treatments kg a.i./ha	Weeds % kill	Weeds score	Crop score	Yield, % of control number	Yield, % of control weight
pendimethalin 0.67	58	7.3	0	107	98
pendimethalin 1.33	65	7.7	0	108	106
pend. 0.67 + linuron 0.25	91	8.7	0	94	104
pend. 1.33 + linuron 0.25	91	9.0	0	90	94
diflufenican 0.025	71	7.7	0	98	100
diflufenican 0.050	88	9.0	0.7	97	86
difl. 0.025 + linuron 0.25	89	9.2	0	95	92
difl. 0.050 + linuron 0.25	95	9.2	0.7	77	87
linuron 0.55	88	8.7	0.7	82	89
L.S.D. (5%) for comparison with control				17	13

Trial 2

Treatments kg a.i./ha	Weeds % kill	Weeds score	Crop score	Yield, % of control number	Yield, % of control weight
pendimethalin 0.67	90	8.7	1.7	92	98
pendimethalin 1.33	86	9.2	3.0	69	94
pend. 0.67 + linuron 0.25	97	9.0	2.3	74	97
pend. 1.33 + linuron 0.25	96	9.7	3.0	70	93
diflufenican 0.025	52	6.3	0	93	101
diflufenican 0.050	77	7.3	0	101	98
difl. 0.025 + linuron 0.25	99	9.5	0	106	101
difl. 0.050 + linuron 0.25	96	9.7	0.7	99	104
linuron 0.55	90	9.3	0	96	102
L.S.D. (5%) for comparison with control				20	19

Drilling and spraying of the second test on 17 June was followed by a very wet period with rain every day in the first week, totalling 49 mm. Weeds were counted on 17 July and control assessed visually on 18 July when crop injury scores were recorded The carrots were harvested on 12 September. Weed emergence was low, mainly *S. media* with a few seedlings of other species. Pendimethalin alone controlled all weeds except *S. vulgaris*, with the addition of linuron however, only isolated plants of this species survived. Diflufenican was only effective when combined with linuron. There were no visible effects on the crop from linuron in this trial but all plots treated with pendimethalin suffered some stunting and with three of

the four treatments crop stand was reduced (Table 2). Diflufenican did not affect root number or total weight.

In two trials made in 1986, pendimethalin alone and in combination with linuron was examined; treatments with SMY 1500 at three rates were also included. The first test was drilled on 28 April and pre-emergence treatments applied the same day. Rainfall in the following three weeks totalled 47 mm. Weed counts were made on 12 June and plots handweeded. Crop injury was assessed on 27 June. The carrots were harvested on 9 September and the number and total weight of roots from each plot recorded. The weed population on the controls was 35/m2. The main species present were V. persica, Capsella bursa-pastoris, P. annua, S. media, F. officinalis and T. arvense. Additional species were present in low numbers. SMY 1500 controlled all the weeds apart from an occasional S. vulgaris. Pendimethalin alone killed all S.media, P. annua, and V. persica. Fumaria

TABLE 3

Response of carrots and weeds to pre-emergence applications of SMY 1500 and pendimethalin, 1986.

Trial 1

Treatments	kg a.i./ha	Weeds % kill	Crop score	Yield, % of control number	Yield, % of control weight
SMY 1500	0.5	99	0.3	107	102
SMY 1500	1.0	99	2.0	98	103
SMY 1500	2.0	100	5.7	67	95
pendimethalin	0.67	93	0	106	96
pendimethalin	1.33	97	0	102	100
pend. 0.67 + linuron	0.25	97	0	95	98
pend. 1.33 + linuron	0.25	99	0	101	101
linuron	0.55	93	1.0	89	99
L.S.D. (5%) for comparison with control				13	8

Trial 2

Treatments	kg a.i/ha	Weeds % kill	Crop score	Yield, % of control number	Yield, % of control weight
SMY 1500	0.5	90	0.3	93	108
SMY 1500	1.0	99	0.3	99	109
SMY 1500	2.0	87	3.3	87	102
pendimethalin	0.67	94	0	109	108
pendimethalin	1.33	96	0.7	101	108
pend. 0.67 + linuron	0.25	95	0	107	105
pend. 1.33 + linuron	0.25	97	0.3	105	107
linuron	0.55	52	0	108	106
L.S.D. (5%) for comparison with control				15	8

officinalis and S. vulgaris were the main survivors at the 1.33 kg a.i./ha rate, with 0.67 kg a.i./ha occasional T. arvense, C. bursa-pastoris and mayweeds also remained. The addition of linuron reduced the number of surviving weeds. The standard treatment of linuron alone, left mainly V. persica and F. officinalis. The highest rate of SMY 1500 caused severe crop injury, plant stand was reduced but survivors recovered and growth of these widely spaced roots compensated for the missing plants and yield per plot was not reduced (Table 3). There was some transient damage with lower rates of SMY 1500. Pendimethalin alone or in the mixture did not check the early growth of the crop or affect the number and weight of carrots at harvest.

The second trial was drilled and sprayed on 19 May. Rainfall in the following three weeks totalled 23 mm. Weed numbers were recorded and crop injury assessed on 7 July. Weed numbers were low, only 12/m2 on the controls with V. persica accounting for more than half of these. Other species present included S. media, P. annua and Solanum nigrum. A few S. nigrum and V. persica seedlings survived on plots treated with the lowest rate of SMY 1500 but at higher rates, plots were again virtually weed free. All the pendimethalin treatments killed V. persica. With 1.33 kg a.i. plus linuron F. officinalis was the only survivor, while pendimethalin alone at this rate failed to control the occasional P. annua seedlings. A few survivors of several species remained on plots treated with 0.67 kg pendimethalin alone or in the mixture. Linuron alone did not kill V. persica which accounted for the poor weed control on these plots. No treatment adversely affected crop weight at harvest (Table 3).

Parsley

In 1983, aclonifen and R-40244 treatments were included in two parsley trials. In the first experiment, drilled and sprayed on April 7, there were 314 weeds/m2 on the controls prior to weeding. Rainfall in the first three weeks totalled 60 mm. R-40244 at 0.5 and 1.0 kg a.i./ha gave complete weed control. All rates of aclonifen gave excellent weed kill though some P. aviculare survived at 1.2 and 1.8 kg a.i./ha. There was complete control of M. perforata, C. recutita, P. annua and Urtica urens. R-40244, especially at 1.0 kg a.i./ha, caused bleaching of the parsley leaves and this persisted until the weather became warmer. After that, the crop recovered and at harvest there was no adverse effect of R-40244 or aclonifen on final yield (Table 4). Plant numbers were not recorded.

In the second experiment prepared on 14 April, the seedbed was rough and weed density was 228 weeds/m2. Rainfall in the first three weeks totalled 82 mm. The R-40244 treatments gave complete weed kill. In this trial P. aviculare, the main weed present, was only controlled by aclonifen at 3.6 kg a.i./ha. A few A. cynapium and S. vulgaris also remained. There was however complete kill of Chenopodium album, Atriplex patula, Viola arvensis, B. convolvulus and Sonchus asper. There was again some initial injury with R-40244 and a slight check with the two higher rates of aclonifen but neither chemical affected final yields (Table 4). Weeding of plots was delayed by the wet weather and there was some competition from P. aviculare where only 1.2 kg a.i. of aclonifen had been applied.

In 1986, a single parsley trial was drilled on 28 April and pre-emergence treatments of SMY 1500 and of pendimethalin plus linuron applied on 30 April. Rainfall in the following three weeks totalled 47 mm. Weed counts were made on 9 June and crop injury and overall weed control assessed on 27 June. At harvest on 27 July the number and total fresh weight of plants were recorded. Weed number on the controls was 33

weeds/m2. The main species were P. annua, C. bursa-pastoris, V. persica, T. arvense, S. media, F. officinalis, M. perforata and C. suaveolens. SMY 1500 at 1 and 2 kg a.i./ha killed all weeds apart from an occasional plant of S. vulgaris. With 0.5 kg a few F. officinalis and T. arvense also survived. Plots treated with 1.33 kg a.i./ha pendimethalin plus linuron were virtually weed free. The main survivor with the lower rate of pendimethalin was F. officinalis. Linuron alone left mainly V. persica and F. officinalis. Crop injury was severe with SMY 1500; all three rates reduced plant stand (Table 5). Only with 0.5 kg a.i./ha was total weight unaffected at harvest. No other treatments affected crop growth or yield.

TABLE 4

Response of parsley and weeds to pre-emergence applications of aclonifen and R-40244, 1983.

Treatments kg a.i./ha		Trial 1 Weeds % kill	Trial 1 Crop score	Trial 1 Yield as % of control	Trial 2 Weeds % kill	Trial 2 Crop score	Trial 2 Yield as % of control
R-40244	0.5	100	0.7	119	100	2.7	100
R-40244	1.0	100	2.3	105	100	3.7	106
aclonifen	1.2	98	0.7	98	57	0	86
aclonifen	1.8	98	0.3	108	81	0.3	95
aclonifen	2.4	100	0.3	110	65	1.0	97
aclonifen	3.6	100	0.7	110	88	0.7	100
L.S.D. (5%) for comparison with control				19			11

TABLE 5

Response of parsley and weeds to pre-emergence applications of SMY 1500 and of pendimethalin plus linuron, 1986.

Treatments	kg a.i./ha	Weeds % kill	Weed score	Crop score	Yield, % of control number	Yield, % of control weight
SMY 1500	0.5	98	8.3	6.3	65	92
SMY 1500	1.0	99	9.5	9.3	4	15
SMY 1500	2.0	99	9.7	9.7	1	1
pend. 0.67 + linuron	0.25	94	9.0	0	100	98
pend. 1.33 + linuron	0.25	99	9.3	0.3	99	102
linuron	0.55	87	6.3	0	99	92
L.S.D. (5%) for comparison with control					14	13

Parsnip

In 1983, aclonifen and R-40244 treatments were included in two parsnip experiments drilled on 7 and 14 April. Rainfall was the same as that

recorded in the parsley trials. The parsnips were thinned to 10 cm apart in the row once the seedlings had established. In the first trial, weed density was 303 weeds/m2 and R-40244 gave complete weed kill. Overall weed control with aclonifen was also good, P. aviculare being the main survivor together with A. cynapium. There was complete kill of M. perforata, C. recutita, V. arvensis, B. convolvulus, and Urtica urens. The characteristic R-40244 bleaching that occurred in the other crops was seen in parsnip and there was also a crop check with aclonifen treatments. The parsnips recovered and there was no effect on root weights at harvest (Table 6).

TABLE 6

Response of parsnip and weeds to pre-emergence applications of aclonifen and R-40244, 1983.

Treatments kg a.i./ha		Trial 1 Weeds % kill	Trial 1 Crop score	Trial 1 Yield as % of control	Trial 2 Weeds % kill	Trial 2 Crop score	Trial 2 Yield as % of control
R-40244	0.5	100	1.7	96	100	3.3	92
R-40244	1.0	100	2.3	93	100	4.0	96
aclonifen	1.2	96	0.3	101	78	0.3	99
aclonifen	1.8	94	0.3	92	81	0.3	99
aclonifen	2.4	97	0.3	95	83	0	103
aclonifen	3.6	99	1.0	93	97	1.7	99
L.S.D. (5%) for comparison with control				9			9

TABLE 7

Response of parsnip and weeds to pre-emergence applications of SMY 1500 and of pendimethalin plus linuron, 1986.

Treatments	kg a.i./ha	Weeds % kill	Weed score	Crop score	Yield, % of control number	Yield, % of control weight
SMY 1500	0.5	99	9.7	3.0	81	95
SMY 1500	1.0	99	9.7	7.0	52	79
SMY 1500	2.0	100	10.0	8.8	10	30
pend. 0.67 + linuron 0.25		98	9.2	0	93	103
pend. 1.33 + linuron 0.25		97	9.2	0	101	94
linuron 0.55		68	5.0	0.6	110	87
L.S.D. (5%) for comparison with control					25	22

The second trial, made on a rougher seedbed, had a weed density of 191 weeds/m2 and once again R-40244 gave complete weed control. The main weed was P. aviculare which remained on all aclonifen treated plots, although survivors were small and less competitive at higher rates. Some S.

arvensis also survived at rates below 2.4 kg a.i./ha. Species killed included V. arvensis, M. perforata, S. asper and P. annua. In addition to the injury seen previously, there was some yellowing of the crop at an early stage where aclonifen at 3.6 kg a.i./ha had been applied. Yield of roots at harvest on 20 September did not differ from those of the controls (Table 6).

In 1986, pre-emergence treatments of pendimethalin plus linuron and of SMY 1500 at three rates were included in a parsnip trial drilled on 28 April. The dates of spraying and assessments were the same as for the 1986 parsley trial. Plant numbers and total weight of roots, for each plot, were recorded at harvest on 4 September. The weed population was 35 seedling/m2 and the main species present were the same as those in the parsley trial. Weed control was virtually complete with all rates of SMY 1500, although a few S. vulgaris survived with 0.5 kg a.i./ha. Plots treated with the mixture of pendimethalin and linuron were almost weed free. A few F. officinalis and P. annua remained with both rates of pendimethalin. Linuron alone, left more of these species together with large numbers of V. persica. Parsnip was less susceptible than parsley to SMY 1500 but a reduction in stand which increased with higher rates of chemical was reflected in the weights at harvest. There was no effect on yield from the other treatments, but poor crop establishment made the results very variable (Table 7).

DISCUSSION

All the herbicides tested, including linuron, caused occasional crop damage under the cold, wet conditions that prevailed during the early stages of some trials. R-40244 was exceptional in giving complete weed control in all three crops at a dose which caused only transient injury. At 1.0 kg a.i./ha damage was more severe especially when growing conditions were poor. SMY 1500 also controlled most of the weeds but at rates which caused unacceptable damage to parsley and parsnip. There was some loss of stand in carrot with 2 kg a.i./ha. Weed control with the other three herbicides was variable depending on the species present but the addition of linuron gave consistently better results. Diflufenican at 50 g a.i./ha was damaging in carrot but the lower dose gave poor weed control. When cold, wet weather followed aclonifen application early crop growth was checked but plants recovered as conditions improved. The damage that occured with pendimethalin in carrots developed after exceptionally heavy rainfall. This could have resulted from uptake of the chemical by the crop at the soil surface.

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THE EFFECT OF FOLIAR AND SOIL-ACTIVE HERBICIDES ON BLACKCURRANTS

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ABSTRACT

Napropamide (4 and 8 kg/ha) and pendimethalin (2 and 4 kg/ha applied in mixture with simazine (1 kg/ha) to newly-planted and established blackcurrants in February caused no adverse effects on growth or fruit yield. Soil residues 9 months after the last of three annual applications were 10% of the annual dose or less. Oxadiazon and oxyfluorfen applied post-planting in February caused severe stunting and necrosis of emerging shoots but damage was subsequently outgrown. At doses required for control of simazine-resistant weeds, applications in February to 1 and 2 year old bushes caused some damage to basal shoots in spring but had no effect on fruit yield or overall shoot growth. Pyridate (1.5 and 3 kg/ha) + simazine (1 kg/ha) applied in December or February had no adverse effect on growth or fruit yield.

Clopyralid (0.2 kg a.e/ha) applied overall at different dates during the growing season caused most damage from spraying in April during flowering or in late September before leaf fall. Fruit yield was reduced and new shoot growth distorted. Subsequent growth was normal and fruit yield the following year unaffected. Results suggested there should be little risk of serious damage from directed sprays for creeping thistle (Cirsium arvense) control.

INTRODUCTION

Weed control in non-cultivated blackcurrants in the U.K. has been largely based on annual applications of simazine. Repeated use of this herbicide has however led to an increase in resistant annual weeds and the spread of perennial weeds. Other herbicides such as dichlobenil, diuron, MCPB and propyzamide have given improved control (Fryer & Makepeace 1978) but there has been a need for alternative effective and economic treatments. Following screening of 30 herbicides for tolerance to blackcurrants in pot tests (Clay 1985) promising herbicides were applied to field-grown blackcurrants as single or repeated annual treatments to assess tolerance. The results of this work are reported.

MATERIALS AND METHODS

Six experiments were carried out at the Weed Research Organisation at Begbroke Hill, Oxford on a sandy loam soil of the Sutton/Badsey series, overlying calcareous gravel to a depth of 0.5 - 0.75 m (o.m. 2 - 3%, pH 6.5 - 7.0). Blackcurrants, cv. Baldwin, were planted in late winter as cuttings or as 1 year old bushes, cut-down immediately after planting. Spacing between plants was 0.6 m and between rows 2.5 m. Herbicides were applied to 4.2 m long plots at a 1 m spray swath using a pressurized knapsack sprayer fitted with a boom with 3, 6502 Spraying System Tee jets, giving 330 l/ha spray volume at 200 kPa pressure. Herbicides and formulations used are shown in the tables (all doses are expressed as kg a.i./ha). Experiments were laid out as randomised blocks with two control treatments, with three

blocks in Expts. 1, 2 and 4, four in Expts. 3 and 5 and six in Expt. 6. Fertilizer was applied each spring and a standard pesticide programme followed. Weeds developing on plots were killed as seedlings by paraquat applied in alleys and hand pulling in rows.

Assessments were made on the central five bushes on each plot row. Herbicide damage was scored using a 0-9 scale where 0=plant dead, 5=50% growth inhibition, 9=plant healthy. A single pick of all fruit was made in July. Growth was recorded in winter by measuring the length of the previous year's extension growth on shoots $>$5cm long. Basal shoot length was recorded separately. In Expt. 2, soil samples were taken in November 1985 from napropamide and pendimethalin treatments for herbicide residue measurement. Ten 2.5 cm diameter samples were taken per plot to 10 cm depth, from positions 20 cm either side of the row centre. Soil was sieved through a 3 mm mesh, mixed and deep frozen. Analysis was by gas chromatography for pendimethalin (lowest detectable dose, 0.01 mg/kg dry soil) and hplc for napropamide (lowest detectable dose, 0.04 mg/kg) (Byast et al. 1977).

RESULTS

Expt 1. Oxadiazon and oxyfluorfen at both doses applied to newly planted bushes caused severe damage to new growth during April and May. Developing shoots were stunted and leaves chlorotic, distorted and often severely necrotic (Table 1). Plants grew out of the damage during the summer, and the height of leading shoots was only slightly less than the control in July for oxadiazon treatments though 20-40% less with oxyfluorfen. Subsequent growth of oxadiazon treated bushes was normal and although bush size was smaller in 1982 at the higher dose, fruit yield and final growth were similar to the control. With oxyfluorfen treatments bushes were smaller than the control treatment and fruit yield reduced by 14-24%. Pendimethalin at the higher dose caused slight stunting of shoots with the post planting application but subsequent growth was similar to the control treatment and growth and fruit yield unaffected following reapplication of the treatments in 1983. Propyzamide at the higher dose caused slight shoot stunting but this was outgrown and subsequent growth and yield were similar to the control treatment.

Expt 2. Napropamide applied each spring at 4 or 8 kg/ha had no adverse effect on growth or fruit yield (Table 2). Soil residues 9 months after the final application were 1.20 and 2.38 kg/ha respectively. Oxadiazon applied post-planting caused severe damage to emerging shoots in spring but this was outgrown during the summer and only the higher dose resulted in smaller bush size in winter and reduced fruit yield the following summer. When the doses were reapplied in February 1985 only the higher doses caused damage to basal shoots (stunting and leaf necrosis) and 13% fruit yield reduction. Oxyfluorfen applied post-planting caused severe damage to emerging shoots but this was outgrown and only the higher dose led to fruit yield reduction (27%) the following year. When the treatments were reapplied in 1985 only the higher dose caused damage - stunting and necrosis of basal shoots and 13% fruit yield reduction. Pendimethalin, 2 and 4 kg/ha, applied post-planting and in two subsequent years had no adverse effect on growth or yield. Soil residues measured 9 months after the final application were 0.38 and 0.98 kg/ha respectively.

Expt 3. Napropamide and pendimethalin applied in February to established bushes had no adverse effect on growth or fruit yield compared

TABLE 1

The effect of herbicides applied before bud burst on 19 Feb. 1982 and 21 Feb. 1983 on the growth and fruit yield of blackcurrants[a] (Experiment 1)

Herbicide[b]	Formulation % ai and product name	Dose (kg ai/ha)	1982				1983		
			Vigour score[d] 5 Apr.	2 Jul.	Shoot height[e] 2 Jul.	Shoot length[e] 15 Nov.	Vigour score[d] 6 May	Fruit yield[e] Jul.	Shoot length[e] Dec.
Oxadiazon[c]	e.c., 20	2.0	4.7	7.0	92	92	8.7	100	100
"	(Ronstar)	4.0	4.3	6.0	92	85	7.0	101	110
Oxyfluorfen[c]	e.c., 24	1.5	4.0	5.0	80	95	7.0	86	93
"	(Goal)	3.0	3.7	3.3	60	80	5.7	76	79
Pendimethalin	e.c., 33	2.0	7.3	8.7	103	93	9.0	105	102
"	(Stomp)	4.0	6.3	8.3	98	99	8.3	109	99
Propyzamide[c]	w.p., 50	0.9	7.3	8.0	102	88	8.7	87	102
"	(Kerb 50 W)	1.8	6.7	7.0	98	89	7.7	96	101
Simazine	s.c., 50	1.0	7.5	8.5	100	100	8.8	100	100
Actual value					50.4 cm	287 cm/bush		0.48 kg/bush	1085 cm/bush
S.E.±			0.48	0.38	3.3	7.5	0.37	9.3	15.1

[a] planted as 1 year old bushes, Feb. 82 [b] Treatments applied as a tank mix with simazine 1kg/ha
[c] Simazine only applied 21 Feb. 83 [d] Vigour score, 0-9 scale [e] % simazine-treated standard

TABLE 2

The effect of herbicides applied in Feb. 1983, 1984 and 1985 on the growth and fruit yield of blackcurrants[a] (Experiment 2)

		Results as % simazine treated standard							
		1983			1984		1985		
Herbicide[b]	Dose (kg ai/ha)	Vigour 6 May	Vigour 13 Jul.	Total shoot length 29 Nov.	Fruit yield July	Total shoot length 3 Dec.	Vigour 3 May	Fruit yield Jul.	Total shoot length Dec.
Napropamide[c]	4.0	98	98	100	102	98	100	100	96
"	8.0	102	107	109	121	107	100	103	97
Oxadiazon	2.0	34	71	97	81	94	81	98	116
"	4.0	26	53	74	58	73	81	87	117
Oxyfluorfen	0.25	45	76	90	107	85	92	97	108
"	0.75	23	53	85	73	65	77	87	113
Pendimethalin	2.0	98	102	103	116	105	100	104	107
"	4.0	98	107	107	99	110	100	103	104
Simazine	1.0	100	100	100	100	100	100	100	100
Actual value		8.8[d]	7.5[d]	309 cm/ bush	0.57 kg/ bush	2373 cm/ bush	8.7[d]	2.64 kg/ bush	2632 cm/ bush
SE±		2.7	3.2	5.1	7.6	5.2	4.6	4.3	7.2

[a] Planted as 1 year old bushes, Feb. 82

[b] Treatments applied as a tank mix with simazine 1 kg/ha; oxadiazon and oxyfluorfen not applied 1984

[c] Napropamide as 45% a.i., s.c. (Devrinol)

[d] 0-9 scale

TABLE 3

The effect of herbicides applied in February 1983 to established blackcurrants planted as cuttings Feb. 1981[a] (Experiment 3)

Herbicide[b]	Dose (kg/ha)	Vigour[c] score 6 May	Fruit yield[d] 13 Jul.	Total shoot length[d] Dec. 83	No. basal shoots[d] Dec. 83
Napropamide	4.0	8.7	102	110	78
"	8.0	9.0	99	87	114
Oxadiazon	2.0	7.0	92	80	16
Oxyfluorfen	0.25	7.0	99	99	106
"	0.75	6.0	93	97	57
Pendimethalin	2.0	9.0	116	91	78
"	4.0	8.7	99	112	82
Simazine	1.0	8.9	100	100	100
Actual value			0.56 kg/bush	637 cm/bush	6.1 per plant
S.E.±		0.13	9.5	6.8	19.1

[a] Planted into polythene, removed Feb. 1983 before spraying
[b] Treatments applied as a tank mixture with simazine 1kg/ha
[c] Vigour score 0-9, [d] % simazine-treated standard

TABLE 4

The effect of oxyfluorfen and pyridate on dormant 1 year-old blackcurrants[a] (Experiment 4)

Herbicide	Dose (kg/ha)	Application date	Vigour score[c] 6 May	Fruit yield[d] 20 Jul.	Shoot length[d] 21 Nov.
Oxyfluorfen[b]	0.75	1 Dec. 82	7.0	90	82
"	1.5	1 Dec. 82	6.0	79	85
"	0.75	21 Feb. 83	6.0	89	109
"	1.5	21 Feb. 83	5.3	76	95
Pyridate[be]	1.5	1 Dec. 82	9.0	86	92
"	3.0	1 Dec. 82	9.0	90	102
"	1.5	21 Feb. 83	8.7	87	87
"	3.0	21 Feb. 83	8.7	87	97
Simazine	1.0	21 Feb. 83	8.5	100	100
Actual value				0.49 kg/bush	1131 cm/bush
SE±			0.25	7.8	8.2

[a] Planted as 1 year old bushes Feb. 82 [b-d], as in Table 3
[e] 50% w.p. (Lentagran)

TABLE 5

The effect of overall sprays of clopyralid 0.2 kg a.e./ha[a] on 2-year-old blackcurrant bushes[b] (Experiment 5)

Application date (1981)	Results as % untreated: Vigour score 10 Jul. 81	17 Aug. 81	5 Apr. 82	Fruit yield July 81	Berry size	Shoot length Jan. 82	Fruit yield Aug. 82	Shoot length Nov. 82
21 Apr.	84	72	100	73	89	97	107	114
13 May	78	61	78	113	101	76	109	153
22 Jun.	88	78	78	127	99	106	106	93
17 Aug.	100	89	69	99	101	104	98	104
Untreated	100	100	100	100	100[d]	100	100	100
Actual value	8.0[c]	9.0[c]	9.0[c]	0.99 kg/bush	63[d]	407 cm/bush	1.40 kg/bush	2029 cm/bush
SE±	2.1	3.5	1.4	7.9	5.8	6.6	5.0	13.3

[a] 100g a.e./l a.c.(Format) [b] planted as 1 year old bushes Feb. 79
[c] 0-9 scale [d] 200 berry wt(g)

TABLE 6

The effect of overall sprays of clopyralid 0.2 kg a.e./ha applied to blackcurrant bushes in the year of planting[a] (Experiment 6)

Application date (1983)	Leaf no. 1 Dec.	Results as % untreated: Shoot length Jan. 84	Vigour score (1984) 18 Apr.	24 May	26 Jun.	Fruit yield 30 Jul.84	Shoot length Feb.85
25 Jul.	184	96	85	111	100	124	98
18 Aug.	390	95	73	109	106	104	102
6 Sep.	515	101	67	96	98	119	100
29 Sep.	870	99	48	73	92	50	103
Untreated	100	100	100	100	100	100	100
Actual value	10.2[b]	300 cm/bush	8.0[c]	8.8	8.2	0.58 kg/bush	2049 cm/bush
SE±		3.7	2.1	2.9	3.1	6.8	5.5

[a] 1 year old bushes, planted Feb. 83, cut down and sprayed with simazine 1 kg/ha
[b] No. of leaves remaining/bush [c] Vigour score, 0-9 scale

with the simazine treated control (Table 3). Oxadiazon 2 kg/ha did not affect fruit yield but caused stunting, necrosis and death of basal shoots. Oxyfluorfen at 0.75 kg/ha caused similar effects but at 0.25 kg/ha there was no reduction in basal shoot numbers the winter after treatment.

Expt 4. Oxyfluorfen caused slightly more damage to basal shoot and leaf growth when applied in February compared with December but subsequent growth and fruit yield were similar (Table 4). Pyridate applied at both dates had no apparent adverse effect on growth or yield.

Expt 5. Clopyralid 0.2 kg a.e./ha applied over bushes on 21 April during flowering caused distortion of new leaves, slight epinasty,leaf cupping, and bending of shoot tips. These leaf symptoms were outgrown and shoot growth in that and the following year was unaffected (Table 5). Fruit yield was reduced by 27% in 1981 with a small reduction in fruit size but yield in 1982 was unaffected. Treatment on 13 May, when fruit was setting, resulted in distortion of leaves growing out in June and bending of shoot tips at the top of bushes; crop yield was not affected. Shoot growth recorded at the end of the year was reduced by 24% but yield and growth in 1982 were not reduced. Application of clopyralid on 22 June caused slight bending of shoot tips in July but no adverse effects on amount of growth or fruit yield in 1981 or 1982. Slight distortion was seen on the first leaves growing out in spring 1982. No adverse effects of the post-harvest application on 17 August were seen in the year of treatment but first leaves produced in 1982 showed formative effects (leaf cupping on upper shoots, vein clearing and increased marginal serration on basal shoots). These effects were outgrown; subsequent growth was unaffected and fruit yield 27% higher than the control.

Expt 6. When young bushes were treated with clopyralid, no effects were seen that year apart from delayed fall of dead leaves in autumn, the later the treatment the more leaves being retained into December (Table 6). All clopyralid treatments affected leaf growth the following spring, the 29 September applications to dormant bushes having severe effects. All developing shoots were stunted and leaves distorted initially as described above. Leaf growth from May became normal but effects remained obvious until June. Effects from the other application dates were less severe particularly that in July. Only the 29 September application had obvious effects on flowering, which was delayed and fruit set appeared less; fruit yield was 50% less than control. Fruit yield was not reduced by the other treatments and no treatment resulted in less shoot growth when recorded at the end of the year. In July 1985 fruit yield was recorded from the 29 September treatment when there was no significant difference from the untreated control (data not shown).

DISCUSSION

The tolerance of blackcurrants to dormant season sprays of napropamide and pendimethalin at recommended and double rates corresponds to results with other perennial crops (Clay 1984) and with earlier pot tests of pendimethalin on blackcurrants (Clay 1985). Both herbicides applied as a tank-mix with simazine in late winter gave a broad-spectrum pre-emergence weed control. The soil residues remaining 9 months after the last of three annual applications were 10% of the annual dose for napropamide and 6-8% for pendimethalin, comparable to amounts of simazine remaining after repeated applications on adjacent land (Clay 1978). There has been no evidence of damage to subsequent crops following widespread use of pendimethalin but

napropamide has caused damage to cereal crops following its use in Brassicae; avoidance of use the season before sowing sensitive crops would therefore be advisable.

Oxadiazon and oxyfluorfen applied to dormant plants caused severe damage to emerging shoots in newly-planted bushes and some damage to basal shoots in established bushes. Since these herbicides do not cause damage through root uptake (Clay 1980,1985) injury is probably caused by transfer of herbicide by splashing of treated soil onto young shoots and leaves near ground level (Clay 1982). At doses necessary for season long control of simazine-resistant weeds any adverse effects were short-term and growth and yield unaffected. Oxadiazon is recommended as a dormant-season treatment in established blackcurrants. Pyridate has caused damage applied to blackcurrants in summer (Clay 1985) but appeared safe in this work as a dormant season treatment. It has potential for post-emergence control of certain problem weeds such as cleavers (Galium aparine).

Clopyralid is widely-used as an overall treatment for the control of creeping thistle (C.arvense) in strawberries. Blackcurrants appeared less tolerant in pot tests (Clay 1985) although damage from applications to the bush base were outgrown. The field experiments showed that over-spraying bushes during April, May or September was most likely to cause leaf and shoot distortion and crop reduction. However, even with overall spraying bushes recovered suggesting that directed sprays, where much less herbicide reaches the bush, should be acceptable considering the alternative of leaving thistle uncontrolled. The effect of September spraying clearly persisted in the bush for a long time considering the effects on leaf fall and on spring flowering and fruit set seen in Expt 6. This contrasts with the apparent tolerance of September spraying of bushes with MCPB, the only phenoxy-alkanoic herbicide recommended in the crop (Fryer & Makepeace 1978).

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FOMESAFEN/TERBUTRYN - A PRE-EMERGENCE HERBICIDE FOR ANNUAL BROAD-LEAVED WEED CONTROL IN LEGUMES FOR PROCESSING

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ABSTRACT

A new pre-emergence herbicide mixture of fomesafen/terbutryn shows good selectivity in peas and beans (Vicia faba) for processing. Data assessed as crop damage during growth, and yield of produce in pea trials have demonstrated crop safety when fomesafen/terbutryn was applied pre-emergence of the crop, however, visible damage was caused when applied to emerged peas. Three years of experiments in the UK have shown activity against a wide spectrum of broad-leaved weeds.

INTRODUCTION

The EEC subsidy scheme for home grown protein has resulted in an expansion in the dry harvest pea and bean areas and also in increased development of herbicides. Some of these materials may also be useful in vining peas and broad beans (Vicia faba) for processing (quick-freezing and canning) but here cultivars are often more sensitive to herbicides and a high level of weed control is desirable as Matricaria or Solanum nigrum seedheads or berries cause contaminant problems in produce.

Fomesafen, a herbicide with residual and post-emergence activity was discovered at ICI's Plant Protection Division, England and the properties are described by Colby et al., 1982. Mixtures of fomesafen and terbutryn have since been evaluated and results for efficacy and crop safety in dry harvest peas are published elsewhere in the proceedings (Lake et al., 1987).

This research report summarises experiments in the UK from 1985 to 1987 with fomesafen and terbutryn mixtures in vining peas and broad beans for processing.

MATERIALS AND METHODS

The mixtures of fomesafen/terbutryn used were coded as follows: FP278 (a 50% SC formulation at 100/400g a.i./l), and from 1986, FP282 (a 48% SC at 80/400g a.i./l). Pre-emergence applications in vining peas at a range of dose rates on different soil types were evaluated for broad-leaved weed control and crop tolerance in 1985 (FP278) and 1986 (FP282) and compared with standard herbicides terbutryn/terbuthylazine as a 350/150g a.i./l SC, and trietazine/simazine as a 402.5/57.5 g a.i./l SC formulation. The work was extended in 1987 to look at crop safety and timing of application at 5-10%, and 50-70% crop emergence for FP282, compared with trietazine/simazine, the only pre-emergence residual herbicide with a UK label recommendation for safe application up to 5% pea emergence. In 1987 FP282 applied pre-emergence was also assessed for crop tolerance of broad bean Beryl, a sensitive cultivar, in comparison with terbutryn/terbuthylazine, trietazine/simazine and simazine also as a 500g a.i./l SC formulation. The site details are shown in Table 1.

At all sites seed was covered by 34 cm of settled soil, and seedbeds

were rolled except at sites 2, 6 and 8. Herbicides were applied pre-emergence of the crop at sites 1,2,3,4,5,6 and 9 at a stage when seed was swollen but no radicle was apparent with the exception of sites 2 and 9 where the seed was dry. At site 7 the first treatments were applied pre-emergence at dry seed stage, later timings were at 5-10% of the crop at emergence stage, and at 60-70% of the crop at emergence stage when some of the plumules had become green but no leaves were unfolded. At site 8 the first timing was pre-emergence when a radicle had formed but no plumule. Heavy rain followed by dry conditions caused soil to 'cap', resulting in delayed crop emergence. Later timings were at 5% of the crop at emergence stage, and 50% of the crop at emergence stage with a small proportion at 1st node stage.

TABLE 1

Site details

Site No./ Location	Soil type	Cultivar	Date sown	Herbicide applied DAS*
1985		Vining pea		
1. Thornhaugh	Sandy silt loam	Sprite	20/6	5
2. Grimston	Sandy loam	Sprite	3/4	1
3. Deeping	Silty clay loam	S.S. Freezer	30/4	10
1986				
4. Thornhaugh	Fine sandy loam	Scout	25/3	2
5. Holbeach	Fine sandy silt loam	Sprite	11/3	15
6. Deeping	Organic silty clay	Bikini	2/5	6
1987				
7. Thornhaugh	Sandy loam	D.S. Perfection	13/4	1,11,13
8. Holbeach	Fine sandy silt loam	Sprite	31/4	10,20,24
		Broad bean		
9. Thornhaugh	Sandy loam	Beryl	21/4	0

* DAS = Days after sowing

Data presented were obtained from replicated small plot experiments of randomised block design with three or four replicates. Plot size was 2 x 5m. All treatments were applied using a van der Weij plot sprayer with Birchmeier cone nozzles delivering 220 l/ha at a pressure of 210 kPa.

Broad-leaved weed control was assessed by quadrat counts of 3 x 0.33m^2 quadrats per plot for each species present. After full emergence crop plant counts were carried out. Crop tolerance was assessed by scoring visible damage. Pea yields at the green quick-freezing or canning stage of maturity were determined by hand harvesting and vining with a plot viner. Maturity of the peas was tested with a Martin Pea Tenderometer. Samples of produce treated with the highest rates of FP282 were canned and quick-frozen and submitted to Campden Food Preservation Research Association for taint testing.

In cultivar susceptibility experiments FP282 was applied at 3.8 kg a.i./ha in 1986 and at 4.8 kg a.i./ha in 1987 to a range of commercially grown and new vining, edible-podded, picking and dry harvest pea cultivars,

and at 4.8 kg a.i./ha in 1987 to broad bean and spring sown field bean cultivars. The method used was that described by King, 1980. FP282 was applied pre-sowing and incorporated to induce root uptake and hence crop damage, and comparisons were made with standard varieties and with standard herbicides terbutryn/terbuthylazine in peas, and simazine in beans applied at four times normal rates for the soil type.

RESULTS

Crop tolerance of vining peas

Results for pre-emergence application of fomesafen/terbutryn formulations and standard herbicides are presented for crop effects, yield and maturity in Table 2 (1985) and Table 3 (1986). Counts of pea plant populations showed that herbicide treatments applied pre-emergence did not reduce plant stand compared with the untreated at any site. There were no visible crop effects from fomesafen/terbutryn at sites 2 and 3 and damage was negligible at site 1 where temporary chlorosis and stunting of peas was observed on plots treated with FP278 at 1.25 kg a.i./ha. There were no statistically significant differences in yield between treated and untreated peas at any site, possibly because weed populations were low except at site 5 and here vigorous pea growth suppressed the weeds. Effects of herbicide treatment and weed control on pea maturity were non-significant, or at sites 1 and 5 were negligible in practical terms.

Results for crop effects and yield and maturity data for timing of application trials in 1987 are presented in Table 4. As in previous experiments FP282 applied pre-emergence showed a wide margin of crop safety even at 2.4 kg a.i./ha. However FP282 caused damage to the emerged and emerging crop in the form of necrosis on leaf margins, and crinkling and distortion of the leaves and these effects were attributable to the fomesafen component of the compound rather than the terbutryn which causes chlorosis in peas. Although damage was at an acceptable level for FP282 applied when 5-10% of the crop was at emergence stage, peas treated at this stage by the standard trietazine/simazine showed few effects. Effects were more severe and damage unacceptable from FP282 at 1.2 and 2.4 kg a.i./ha at the latest timing, with stunting and some plant death at site 8 as indicated by statistically significant reduction in plant population compared with untreated plots. The twice normal rate of trietazine/simazine applied when 50% or more of the crop emerged also caused severe visible damage. However, the visible effects were not reflected in pea yields or maturity and there were no significant differences between treated and untreated plots.

Crop tolerance of broad beans

There were few visible damage effects from pre-emergence applications of FP282 or standard herbicides in broad bean cultivar Beryl which is often sensitive to simazine, possibly because there was little herbicide leaching during the dry weather conditions which followed application. There were no reductions in plant stand from FP282 which appeared very safe to broad beans, while simazine at 1.7 kg a.i./ha gave a slight but significant reduction compared with untreated plots.

Broad-leaved weed control in vining peas

Results for efficacy of broad-leaved weed control overall and weed counts for individual species are presented for the pre-emergence herbicide experiments in Table 2 (1985) and Table 3 (1986). Data is not shown for site 6 where conditions were dry and only a few potato seedlings emerged

which were not controlled by any treatment. With the exception of site 5, weed populations were low, but included the main species usually found in pea crops.

In the 1985 experiments control of Bilderdykia convolvulus, Polygonum aviculare, Veronica persica and Chenopodium album was poor or variable for FP278 at the lower rates and was inferior to standard herbicides terbutryn/terbuthylazine and trietazine/simazine at sites 1 and 2. At site 3, where Stellaria media was the predominant species, FP278 at 1.00 kg a.i./ha and below was ineffective and here trietazine/simazine also gave an unacceptable level of weed control. FP278 at rates of 1.25 kg a.i./ha on light, and 2.00 kg a.i./ha on medium soil appeared to give an acceptable level of weed control but no better than the standard terbutryn/terbuthylazine. FP278 appeared effective against Solanum nigrum, Matricaria spp., Viola arvensis and Fumaria officinalis which occurred at low populations.

In the 1986 experiment a revised formulation, FP282, a 48% SC with fomesafen/terbutryn 80/400 g a.i./l was used. At site 5 all treatments gave good control of high populations of Urtica urens, Polygonum persicaria, B. convolvulus , Matricaria spp. and V. persica, but at site 6 FP282 at 0.72 kg a.i./ha was inadequate for control of P. aviculare. While FP282 at 0.96 kg a.i./ha and above gave acceptable weed control, no treatment performed better than terbutryn/terbuthylazine at normal rate.

In the 1987 timing experiment (Table 4), 1.2 and 2.4 kg a.i./ha of FP282 at all timings performed better in control of early germinating S. nigrum, the predominant species at site 7, and on B. convolvulus at site 8, than the normal and twice normal rates of trietazine/simazine. Both materials gave some control of weed beet (Beta vulgaris). FP282 had some contact action on emerged weeds at the later timings and achieved better weed control than pre-emergence applications.

Broad-leaved weed control in broad beans

FP282 at 1.2 kg a.i./ha performed better overall than normal rates of the cheapest pre-emergence herbicide simazine, was comparable to trietazine/simazine, but not as effective as terbutryn/terbuthylazine. Control of B. convolvulus was poor particularly for simazine applications. FP282 was less effective than other treatments on S. media.

Cultivar susceptibility

Results for susceptibility tests in 1986 and 1987 indicated that most cultivars of vining, edible-podded and dry harvest peas were classified as tolerant or highly tolerant to FP282. Exceptions were Vedette and Printana dry harvest peas, Petila, a small-seeded vining pea, and Minerva, a forage type used for pigeon feed, which were all slightly sensitive, but a further years testing is required before a final classification is made. Cultivars appeared less sensitive to FP282 than to terbutryn/ terbuthylazine. In 1987, the first year of tests, all broad beans and spring sown field bean cultivars tested appeared tolerant or highly tolerant to FP282 including Beryl, Rowena and Minica normally sensitive to simazine. The only symptoms of damage in these crops from 4.8 kg a.i./ha rates of FP282 was slight leaf chlorosis.

DISCUSSION

In three years experiments in vining peas and one year in broad beans,

excellent selectivity was shown for pre-emergence applications of fomesafen/terbutryn mixtures including fomesafen/terbutryn 80/400 g a.i./ha as the 48% SC formulation FP282, now developed in some countries. Many cultivars of vining, edible-podded, picking and dry harvest peas, field beans and broad beans appear tolerant to FP282 at high rates of 4.8 kg a.i./ha and none tested so far appeared sufficiently sensitive to warrant exclusion from treatment.

In timing experiments in vining peas the safety margin was reduced where FP282 was applied when 5-10% of the crop was at emergence stage, and visible damage was unacceptable when 50-70% of the crop was at emergence stage. This damage was not reflected in yields, however. Fomesafen and terbutryn both have contact action and thus the FP282 mixture does not appear to have the same flexibility of timing as trietazine/simazine which has a UK label recommendation for application up to 5% pea crop emergence.

The results indicated a need for a minimum dose of FP282 of 1.2 kg a.i./ha (fomesafen/terbutryn 200/1000 g a.i./ha) on a light soil and 1.44 kg a.i./ha (fomesafen/terbutryn 240/1200 g a.i./ha) on a medium soil to give acceptable weed control and higher doses may be necessary to consistently achieve a similar level of control to terbutryn/terbuthylazine. FP282 controlled a wide spectrum of weeds commonly found in pea crops such as C. album, U. urens, P. persicaria, P. aviculare, V. persica, P. annua, B. convolvulus and including weeds which can cause crop rejection of vining peas because of contamination of produce, Matricaria spp. (with flower heads) and S. nigrum (with poisonous berries).

No taints have been found so far in canned and quick-frozen samples of produce treated with FP282 in tests by Campden Food Preservation Research Association. Further data is required before taint clearance can be given.

FP282 is thus a promising new herbicide with a wide margin of crop safety when applied pre-emergence in peas and beans.

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TABLE 2

Weed assessments, population counts for main weed species and total including other species, crop assessments yield and maturity data for pre-emergence applications in vining peas at sites 1, 2 and 3 in 1985

Material≠	Rate kg a.i./ha (a)	(b)	Weed Score			Weed Counts/m²												Crop Score**	Yield shelled peas % untreated			Maturity Tenderometer Reading		
						P. aviculare	B. convolvulus	C. album	V. persica	Total	V. persica	B. convolvulus	P. aviculare	Total	S. media	V. persica	C. album	Total							
		site:	1	2	3	1					2				3				1	1	2	3	1	2	3
		date:	7/7	9/7	30/7	16/5					23/5				14/6				18/4	12/7	16/7	30/7	12/7	16/7	30/7
terb/terb	1.15	1.40	9	10	8	2	3	0	0	5	0	3	0	3	15	1	0	21	10	98	88	106	92	111	97
terb/terb	2.30	2.80	10	10	9	0	1	0	0	1	0	0	0	0	2	1	0	5	8.2	91	80	105	92	113	97
triet/sim	1.20	1.20	8	10	5	3	3	0	0	6	0	5	1	11	24	6	2	45	10	110	93	105	95	112	97
FP 278	0.50	0.62	4	5	4	12	2	0	0	14	12	8	1	25	42	4	3	60	9.5	94	98	105	92	110	96
FP 278	0.62	0.75	5	6	5	7	4	0	1	11	6	4	1	13	42	4	1	57	9.0	108	86	105	93	113	97
FP 278	0.72	1.00	6	8	6	6	2	0	2	10	5	3	1	10	36	3	2	47	8.5	89	98	104	91	113	97
FP 278	1.25	2.00	7	9	8	6	1	0	0	7	1	1	0	2	16	1	1	20	7.7	98	96	106	95	113	97
untreated	-	-	0	0	0	23	4	7	9	46	35	10	5	69	42	4	3	69	10	100	100	100	95	113	94
Yield of untreated (tonnes/ha)																				4.5	6.3	4.3			
Significance @ P = 0.05																				NSD	NSD	NSD	SD	NSD	NSD
LSD @ P = 0.05																				-	-	-	2.7	-	-
S.E. as % general mean																				10.0	20.4	4.6	1.7	3.0	1.8

≠ FP 278=fomesafen/terbutryn (100/400)g a.i./l as a % SC formulation;
terb/terb=terbutryn/terbuthylazine; triet/sim = trietazine/simazine.

* Dose rates (a) were based on light soils at sites 1 and 2, rate (b) on medium soil at site 3

Key: Crop Score 10 = no visible damage, 7 = acceptable damage, 0 = crop killed
Weed Score 10 = complete control, 7 = acceptable control, 0 = no control

**Crop Scores 10 for all treatments and untreated assessed on 10/5 at site 2 and on 2/6 at site 3

TABLE 3

Weed assessments, population counts for main weed species and total including other species, crop assessments, yield and maturity data for pre-emergence applications in vining peas at sites 4, 5 and 6 in 1986

Material≠	Rate* kg a.i./ha (c)	(d)	Weed Score		Weed Counts/m²										Crop Score			Yield shelled peas % untreated			Maturity Tenderometer Reading		
					P.aviculare	P. annua	Matricaria spp.	Total	U. urens	P. persicaria	B. convolvulus	Matricaria spp.	V. persica	Total									
site:			4	5	4				5						4	5	6	4	5	6	4	5	6
date:			29/6	30/6	23/5				22/5						2/5	7/5	30/5	8/7	11/7	23/7	8/7	11/7	23/7
terb/terb	1.15	1.40	10	10	0	0	0	1	0	0	0	0	0	1	9.5	9.5	10	98	104	110	97	96	92
terb/terb	2.30	2.80	10	10	0	0	0	0	0	0	0	0	0	1	8.5	9.1	10	101	111	104	97	96	89
FP 282	0.72	0.96	4.0	8.5	7	2	1	12	0	0	0	0	0	2	10	9.5	10	100	103	108	98	96	94
FP 282	0.96	1.20	8.0	9.5	1	0	0	1	0	0	0	0	0	1	9.8	9.5	10	111	97	99	98	96	90
FP 282	1.20	1.44	8.5	9.8	1	0	0	1	0	0	0	0	0	1	9.8	9.0	10	103	107	109	98	99	90
FP 282	1.92	2.40	9.0	10	0	0	0	1	0	0	0	0	0	1	9.8	8.8	10	102	104	101	95	97	93
untreated	-	-	0	0	28	9	3	44	123	34	39	31	34	334	10	10	10	100	100	100	96	95	92
Yield of untreated (tonnes/ha)																		4.0	7.8	5.1			
Significance @ P = 0.05																		NSD	NSD	NSD	NSD	SD	NSD
LSD @ P = 0.05																		-	-	-	-	3.0	-
S.E. as % general mean																		7.8	9.4	8.9	2.3	2.1	3.4

≠ FP 282=fomesafen/terbutryn 80/400g a.i./l as a 48% SC formulation;
terb/terb=terbutryn/terbuthylazine

* Dose rates (c) were used on light soils at site 4 and (d) at sites 5 and 6

Key: Crops Score: 10 = no visible damage, 7 = acceptable damage, 0 = crop killed
Weed Score: 10 = complete control, 7 = acceptable control, 0 = no control

TABLE 4 Weed assessments, population counts for main weed species and total including other species, crop assessments and population counts, yield and maturity data for herbicides applied pre-emergence and later in vining peas at sites 7 and 8 in 1987.

Material	Rate kg a.i./ha	Timing	Weed Score		Weed counts/m²						Population Pea Plants /m²		Crop Score		Yield shelled peas % untreated		Maturity Tenderometer Reading	
					S. nigrum	S. media	Total	B. convolvulus	B. vulgaris	Total								
		site:	7	8	7			8			7	8	7	8	7	8	7	8
		date:	21/6	23/6	15/5			17/5			29/4	3/5	16/5	17/5	20/7	13/7	20/7	13/7
triet/sim	1.2	pre-em	7.0	6.8	13	10	23	4	2	7	84	87	10	9.6	92	98	94	93
triet/sim	2.4	"	8.8	8.0	7	1	8	3	1	5	82	87	8.5	8.2	95	101	88	95
FP 282	1.2	"	8.8	7.8	5	11	19	3	1	5	84	88	9.5	9.4	96	106	88	97
FP 282	2.4	"	9.5	9.3	2	1	3	1	1	1	83	88	9.0	9.2	92	96	88	96
triet/sim	1.2	5% em.*	7.5	8.0	10	3	13	2	1	3	82	87	9.5	9.0	92	107	90	96
triet/sim	2.4	"	8.8	9.5	9	1	10	4	1	5	82	85	8.0	7.8	107	103	92	96
FP 282	1.2	"	9.5	9.5	4	1	5	1	1	2	82	90	8.0	8.5	96	100	87	97
FP 282	2.4	"	9.8	9.8	3	0	3	1	1	2	82	90	7.0	7.5	104	101	88	98
triet/sim	1.2	50% em.**	7.5	9.0	4	5	10	2	0	2	81	87	8.0	7.6	98	109	90	96
triet/sim	2.4	"	9.0	9.5	5	0	5	2	0	2	81	85	6.5	5.3	94	106	86	94
FP 282	1.2	"	9.5	9.8	2	0	2	0	0	1	80	81	6.5	5.3	94	103	89	97
FP 282	2.4	"	9.8	10	1	0	2	0	1	1	79	76	5.0	3.6	93	99	92	96
untreated	-	-	0	0	18	17	36	13	7	20	81	86	10	10	100	100	94	96
Yield of untreated (tonnes/ha)															5.40	6.27		
Significance @ P = 0.05											NSD	SD			NSD	NSD	NSD	NSD
LSD @ P = 0.05											-	4.5			-	-	-	-
S.E. as % general mean											4.2	3.1			7.8	7.69	4.9	2.8

≠ FP 282 = fomesafen/terbutryn 80/400g a.i./l as a 48% SC formulation;
triet/sim = trietazine/simazine

* timing was at 5-10% crop at emergence stage site 7, (5%, site 8), and ** 60-70% emerged site 7, (50%, site 8)

Key: Crop Score: 10 = no visible damage, 7 = acceptable damage, 0 = crop killed
Weed Score: 10 = complete control, 7 = acceptable control, 0 = no control

CROP TOLERANCE TO TRIFLURALIN AND ISOXABEN, APPLIED ALONE OR IN MIXTURE WITH NAPROPAMIDE, AS LATE WINTER HERBICIDE TREATMENTS IN ESTABLISHED STRAWBERRY AND RASPBERRY

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ABSTRACT

Trifluralin and isoxaben were evaluated alone and in mixture with napropamide as potential surface-applied winter herbicide treatments in established strawberry and raspberry. At rates of 2 kg a.i./ha and above trifluralin adversely affected growth and yield of strawberry and delayed cane and sucker emergence in raspberry. Isoxaben had no phytotoxic effects on either crop at up to 0.8 kg a.i./ha. The addition of napropamide at up to 4 kg a.i./ha had no influence on the reaction of the crops to either trifluralin or isoxaben. Isoxaben alone or in mixture with napropamide is recommended for further development for use in these two crops.

INTRODUCTION

Soft fruit growers are becoming increasingly interested in extending the 'spraying window' for residual soil-applied herbicides to include application during the winter months. To be effective, herbicides applied at this time should be a) not readily leached by winter rains and b) sufficiently persistent to control spring-germinating weeds. Two candidate herbicides with these characteristics, trifluralin and isoxaben, were evaluated for crop tolerance in raspberry and strawberry.

Napropamide has already been shown to be a safe and effective herbicide for winter application in various soft fruit crops, but fails to control several important species (particularly brassica weeds) and may be too persistent in the soil, at the rate recommended, for use in the final years of a crop to be followed by cereals (Clay, 1984; Lawson & Wiseman, 1987; Mathews & Wright, 1984). In an attempt to broaden the spectrum of weeds controlled and to reduce the risk of residues of high rates of napropamide in the soil affecting the growth of subsequent crops, mixtures of this herbicide and other residual herbicides are being assessed. Crop tolerance to mixtures with trifluralin and isoxaben was examined in the current series of experiments.

MATERIALS AND METHODS

Four experiments were carried out at Invergowrie on a sandy loam soil with an organic matter content of 6-8% (as determined by loss on ignition). In the two strawberry experiments, plots consisted of single matted rows of cv Cambridge Favourite, 45 cm wide by 6.75 m long, with 45 cm alleys between rows. In the two raspberry experiments, plots comprised single stooled rows of cv Glen Prosen, each 9 m long and with 2 m alleys between rows. Both plantations were established in spring 1983. Plots were arranged in randomised blocks with four replications. All except the 1986 raspberry experiment had two untreated plots in each block.

Herbicide treatments were applied using an Oxford Precision Sprayer, with fan jets delivering a spray volume of 780 l/treated ha. In 1985 treatments were applied on 5 February (strawberry) and 28 February

(raspberry), while in 1986 the relevant dates were 7 March (strawberry) and 13 March (raspberry). Herbicides were applied to a 45 cm band centred on the strawberry row and 50 cm bands on either side of each raspberry row; the herbicides were not incorporated into the soil. No other residual herbicides were applied in any of the experiments. Weeds were removed by hand-weeding and shallow hand-hoeing along the rows and by shielded spray treatment with paraquat in the alleyways.

Trifluralin (as Treflan), isoxaben (as Flexidor - both Elanco Products Ltd) and napropamide (as Devrinol - Stauffer Chemicals Ltd) were applied at the rates and in the combinations shown in Tables 1 and 3.

RESULTS

In 1985, treatments were applied in mild weather, after a relatively mild winter. Treatments made in 1986 were delayed, due to hard frost and lying snow during the greater part of February. No new growth was evident in any experiment at the time of treatment.

1985 experiments

Treatment with trifluralin at 2 kg a.i./ha and above delayed, malformed and reduced foliage development and killed a proportion of crowns in strawberry plots in spring (Table 1). This resulted in reductions in truss numbers and hence in yield of fruit. At 4 and 8 kg a.i./ha, berry size was also reduced. Continuing adverse effects of higher application rates were recorded in truss counts taken in May 1986. In raspberry, trifluralin at 2 kg a.i./ha and above delayed and stunted emergence of suckers in the alleys and between the stools (Table 2). Young stool canes were less sensitive than suckers at all but the 8 kg a.i./ha rate. There was no evidence of any translocation into fruiting canes or of long-term suppression of vegetative cane growth.

In both experiments the addition of napropamide to trifluralin had no extra effect on crop growth or yield, regardless of rate of application. Any crop injury reflected the rate of application of trifluralin included in the mixture.

1986 experiments

Treatment with isoxaben, whether applied alone or in mixture with napropamide, caused no adverse effects on any aspect of vegetative development or fruit production in either crop within the eight-fold dose range tested (Tables 3 and 4).

DISCUSSION

These experiments confirmed the wide margin of safety to napropamide of both strawberry and raspberry reported earlier by Lawson & Wiseman (1987).

Trifluralin has a similar weed control spectrum, is less persistent in the soil (Walker et al, 1985) and is considerably cheaper in comparison with equivalent rates of napropamide. It is also already recommended as a pre-plant incorporated herbicide treatment for use in maiden strawberry and raspberry plantations in the United Kingdom. There would therefore have been several advantages to be gained if trifluralin could have been substituted for, alternated with, or mixed with napropamide for use in established crops. Mixtures are currently used in several brassica crops in the United Kingdom (Walker et al, 1985). However, the greater

phytotoxicity of trifluralin to both crops and especially to strawberry, when applied as a surface treatment, makes these options much less attractive. While the early effects on cane and sucker emergence in raspberry caused no reduction in total cane production in this experiment, the possibility of such a reaction would need to be examined in detail over a range of seasons and cultivars, before any recommendations could be formulated.

Isoxaben, by contrast, showed no evidence of phytoxicity to either crop at more than three times the rate of 250 g a.i./ha likely to be recommended for use in fruit (Elanco Products Ltd - personal communication). It controls a wide range of broad-leaved weeds, but is ineffective on several grass species (Drinkall & Ryan, 1984). It is relatively persistent and brassica crops are those most susceptible to residues of isoxaben in the soil (Huggenberger & Ryan, 1985). While isoxaben should readily find a place as a fruit herbicide in its own right, the complementary nature of the weed control ranges of isoxaben and napropamide and the absence of phytotoxic reaction by the crops to tank-mixtures suggest that combinations might achieve a very wide spectrum of weed control at rates of the two constituents below those which would pose problems for succeeding crops.

ACKNOWLEDGEMENTS

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Table 1

1985 Strawberry Expt. - Crop records

Treatment	kg a.i./ha	Ground≠ cover	Truss no. /plot	Fruit yield t/ha	Berry no./ truss	Overall mean wt g/berry	Mean harvest dateØ	1986 truss no. /plot
Untreated		57	316	20.8	3.62	11.1	12.1	599
S.E. mean ±		3.1	8.1	0.58	0.149	0.17	0.39	21.2
Trifluralin	1	54	319	20.7	3.75	10.6	11.5	634
	2	46	283*	18.7*	3.78	10.7	11.8	607
	4	33***	249***	16.9***	4.10	9.9***	11.2	556
	8	20***	207***	13.9***	3.98	10.1**	11.6	520*
Trifluralin + napropamide	0.5+0.5	66	339	21.5	3.54	10.9	12.2	589
	1 + 1	60	338	20.5	3.48	10.6	12.1	650
	2 + 2	44*	298	19.6	3.73	10.7	11.9	610
	4 + 4	29***	240***	16.4***	3.96	10.3*	12.0	558
S.E. mean ±		4.4	11.5	0.82	0.210	0.24	0.55	30.0
Sig. of effect								
T linear		+++	+++	+++	NS	+	NS	++
T+N linear		+++	+++	+++	NS	NS	NS	NS
T±N (at equivalent rates)		NS	NS	NS	NS	NS	NS	NS

*, **, *** - Significantly different from untreated at the 5%, 1% or 0.1% level.
+, ++, +++ - Effect significant at the 5%, 1% or 0.1% level.
NS - not significant.
≠ - % ground cover by new leaves mid-May.
Ø - days after 9 July.

Table 2

1985 Raspberry Expt. - Crop records

Treatment	kg a.i./ha	Vigour Score (10-0) 30 April Stool canes	Suckers	Fruit yield t/ha	Yield g/metre of cane	Mean wt(g) /100 berries	Cane production /plot Total no.	Mean ht(cm)
Untreated		10.0	10.0	9.20	46.4	318	186	143
Trifluralin	1	8.9	8.2	8.94	39.4	317	188	137
	2	10.0	7.6*	9.35	44.0	303	180	137
	4	7.6	5.9***	8.76	41.4	324	187	140
	8	4.1**	4.6***	10.07	43.2	334	188	143
Trifluralin + napropamide	0.5+0.5	9.4	9.4	9.29	40.1	325	192	142
	1 + 1	8.4	8.6	9.48	44.8	309	182	135
	2 + 2	8.6	5.5***	9.77	45.2	324	177	135
	4 + 4	6.8	5.1***	9.95	43.1	328	176	139
S.E. mean ±		1.30	0.75	0.501	2.85	11.1	9.5	3.6
Sig. of effect								
T linear		++	+++	NS	NS	NS	NS	NS
T+N linear		NS	+++	NS	NS	NS	NS	NS
T±N (at equivalent rates)		NS	NS	NS	NS	NS	NS	NS

Key - see Table 1.

Table 3

1986 Strawberry Expt. - Crop records

Treatment	kg a.i./ha	Ground≠ cover	Truss no. /plot	Fruit yield t/ha	Berry no./ truss	Overall mean wt g/berry	Mean harvest dateØ	1987 truss no. /plot
Untreated		68	600	21.3	2.46	9.0	10.4	283
S.E. mean ±		2.3	26.7	1.01	0.150	0.21	0.27	13.1
Isoxaben	0.1	71	631	22.2	2.45	8.8	10.1	282
	0.2	74	631	22.5	2.51	8.7	10.0	288
	0.4	72	616	25.7	2.86	8.9	10.5	272
	0.8	71	610	22.5	2.45	9.2	10.2	256
Isoxaben + napropamide	0.05+0.5	68	562	22.5	2.76	8.8	10.2	269
	0.1 +1	78	616	24.6	2.70	9.3	11.3	302
	0.2 +2	70	537	20.9	2.75	8.5	10.0	237
	0.4 +4	76	611	25.1	2.87	9.0	10.1	278
S.E. mean ±		3.3	37.7	1.43	0.212	0.30	0.38	18.5
Sig. of effect								
I linear		NS	NS	NS	NS	NS	NS	NS
I+N linear		NS	NS	NS	NS	NS	NS	NS
I±N (at equivalent rates)		NS	NS	NS	NS	NS	NS	NS

Key - see Table 1.

Table 4

1986 Raspberry Expt. - Crop records

Treatment	kg a.i./ha	Young canes 8 July No/ stool	Young canes 8 July Mean ht(cm)	Fruit yield t/ha	Yield g/metre of cane	Mean wt(g) 100 berries	Cane production /plot Total no.	Cane production /plot Mean ht(cm)
Untreated		16.1	82.9	8.47	158	372	182	121
S.E. mean ±		1.14	2.54	0.291	4.9	5.9	7.3	2.1
Isoxaben	0.1	14.6	81.0	8.28	158	355	160	118
	0.2	13.9	83.0	8.50	165	385	174	120
	0.4	15.9	80.0	8.51	167	365	169	121
	0.8	16.8	84.0	7.98	150	376	181	121
Isoxaben + napropamide	0.05+0.5	14.9	85.8	9.01	173	376	177	120
	0.1 +1	16.6	85.5	8.01	158	382	180	124
	0.2 +2	15.0	84.0	7.87	143	366	186	118
	0.4 +4	14.9	88.3	8.57	160	377	174	123
S.E. mean ±		1.61	3.59	0.412	6.9	8.3	10.3	3.0
Sig. of effect								
I linear		NS	NS	NS	NS	NS	NS	NS
I+N linear		NS	NS	NS	NS	NS	NS	NS
I±N (at equivalent rates)		NS	NS	NS	NS	NS	NS	NS

Key - see Table 1.

THE USE OF IMAZAQUIN IN THE MANAGMENT OF PLUM ORCHARDS

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ABSTRACT

Spring treatment with imazaquin alone 0.15 and 0.30 kga.i./ha and in mixture with pendimethalin 0.15 + 1.32 kg a.i./ha were carried out in field trials in new plum orchards. The influence of these herbicides on growth and on the contents of leaf pigments were assessed together with weed control.

INTRODUCTION

Imazaquin (AC 252,214) formulated as Scepter is anew selective herbicide that can be applied for control of a wide spectrum of broadleaved weeds and some grasses (Orwick et al, 1982; Umeda et al, 1983). According to Shander (1982) the greenhouse results exibit a high degree of tolerance of soybean to post-em. applications at 63-100g a.i./ha. Imazaquin was reported as a reliable herbicide for weed control in tobacco (Lolas,1985). Prior to this paper there are no trials which reported efficacy and selectivity of imazaquin in new plum orchards.

The effect of imazaquin alone and in combination with pendimethalin on weeds, on the growth of the newly planted plum trees and on the contents of leaf pigments is reported.

MATERIALS AND METHODS

Experiment 1

During 1985-87 field trials were carried out on light soils (o.m. 1.98%, pH 5.3). One, two and three years old plum trees cvKustendilska were used. The experiment was laid down after the standard method of Konstantinov (1952), replicated three times, the area of test plot being 35 m^2 (7 x 5). Imazaquin was used at 0.15 and 0.30 kg a.i./ha. The treatments were applied on 15 May 85, 13 May 86 and 6 June 87. Weed control was assessed 40 and 90 d during 85, 86 and 30 d in 87 after spraying.

Experiment 2

Field experiment were conducted in 1986-87 on a grey forest soil (o.m. 1.87%, pH 6.2). One and two year old trees cv Kustendilska, Stanley, Strinava and Gabrovska were used. All treatments were applied on 23 April 86 and 22 April 87 to plots of 20 m^2 (5 x 4). The trial was randomized block design with four replicates. Imazaquin 0.15 kg a.i./ha alone and in mixture with pendimethalin (Stomp 33% a.i.) 0.15 + 1.32 kg a.i./ha were used. Weed control assessments were made on 4 June 86 and 28 May 87. The herbicides were applied each year to the same area with a hand sprayer Solo 455E-ZESSUR at a volume rate 800 l/ha. The soil was cultivated in advance. Weed control was assessed

by counting the individual weed species present in a 1 m^2 area in each plot. Crop tolerance was evaluated visually at intervals using the EWRS scale 0-9 (9-healthiest control; 7-obvious damage; 5-50% growth inhibition; 3-severe leaf damage; 1-all leaf dead; 0-plant dead). Trunk diameters (c. 30 cm from ground level) and growth of four branches of each tree were measured at the end of October during 85 and 86. The effect of herbicides on chlorophyll a, chlorophyll b and carotene content in the leaves was determined 30 and 60 d after treatment by a spectrophotometer using wave lenghts of 663, 664 and 452 nm respectively.

RESULTS AND DISCUSSION

Weed control

TABLE 1

Effect of imazaquin on the control of annual weeds

Weed species	Mean percent control					
	1985		1986		1987	
	*0.15	0.30	0.15	0.30	0.15	0.30
Amaranthus retroflexus	85	93	93	100	100	100
Chenopodium album	88	100	91	100	100	100
Daucus carota	87	100	-	-	-	-
Galinsoga parviflora	91	100	-	-	-	-
Polygonum lapathifolium	80	90	-	-	-	-
Setaria viridis	90	95	90	100	100	100
Sinapis arvensis	60	80	67	84	-	-
Mean no. of weeds m^2 in untreated plots						
grasses	20		30		30	
broadleaved	71		40		32	

*Rate of imazaquin kg a.i./ha

The data from Table 1 and 2 shows clearly that imazaquin performed well in reducing the naturally occuring weed population by 60-95%. Complete control of Amaranthus retroflexus, Chenopodium album, Daucus carota, Galinsoga parviflora and Setaria viridis was achieved.

A combination of imazaquin with pendimethalin gave better control of weeds than imazaquin applied alone at rate 0.15 kg a.i./ha. Imazaquin 0.15 + pendimethalin 1.32 kg a.i./ha provided seson long weed control (Table 2).

TABLE 2

Effect of imazaquin alone and in combination with pendimethalin on the control of annual weeds.

Weed species	Mean percent control			
	1986		1987	
	*0.15	0.15+1.32	0.15	0.15+1.32
Amaranthus retroflexus	93	100	100	100
Fumaria officinalis	87	97	100	100
Setaria viridis	90	97	100	100
Sinapis arvensis	85	100	-	-
Stellaria media	60	80	-	-
Xanthium strumarium	80	100	80	95
Mean no. of weeds m^2 in untreated plots				
grasses	30		25	
broadleaved	50		30	

*Rate of imazaquin and pendimethalin kg a.i./ha

Plum growth

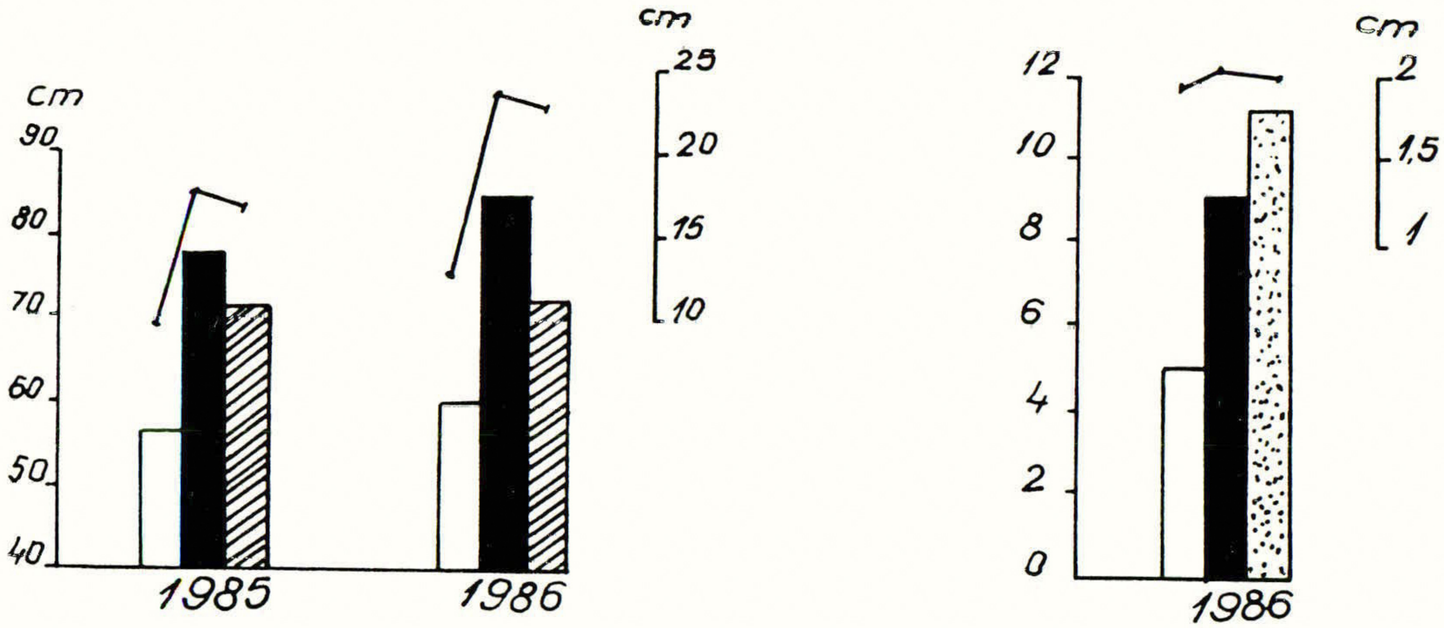
The observation completed of plum trees growth indicated that no tree injury had occured following treatment with either imazaquin alone or in combination with pendimethalin. In addition no phytotoxic effect on leaves had occured with either treatment.

A significant effect of herbicide application due mostly toincreasing of growth on tree receiving soil applications of imazaquin o.15kg a.i./ha alone as well combination with pendimethalin 1.32 kg a.i./ha, has been observed (Figure 1). Imazaquin at rate 0.30 kg a.i./ha, in comparing with 0.15 kg a.i./ha, reduced the branch lenght by 6 cm during 1985 and 12 cm in 1986 (Exp. 1).

The trunk diameter of the plum tree grown on two years treated soil with imazaquin 0.15 kg a.i./ha was significantly more than that of untreated control (Figure 1).

Pigments content

Trials were carried out to determine the influence of imazaquin alone and in combination with pendimethalin on the content of the pigments in plum leaves. Analysis of the data (Table 3 and 4) shows that imazaquin alone or in combination with pendimethalin do not exert any essential influence on the chlorophyll or carotene contents of the plum leaves.



control imazaquin 0.15 kg a.i./ha imazaquin 0.30 kg a.i./ha

imazaquin 0.15 + pendimethalin 1.32 kg a.i./ha trunk diameter

Fig. 1. Effect of imazaquin alone and in combination with pendimethalin on growth of brunches and trunk diameters

TABLE 3

Effect of imazaquin on content of pigments in plum leaves mg/1 g fresh wt.

Year	Rate kg a.i./ha	D A T*					
		30			60		
		Chlorophyll a	Chlorophyll b	Carotene	Chlorophyll a	Chlorophyll b	Carotene
1985	Control	0.612	0.340	0.157	0.603	0.374	0.146
	A*0.15	0.602	0.277	0.111	0.522	0.365	0.128
	A 0.30	0.522	0.245	0.108	0.494	0.210	0.145
1986	Control	0.570	0.552	0.117	0.496	0.560	0.115
	A 0.15	0.516	0.496	0.087	0.458	0.545	0.090
	A 0.30	0.503	0.434	0.061	0.445	0.525	0.086
1987	Control	0.622	0.540	0.212	-	-	-
	A 0.15	0.542	0.532	0.175	-	-	-
	A 0.30	0.523	0.500	0.148	-	-	-

* D A T - Days after treatment
* A - imazaquin

TABLE 4

Effect of imazaquin alone and in combination with pendimethalin on content of pigments in plum leaves mg/1 g fresh wt.

Year	Herbicides rate kg a.i./ha	D A T*					
		30			60		
		Chlorophyll a	Chlorophyll b	Carotene	Chlorophyll a	Chlorophyll b	Carotene
1986	Control	0.483	0.399	0.173	0.523	0.500	0.101
	A*0.15	0.535	0.496	0.140	0.458	0.602	0.150
	A 0.15 B*1.32+	0.523	0.500	0.139	0.540	0.571	0.116
1987	Control	0.665	0.486	0.170	0.686	0.478	0.212
	A 0.15	0.564	0.484	0.200	0.540	0.571	0.185
	A 0.15 B 1.32+	0.546	0.453	0.155	0.503	0.500	0.143

* D A T - Days after treatment
* A - imazaquin
* B - pendimethalin

The results of this work shown that imazaquin 0.15 kg a.i./ha and imazaquin 0.15 + pendimethalin 1.32 kg a.i./ha is a promising herbicide for pre-em. control of annual grass and broadleaved weeds in managment of plum orchards.

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ALLELOPATHY OF WEEDS IN VINEYARDS

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ABSTRACT

The weed flora of vines has changed considerably due to the regular use of fertilizers, herbicides and mechanical cultivation methods. According to observation and investigation we suggest that allelopathy plays an important role in the control of weed succession of vineyards. These effects have favoured some weeds such as Agropyron repens, Cynodon dactylon, Digitaria sanguinalis, Cirsium arvense and Conyza canadensis. Weed control approaches to allelopathy was studied in our examinations. D. sanguinalis and C. canadensis exert sufficent allelopathic activity against some vineyards weeds to eliminate them from weed succession of vineyards. Chlorogenic and sulfosalicylic acids, allelochemicals of D. sanguinalis, exert their phytotoxicity on photosynthesis according to fluorescence induction measurements.

INTRODUCTION

Allelopathy is a fast broadening area of chemical ecology and according to our observations, it seems to play an important role in control of weed succession of vineyards /Mikulás, 1976; Mikulás, 1981/, acting together with various human interventions.

Current evidence indicates allelopathic inhibition most often results from the combined action of several different chemicals. A specific allelochemical may be present at a concentration below its growth inhibition threshold and still affects growth. Several combinations of allelochemicals have been shown to have either additive or synergistic action /Einhellig, 1987/.

An important aspect concerning allelopathy is that its effect depends on chemical compound being added to the environment. Evidence indicates that allelopathic compounds are released from plants by volatilization /Elakovich, 1987/, exudation from roots /Stevens and Tang, 1985/, leaching from plants or residues by rain /Kanchan and Jayachandra, 1980/, or decomposition of residues /Chou and Patrick, 1976; Rice, 1984/.

Allelochemicals, chemical compounds produced by a plant species may operate directly on another plant species, indirectly on its symbiotic organisms, or through modification of the ecosystem.

The role of human activity may be surprising when using additional chemicals to the plant ecosystem. Mikulás /1976/ found heavy Sorghum halepense infestation on maize fields with

soils of high seed content of Amaranthus retroflexus but with no plants of this species present. After destroying S. halepense the fields became covered by A. retroflexus in more than 80 % of total but with only few seedlings of S. halepense.

The first part of our work reported here was to investigate biological effects by means of laboratory test methods. Most workers using biotests for allelopathic investigations employ specially sensitive plant species as indicator plants. In this study, however, both donor and acceptor plant species were chosen from the same ecosystem. C. arvense, C. canadensis and D. sanguinalis were used as donor weed species examined in such biological situations during this study. A. retroflexus, Ambrosia elatior, D. sanguinalis, Chenopodium album, Lepidium sativum and C. canadensis appeared as test plant species. Extracts of different plant parts and phenolic acids found in such extracts were used for these investigations.

The second area of study was the investigation of possible mechanisms affecting germination and plant development. Ferulic, vanillic and p-coumaric acids can depress chlorophyll content /Einhellig and Rasmussen, 1979/ and extracts or leachates from allelopathic weeds may also depress chlorophyll /Kanchan and Jayachandra, 1980; Colton and Einhellig, 1980/. It follows therefore that such reactions would inhibit photosynthesis. Among different possible approaches the investigation of the effects on the photosynthetic apparatus /photosystems/ was chosen for this study and this was made by means of fast fluorescence induction, a dynamic instrumental method. There are several publications in this area /Einhellig and Rasmussen, 1979; Colton and Einhellig, 1980; Moreland and Novitzky, 1987/ however further efforts are needed to understand possible roles of allelochemicals at the biochemical level.

The third part of our study involved the application of weed-weed allelopathic interactions in manipulated agricultural ecosystem. Investigations using either whole plants in the fields or allelochemicals produced by means of microorganisms or plant tissue cultures /Bu'Lock et al., 1955; Norton and Towers, 1986/ were employed.

MATERIALS AND METHODS

Plant materials

Weed plants were grown under field condition near Kecskemét, Hungary. The plants were harvested at several stages of growth and broadleaved plants separated into leaf, stem and root tissue. The grass plant D. sanguinalis was separated into leaf and root tissue.

Seed germination

Effects on seed germination were evaluated with extracts of dried tissue prepared by shaking 10 g of ground tissue with 100 ml distilled water for 48 h at 25 °C. The extracts were filtered and 10-fold dilutions prepared. A hundred seeds were placed in Petri dishes containing the test substance. Germination was registered after 7 d at 25 °C.

Growing test

Seeds of L. sativum were germinated in Petri dishes containing water extracts of D. sanguinalis at 20 °C. Lengths of the roots were measured after treatment for 72 h.

Field experiments

Weed supression effect of C. canadensis and D. sanguinalis desiccated with paraquat in vineyards plots /10m² / was examined. Percentage emergence of eight vineyards weeds in response to residues of C. canadensis and D. sanguinalis was also investigated.

Fluorescence induction measurements

In order to study the effect of allelochemicals of D. sanguinalis on photosynthesis detached leaves of C. album were treated with chlorogenic acid 10^{-4} M, sulfosalicylic acid 10^{-4} M and water extract /30 mg/ml dry wt/vol/ respectively.

Fluorescence induction measurements on excised leaves were carried out with a laboratory built apparatus after a 30 min dark adaptation /Lehoczki et al., 1984/. A xenon lamp of 650 W was used to produce the actinic beam. Blue actinic light of 5 mW/cm² intensity was transmitted by a Schott BG 12 filter /Schott, Mainz, FRG/. The opening of the shutter was completed within 2 milliseconds /ms/. Fluorescence emitted at 90 °C was detected with a photomultiplier through a red SIF 675 interference filter /VEB C. Zeiss, Jena, GDR/ and recorded with a transient recorder. The dwell time between 1024 samplings was 1 ms and 300 ms in the fast and slow fluorescence induction measurements, respectively. In each experiment, 16 independent curves were recorded and averaged automatically with an averaging unit attached to the transient recorder.

RESULTS

Germination and growing tests

The germination of the important broadleaved weed of vineyards, A. retroflexus in response to extracts is shown in Table 1.

TABLE 1

Germination response of Amaranthus retroflexus seeds to water extracts of Conyza canadensis, Digitaria sanguinalis and Cirsium arvense

Weeds	Germination as percentage of control					
	Undiluted			1/10 Dilution		
	Leaf	Stem	Root	Leaf	Stem	Root
Conyza canadensis	35	82	63	47	105	82
Digitaria sanguinalis	-	-	11	-	-	24
Cirsium arvense	27	-	9	39	-	17

Water extracts of C. canadensis leaves, D. sanguinalis roots and C. arvense roots are sufficiently strong to inhibit germination of A. retroflexus. Root extracts of C. arvense and D. sanguinalis proved to be particularly efficient. As shown in Table 2 C. canadensis also displays an inhibitory effect on its own seed germination.

TABLE 2

Autotoxic effect of Conyza canadensis crude extracts on its own germination

Tissue	Germination as percentage of control		
	Undiluted	1/10 Diluted	1/100 Diluted
Leaf	5	12	28
Stem	34	58	97
Root	12	26	51

The growth inhibitory effect of D. sanguinalis on L. sativum is presented in Table 3. An increase in concentration of extracts caused a reduction in root growth of L. sativum.

TABLE 3

Effect of D. sanguinalis root extracts on growing of L. sativum

Dry matter content of extracts /ug/ml/	Root length of L. sativum
0.0	46.4
1.9	42.7
3.8	38.5
7.5	36.3
15.0	25.0
30.0	19.0
37.5	19.0

Field experiments

Residues of D. sanguinalis and C. canadensis produced by desiccation can act as weed supressors in vineyards /Table 4/.

TABLE 4

Weed supression of C. canadensis and C. sanguinalis in field plots of vineyards

Weed species	Reduction of weed dominance /%/	
	with C. canadensis	with D. sanguinalis
Amaranthus retroflexus	45	92
Chenopodium album	52	94
Conyza canadensis	90	NS
Digitaria sanguinalis	75	NS
Portulaca oleracea	100	98
Polygonum aviculare	50	75
Senecio vulgaris	63	NS
Setaria viridis	71	81

Effects on photosynthesis of phenolic type allelochemicals

It was observed that D. sanguinalis exerts sufficient allelopathic activity against some vineyards weeds to eliminate them from weed succession. Chlorogenic, isochlorogenic and sulfosalicylic acids were identified in whole plant extracts /Rice, 1984/. In the study the possible mechanism of action of these allelochemicals was investigated. The photosynthetic electron transport capacities of the triazine resistant C. album in the presence of chlorogenic acid, sulfosalicylic acid and whole plant extract of D. sanguinalis by means of fast fluorescence induction were characterized. It can be used as a sensitive assay of PS-II inhibitors /like phenol type herbicides/ on photosynthesis. These investigations revealed that chlorogenic acid, sulfosalicylic acid and water extracts of D. sanguinalis caused alteration in the fluorescence characteristics kinetics of C. album /Fig.1/.

The values of the ratio $F_m - F_i / F_m$ calculated from the fluorescence induction curves were 0.41 $\pm$ 0.03 and 0.010 $\pm$ 0.004 for the untreated and chlorogenic acid treated plants, respectively.

DISCUSSION

In the agroecosystem there are two types of chemical interference from natural sources such as allelochemicals and synthetic sources such as herbicides /Einhellig, 1987/. According to our results, and those of others /Rice, 1984/, it was concluded that favoured weeds of vineyards have an allelopathic effect. It appears that C. canadensis, D. sanguinalis and C. arvense exert their phytotoxicity in germination and plant development. The inhibitory effect against weeds of vineyards was observed

in field experiments. Allelochemical action of C. canadensis and D. sanguinalis can synergize with the activity of herbicides. These weeds were selected by continued triazine herbicid treatment. Atrazine resistance or tolerance appeared. If C. canadensis and D. sanguinalis are destroyed by a contact herbicide its residues will act as an allelochemical and show inhibitory effect on its own seedlings or other weeds. Reduced or no tillage operation will result in increase of levels of allelochemicals. C10-polyacetylenes as allelopathic substances of C. canadensis were identified by Kobayashi et al. /1980/.

The effect of phenolic type allelochemicals on photosynthesis was investigated via fluorescence induction measurements. It is known that fast fluorescence induction gives information about the functioning of PS-II units, the redox state of the first stable quinone type electron acceptor of PS-II /Q/ and the rate of electron flow between Q and the plastoquinone /PQ/ pool, where the phenol type herbicides also act to prevent the electron transport from Q_A to Q_B without affecting the reduction of Q_A. The calculated ratio $F_m - F_i / F_m$ may be a useful measure for estimation of the rate of Q reoxidation. The values of the ratio $F_m - F_i / F_m$ were different for the control and treated plants indicating that the rates of Q_A-reoxidation was inhibited by allelochemicals. From these results, it was concluded that allelochemicals of D. sanguinalis act on photosynthesis.

In conclusion it is suggested that allelochemicals of some weeds in combined action with herbicides have a role to play in weed control strategy of vineyards.

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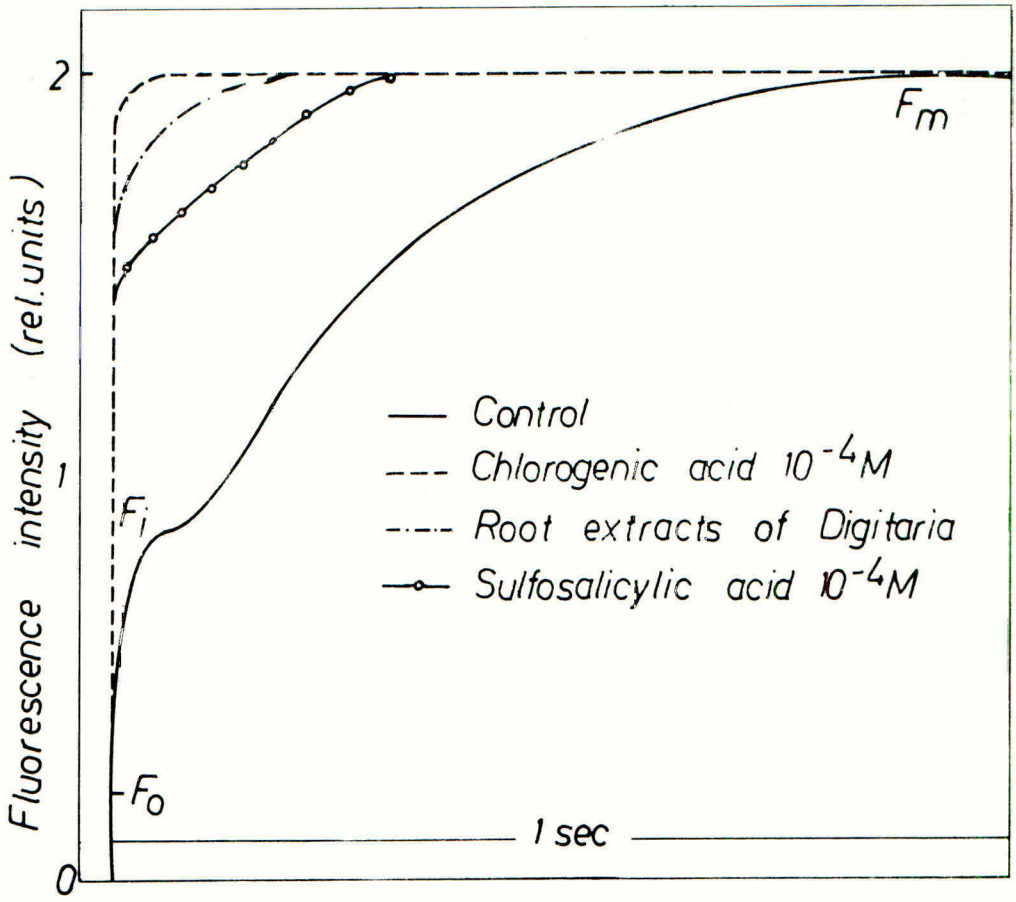

Fig.1. Fluorescence induction curves of excised Chenopodium album infiltrated with chlorogenic, sulfo salicylic acids 10^{-4} M and water extracts of Digitaria sanguinalis roots for 6 h.

Legend: F_o: initial fluorescence intensity;
F_i and F_m: fluorescence intensities at 40 ms and 1 s, respectively.

EXTENDED AVAILABILITY OF PROPACHLOR FOR HORTICULTURAL CROPS

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ABSTRACT

Extended delivery forms could be very useful in manipulating the availability of soil applied herbicides giving less crop damage early in the season and prolonging the period of weed control. Leaching and other losses may be reduced. This paper describes the design of kraft lignin-based formulations of propachlor which modify and extend the availability of the active agent. The characteristics of these formulations and their release profiles in laboratory and soil environments are assessed. The bioactive availability of the herbicide in soil was shown for the lignin formulations to be more than 9 weeks when compared with less than 3 weeks, under experimental conditions, for conventional methods. Manipulation of soil concentrations could improve the utilization of propachlor, and other herbicides, in horticultural crops.

INTRODUCTION

Many soil-applied herbicides suffer losses in use due to breakdown, leaching or evaporation. Persistent herbicides, on the other hand can cause problems of leaching, pollution and carry-over effects in following crops. The availability of soil-applied herbicides can be manipulated by the use of controlled or slow release systems to provide localised soil concentrations of the herbicide.

The residual herbicide, propachlor, provides an excellent example of a short-lived herbicide with numerous minor crop applications including brassicas, leeks, onions and strawberries. To provide protection for these weed-susceptible crops throughout the growing period, expensive herbicide programmes, often including propachlor applied pre-emergence, are needed (e.g. in the case of leeks, Wiseman and Lawson, 1976). In the swede crop where long-lasting herbicides are needed, a herbicide programme is expensive in relation to the value of the crop. An additional problem is crop injury if rain follows applications of propachlor.

Improving the availability of propachlor could also help overcome the critical timing of application in relation to weed emergence, as control by propachlor after weed emergence is poor.

Thus, propachlor, as a soil-applied herbicide, could be improved by formulation to regulate its availability to crop and weeds. Current approaches to achieve this, and particularly for another chloroacetanilide, alachlor, have been based on microencapsulation (Tsuji, 1987) but polymer matrix methods offer advantages for granule formulations (Kydonieus, 1980). The biological and physical properties of alkali lignins (Wilkins, 1984a) can make these byproduct polymers useful as formulating bases for herbicide granules, as shown with 2,4-D for forest weed control (Wilkins, 1981), and also for simazine (Dellicolli, 1977).

The purpose of the work reported here was to investigate the preparation of lignin-based granule formulations of propachlor and to evaluate these for controlling the availability of the active ingredient, with potential for horticultural crops.

MATERIALS AND METHODS

Preparation of the lignin formulations

The kraft lignin matrix was prepared by mixing under melt conditions (Wilkins, 1984b). Technical grade propachlor was melted in an aluminium dish at 60-65° and powdered pine kraft lignin (Indulin AT, Westvaco Inc.) was added with stirring to produce a uniformly plasticised mix. This was formed and cooled to make a sheet (1mm thick) which was then cut into discs (10mm diameter) or cooled and granulated (0.5-1.0mm). Formulations were prepared containing from 20 to 50% propachlor.

Study of release kinetics

To determine the possible mechanisms involved in release of propachlor, discs of the formulation with known surface area and weight were prepared. Five discs of each formulation were weighed and placed in 200ml static distilled water at 30± 1°C. The water was sampled (10ml) daily and then at every 5 days, with the volume maintained at 200ml by adding fresh water. The released propachlor was estimated at each time up to 60 days by UV spectroscopy of the sampled water at 260 nm. The reliability of this method was checked by analysing the remaining propachlor content of the discs by (a) weight loss of the dried discs, and (b) extracting the disc with acetone, and separating the propachlor from the lignin on alumina, using dichloromethane followed by ethyl acetate-hexane mixtures. The fractions were combined, the solvents removed and the extracted propachlor quantified by weight.

Persistence of availability in soil

The biological activity of propachlor in a friable soil of low organic matter was measured by using a bioassay based on the emergence of annual meadow-grass (*Poa annua*) seedlings. The response of *P. annua* to propachlor was determined by placing seeds in soil (200g dry weight) in pots treated with different levels of propachlor, replicated seven times. The pots (7.5cm diameter) were maintained in the greenhouse at 20°C, 75% relative humidity and continuous light. At 7 days, counts were made on the number of emerged seedlings more than 4mm long.

In a similar way the persistence of action in soil of the lignin formulations were evaluated. The treatments were:

10.6mg technical grade propachlor
26mg 40% propachlor-lignin granules (containing 10.6mg a.i.)
52mg 20% propachlor-lignin granules (containing 10.6mg a.i.)
0 control (no propachlor)

The granules were lightly mixed into the surface of the soil in the pots. Technical grade propachlor in acetone solution was pipetted evenly onto the soil and mixed in. Pre-soaked seeds (20 per pot) of *P. annua* were placed into the soil surface and emergence counts made 7 days later. Any seedlings that had emerged were removed and the pots were resown. This was repeated until the end of the experiment. The moisture content of the soil was maintained at 60% of field capacity, without causing any drainage. Treatments were replicated 5 times and placed in a randomised block design.

RESULTS

Compatability in formulation with lignin

The ability of the active agent to dissolve or plasticise the kraft lignin can be predicted from a comparison of their respective solubility parameters. Using Small's constants (Small, 1953), the calculated solubility parameter for propachlor is 12.35 (density = 1.249, 20°). This is close to the estimated solubility parameter for pine kraft lignin of 12.8 (Roberts, 1974). In fact, propachlor was compatible with kraft lignin and readily formed a glassy matrix from 50 down to 20% active ingredient.

Release from disc formulations into water

The release of propachlor into distilled water is presented in Figure 1. The release profile generated for each of the formulations is

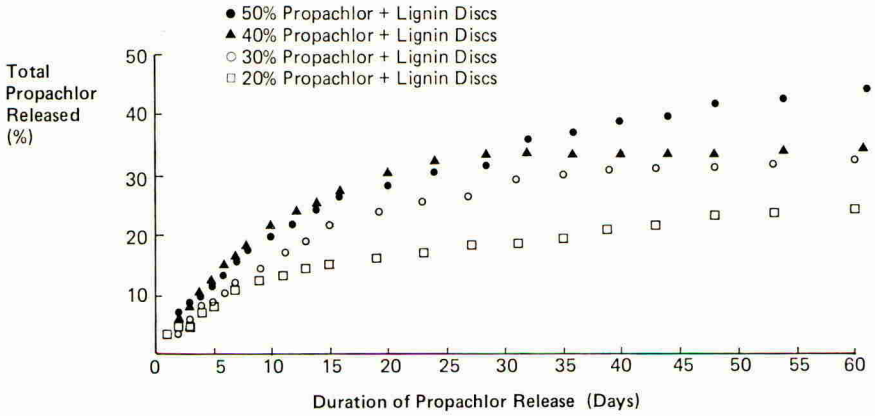

Figure 1. The cumulative release of propachlor from kraft lignin discs into static distilled water

typical where diffusion within the matrix is the rate controlling step providing an initial rapid rate followed by a gradually decreasing release. This is shown for the 50% formulation in Figure 2, which following the initial "burst effect", was releasing about 0.3% or 0.15mg/day under the test conditions.

Persistence of propachlor availability from lignin granules in soil

The biological persistence of propachlor from lignin granules was compared with a freely available application using a P. annua bioassay conducted in pots. The inhibition of emergence of seedlings over a 9 week period is shown in Figure 3. Both lignin granular formulations gave good weed control throughout the test period. After 21 days, there was significant ($p = 0.05$) difference between the means for the lignin granules and the technical propachlor application. Although the experiment was terminated at 63 days, good weed control is likely to persist further.

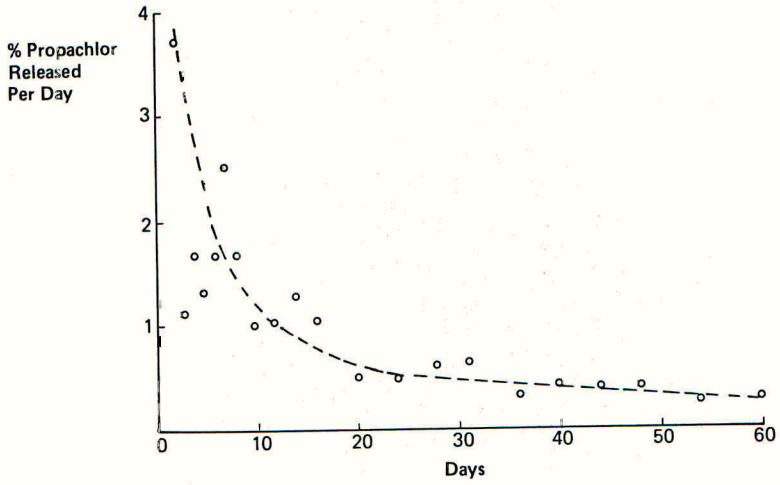

Figure 2. The rate of release (percent per day) of propachlor from a 50% disc formulation into static water

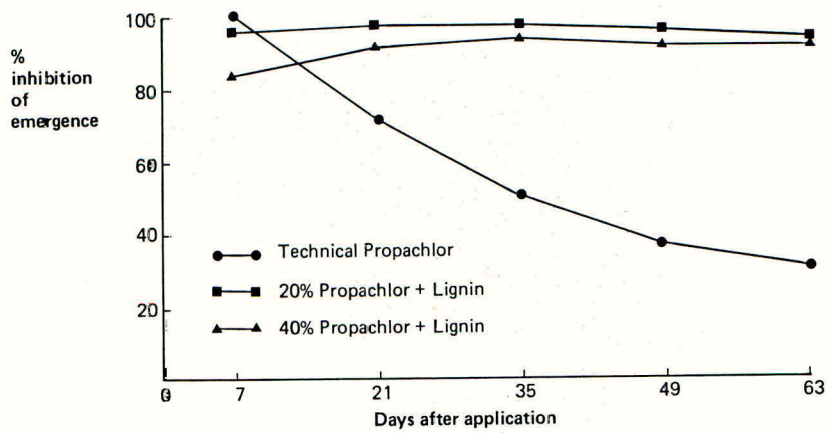

Figure 3. Inhibition of Poa annua emergence after soil treatment with different propachlor formulations.

Estimation of freely-available propachlor in soil

The results of the standardization of the P. annua emergence bioassay are represented in the equation (I). This is a regression of probit percent inhibition of emergence against log dosage of propachlor per pot. This regression allows estimation of the biologically-active amounts of herbicide available in the soil (mg per pot) using the relationship:

$$\text{Probit \% inhibition} = 2.75 + 2.06\ (\log \text{dose} + 1) \qquad (I)$$

with a correlation coefficient of 0.9999 and where the dosage causing 50% inhibition was 1.23mg per pot (95% confidence limits 0.71-2.11mg).

The amounts of freely-available propachlor in the soil for the three treatments are thus estimated as follows (Table 1).

TABLE 1

Amount of biologically-available propachlor in the surface soil at various times after application.

treatment	propachlor concentration, mg per pot (equivalent g/m^2)				
	days after application				
	0-7	14-21	28-35	42-49	56-63
tech. grade propachlor	10.58 (2.40)	1.76 (0.40)	1.22 (0.28)	0.91 (0.21)	0.76 (0.17)
40% propachlor-lignin	2.06 (0.47)	2.26 (0.51)	2.31 (0.52)	2.26 (0.51)	2.26 (0.51)
20% propachlor-lignin	2.31 (0.54)	2.38 (0.54)	2.33 (0.53)	2.28 (0.52)	2.28 (0.52)

Applied dosage: 10.58mg/pot propachlor. Area of soil surface in pot: 4.4 x 10^{-3} m^2. Estimated half-life of propachlor under test conditions: 14 days.

DISCUSSION

The use of lignins as controlled release formulating agents exploits their protective properties against light, biodegradation, water and evaporative loss. Propachlor is a short lived herbicide and can be easily formulated with kraft lignin without the need of processing aids. This is facilitated by the relatively high melting point of the active ingredient (67-76°C), in contrast to its analogue, alachlor, which melts at 40-41°C. However, the preliminary formulations described here are experimental only, with many practical requirements not considered.

The use of disc or sheet formulations for studying the release kinetics allows consideration of surface area relative to the size and is not intended for practical soil application, although there may be appropriate applications for tablet size herbicide dispensers, particularly for weed control in potted ornamentals (Ruizzo et al., 1983). Also, there are many different regimes for evaluating release rates in the laboratory and the use of static water has provided useful information for lignin systems in previous studies (Wilkins, 1984b). In practice, different rate controlling steps may operate depending on the nature of the microenvironment of the dispenser. Electron micrographic studies of the

depleted propachlor-lignin matrix indicated a progressive extension of a porous structure with propachlor release, suggesting a dissolution-diffusion process operating.

In the soil experiments the granular controlled release formulations showed no decline in high levels of control of P. annua for 9 weeks. Although high equivalent dose rates of propachlor were used, the technical grade application only gave control for less than 3 weeks. The release from the granules was clearly higher than from the discs used in the water immersion tests but none-the-less demonstrated extension in the active life of the herbicide. Thus the results of these preliminary pot tests indicate the potential for unsophisticated extended release formulations for propachlor, and other soil-applied herbicides and their possible application to a range of horticultural crops.

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SESSION 7C

BIOLOGY OF WEED SEED

CHAIRMAN DR R. W. SNAYDON

SESSION ORGANISER DR P. D. PUTWAIN

INVITED PAPERS 7C-1 to 7C-4

THE INTERACTION OF ENVIRONMENTAL FACTORS ON SEED DORMANCY

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ABSTRACT

The main environmental factors which trigger the germination of small weed seeds are light, alternating temperatures and, in some cases, chilling (stratification) and nitrate ions. Frequently there are strong positive interactions, especially between light and alternating temperatures so that most seeds in a population may require both. White light is usually promotory at photon doses up to about 10^{-1} mol m^{-2} d^{-1}, but inhibitory above this level. Any light filtered through a leaf canopy tends to be inhibitory because of the high far-red/red ratio. The stimulation of alternating temperatures generally increases with increase in amplitude, decrease in mean temperature, and increase in number of cycles (days). These properties of light, temperature, and their interactions largely explain seed responses with respect to position (in relation to soil profile and the vegetation cover) and season.

INTRODUCTION

Many weeds are opportunists: most of the individuals in a field at any one time are dormant seeds waiting for conditions to arise when they can germinate with some probability of developing into mature plants capable of producing more seeds. To this end seeds need to germinate at the right time in the right place. The right time usually means germinating when growth of vulnerable young seedlings would not occur under stressful conditions (e.g. in the winter in cool temperate latitudes or in the dry season in Mediterranean climates and the tropics). Since many weed seeds are small, the right place usually means at or near the soil surface, otherwise food reserves would run out before emergence. But germination at the soil surface could still be inappropriate if the ground already supports a luxuriant vegetation which would provide more shade and competition than might be healthy for a young seedling. Germination at the soil surface could also be inappropriate if the seed is exposed to bright sunshine which could rapidly dry the surface.

The main purpose of this paper is to identify the main environmental factors which determine that seeds respond appropriately, to characterize these factors in more detail, and to illustrate the importance of interactions between them.

ENVIRONMENTAL STIMULI AND THEIR CHARACTERISTICS

Although the gaseous composition of the soil atmosphere may have some influence in the deeper layers of the soil or under water-logged conditions, the main factors affecting germination in the upper layers of agricultural soils appear to be temperature and light (Roberts, 1972).

Temperature

The effect of temperature differs depending on whether the seed is wet or dry. Under dry conditions seeds tend to lose dormancy at a rate which increases semi-logarithmically with increase in temperature (Roberts, 1988);

such responses may be important during hot dry seasons although, of course, the seeds would not be able to germinate until the soil is subsequently re-moistened. However 'dry after-ripening', as it is called, has not yet been adequately studied in weed species.

When seeds are moist, as most buried seeds are for most of the time in many climates, the responses to temperature are quite different. Either excessively warm or excessively cool conditions may induce dormancy (Bewley & Black, 1982). On the other hand, many temperate species show a stratification response in which cool temperatures (typically -5 to 15 C) stimulate germination, providing the seeds subsequently experience warmer temperatures. An example is shown in Fig. 1 for *Rumex obtusifolius* which also shows that the ability to germinate depends on the duration of the treatment. Furthermore in this species, and probably others, the proportion of the population able to germinate may decrease after prolonged treatment because of the induction of secondary dormancy at a rate which increases with increase in temperature.

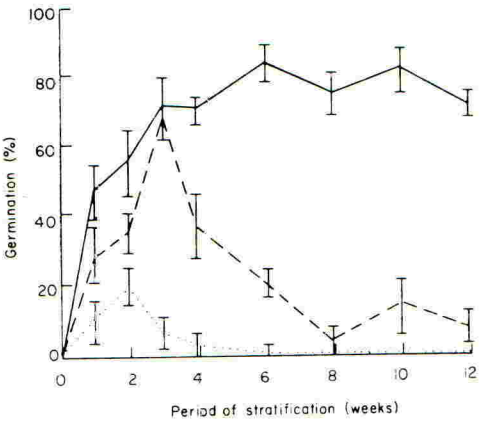

Fig. 1. Germination of *Rumex obtusifolius* after 4 weeks at 25 C in the light following stratification for various periods in the dark at 1.5 C——, 10 C– – –, or 15 C·····. (From Totterdell & Roberts 1979.)

Another common factor affecting the germination of small seeds is the stimulatory effect of alternating temperatures. The stimulation could, conceivably, be due to a number of characteristics. Any of these may be classified as primary if it can be altered independently within an experiment. A secondary characteristic is determined by more than one primary characteristic and cannot be altered, therefore, without altering a primary characteristic. If it is intended to hold a secondary characteristic constant within an experiment, then if one of the primary characteristics which determines its value is altered, this has to be compensated by confounding it with a change in another determining characteristic. This is made clear in Fig. 2 which shows, for example, that amplitude is a secondary characteristic dependent on the primary characteristics of minimum and maximum temperature. It is only possible to alter minimum temperature, while holding amplitude constant, by confounding it with a compensating alteration in maximum temperature. For reasons such

as this it is impossible to design experiments which unequivocally determine which characteristics of alternating temperatures are controlling germination responses.

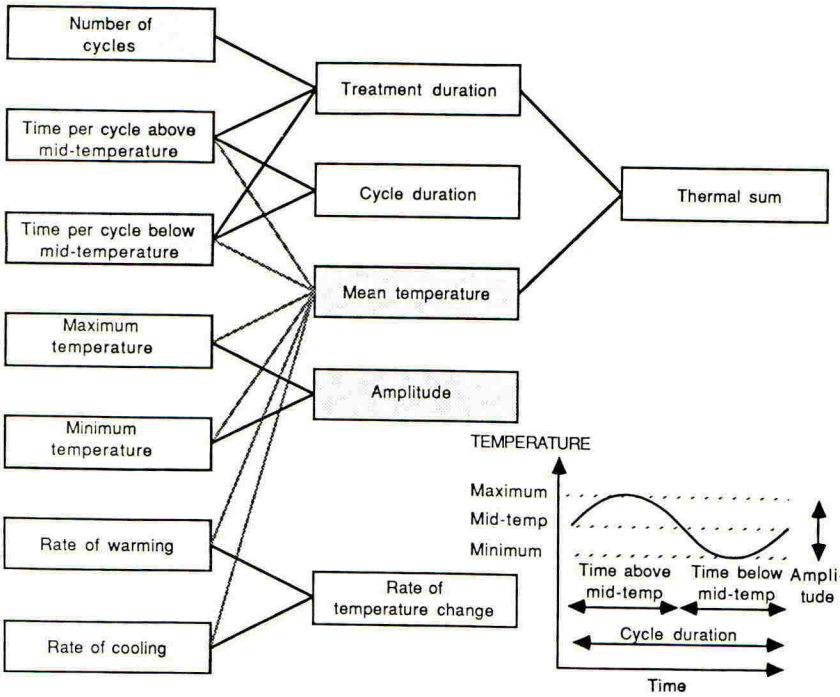

Fig. 2. Characteristics of alternating temperatures which might stimulate germination. Those characteristics thought to be important are shaded. Primary characteristics are shown in the left-hand column.

We believe the best solution to the problem is to carry out large experiments which include variations in many of the characteristics and to search for the simplest model which explains the results. Fig. 3 shows an interim stage in the process using experimental data on *Chenopodium album* obtained from a two-way thermogradient plate. Many responses are normally distributed amongst the seeds of a population and accordingly it is usually helpful to transform germination percentages to probit (or present the data on a probability scale, as has been done in Fig. 3). It then emerges that in constant temperatures there is a positive linear relation between temperature and probit percentage germination up to an optimum value, above which there is a negative linear relation. It is only at mean temperatures less than this constant-temperature optimum that alternating temperatures are stimulatory. In this region the stimulatory effect of alternating temperatures increases with increase in amplitude, nd the optimum mean temperature of alternating temperature regimes decreases with increase in amplitude. Thermoperiod (the relative time spent in the warmer and cooler

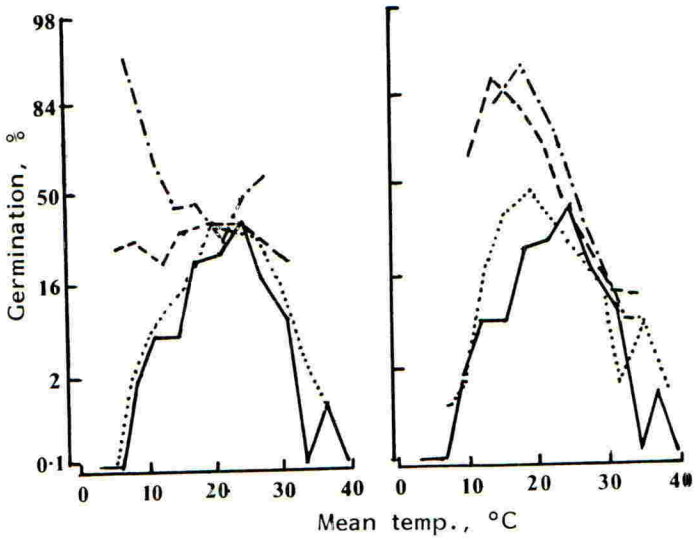

Fig. 3. Germination of *Chenopodium album* after 28 d of alternating temperature in thermoperiods when either 8 h in each day was spent at the warmer temperature (left) or 16 h (right). Temperature amplitude:——0° (constant temperatures); ····· 6.2°C; – – – 12.3°C; –·–·– 18.5°C. (Murdoch & Roberts, previously unpublished.)

parts of the cycle) is also important: in *C. album*, for example (Fig. 3), it is clear that cycles with the longer period spent at the warmer temperature are generally more stimulatory at any given mean temperature and amplitude. But in *Chenopodium polyspermum* and *Rumex crispus* (Figs 5 and 6) it is clear that the converse is true. Apart from these differences in preferred thermoperiod, however, the general response pattern illustrated by Fig. 3 appears to be of wide application and, for example, applies equally well to the tropical grass *Panicum maximum* (unpublished data).

Light

It is now well established that the phytochrome system provides a mechanism which not only allows seeds to respond positively to light of appropriate quality (daylight) but also negatively to light filtered through a leaf canopy (Frankland & Taylorson 1983). This is controlled by the equilibrium ratio between the active and inactive forms of phytochrome, commonly referred to as the Low Energy Reaction. Thus most small seeds are provided with a sensor which contributes to their ability to germinate at or near the soil surface providing it is not covered by a dense leaf canopy.

In addition to this response, however, is the so-called High Irradiance Reaction in which light of almost any quality inhibits germination if applied at high irradiances for sustained periods. This may be due, at least in part, to rapid cycling of the alternative forms of the phytochrome pigment, but it is also possible that an additional pigment is involved (Frankland & Taylorson 1983). Recent work on several species of Gramineae has shown that there is an increase in germination with increase in daily photon dose of white light up to about 10^{-1} mol m^{-2} (Ellis *et al.* 1986*a*). The response is linear if the probit of percentage germination is plotted as a function of the logarithm of photon dose. As an example, the results for *Echinochloa turnerana* are shown (Fig. 4) in which it can be seen that

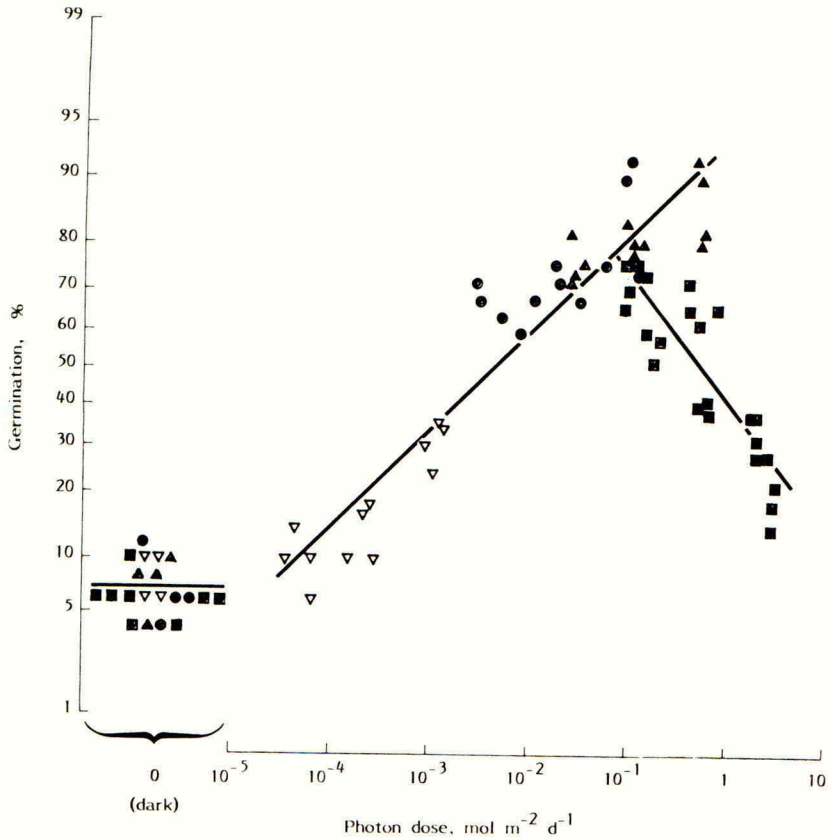

Fig. 4. Germination of *Echinochloa turnerana* after 7 d in alternating temperatures of 30 C (8 h)/20 (16 h) in response to photon dose in different photoperiods: ■ 24 h d^{-1}; ▲ 8 h d^{-1}; ● 1 h d^{-1}; ▽ 1 min d^{-1}. (From Ellis *et al.* 1986.)

a few seeds are stimulated to germinate at doses as low as 10^{-5} mol m^{-2} d^{-1}, but some require a minimum of 10^{-1} mol m^{-2} d^{-1}. Above this dose, however, some seeds are inhibited; the number inhibited increases with dose and a few require more than 10 mol m^{-2} d^{-1} to prevent germination. The negative response at doses above 10^{-1} mol m^{-2} d^{-1} is common in other species. Although in Fig. 4 the inhibitory effect is only shown in continuous light, data from other species suggests that normal photoperiods (≥8 h d^{-1}) are sufficient to inhibit germination when doses are of this magnitude (Ellis *et al.* 1986*a*, 1986*b*). If this is the case, then typical summer days in UK, when photon doses vary between $10^{2.2}$ and $10^{2.7}$ mol m^{-2} d^{-1}, are certainly sufficient to inhibit seeds exposed on the surface of the soil. The ecological significance of the High Irradiance Reaction has not been studied in any detail, but it may bestow an advantage in preventing seeds from germinating when bright sunshine could lead to rapid drying of the soil surface.

7C—1

INTERACTION OF ENVIRONMENTAL STIMULI

Laboratory experiments suggest that seeds seldom rely on a single environmental signal to stimulate germination. For example, light on its own seldom stimulates the germination of many seeds, but only does so in combination with alternating temperature or after stratification.

Figs 5 and 6 illustrate responses typical of many weed seeds to the effects of light, alternating temperatures, and nitrate ions investigated in 2^3 factorial experiments. Nitrate was included in these experiments because it is the only common inorganic ion in soil water which affects the germination of a wide range of species and, because of its distribution in the soil profile and in time, it could conceivably have some ecological significance. Its concentration is normally greater near the soil surface and at the beginning of the normal growing season - i.e. in spring in temperate climates and at the beginning of the rainy season in the tropics. Although nitrate frequently interacts with the other stimulatory factors, it generally has less influence than light or alternating temperatures, and its ecological significance is still a matter of speculation.

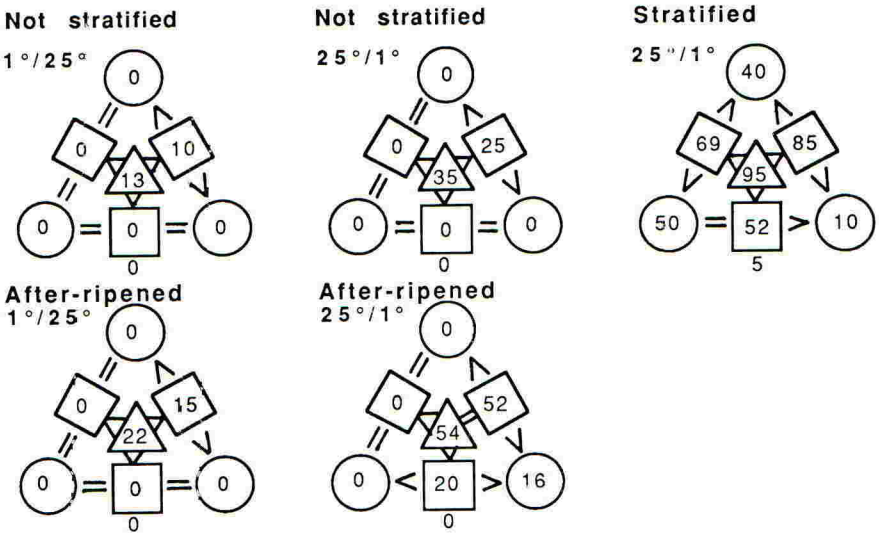

Fig. 5. Germination of *Chenopodium polyspermum* after 28 d in the presence or absence of light, 10^{-2} M KNO_3, and alternating temperatures (8 h/16 h thermoperiods; temperatures indicated on diagrams) in 2^3 factorial combination, before and after stratification (1°C for 4 weeks) or dry after-ripening at 1°C for 1 year). Results of single-factor treatments are shown in circles: light (top); alternating temperature (right); nitrate (left). Two-factor combinations are shown in rectangles between contributing single factors, and the three-factor combination in a triangle. Results of control treatment (dark, constant temperature, no nitrate) are shown below. (From Vincent & Roberts 1977.)

Fig. 5 shows that in *C. polyspermum* there is considerable variation in dormancy within a seed population and that there are a number of alternative

routes to loss of dormancy. For example no seeds germinated in the presence of only one potentially stimulatory factor but, in the absence of stratification or after-ripening, some seeds responded to light + alternating temperatures and a few more responded when nitrate was added to this combination. Either stratification or dry after ripening markedly increased these responses but also enabled light, nitrate or alternating temperatures on their own to be stimulatory under some circumstances. Similar features are shown by *Rumex crispus* but with even more extreme first and second-order interactions (Fig. 6).

The results of these 2^4 factorial experiments show the importance of interactions but are of limited value since only one level of each potentially stimulatory factor is included. The next problem is to quantify the effects of interacting factors so that laboratory responses can be used to explain and predict field behaviour. A good start in this direction has been made in *Dactylis glomerata* (Probert *et al.*, 1985*a*, 1985*b*, 1986).

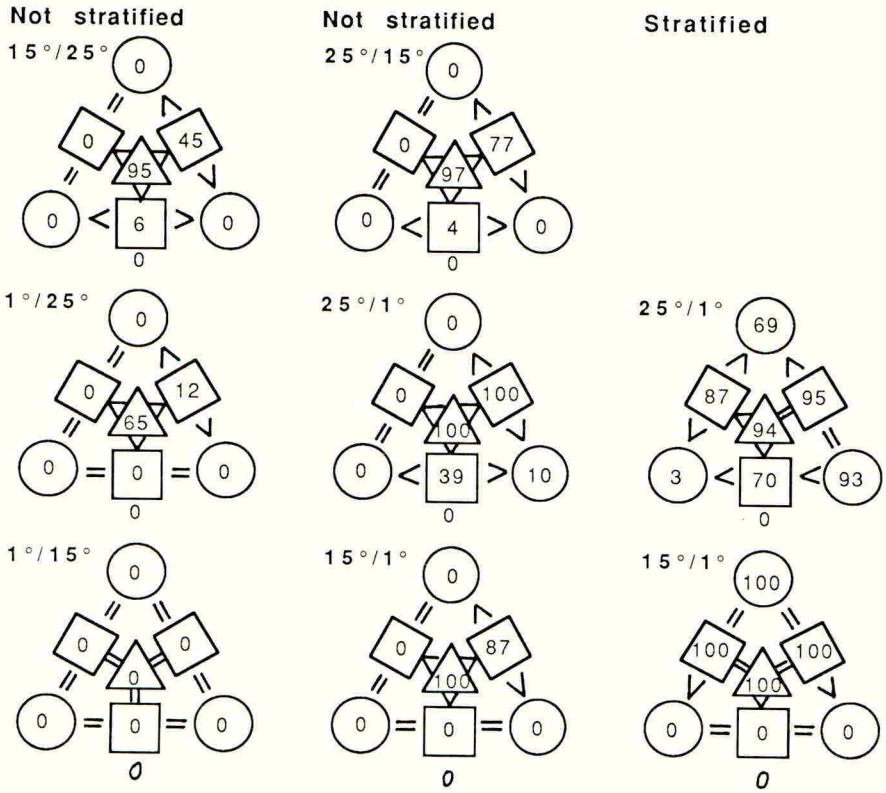

Fig. 6. Germination of *Rumex crispus* after 28 d before and after stratification. Further explanation as for Fig. 5. (From Vincent & Roberts, 1977.)

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ENVIRONMENTALLY INDUCED CHANGES IN THE DORMANCY STATES OF BURIED WEED SEEDS

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ABSTRACT

Seeds of many species in the buried seed pool undergo changes in dormancy states. Conditions and factors of the soil environment that cause these changes include high and low temperatures, darkness, low levels of oxygen, high levels of carbon dioxide, low water potentials, nitrate, nitrite and ethylene. Vegetation effects changes in the dormancy states of seeds by altering light quality (decreased R/FR ratio) and decreasing the amplitude of diurnal temperature fluctuations on or near the soil surface, and through its influence on the soil chemical environment. Of the environmental factors that cause changes in the dormancy states of buried seeds in temperate regions, temperature is the most important one. A knowledge of the dormancy states in seeds may be useful in planning a strategy for weed control by chemicals that stimulate germination of buried seeds.

INTRODUCTION

According to Roberts (1981), "seed bank" means the reserves of viable seeds in the soil and on the soil surface. In cultivated fields, the numbers of buried seeds may be as high as 70,000 to 90,000 per m^2 in the upper 15 to 25 cm of soil (Roberts, 1981). Thus, from the agriculturalist's point of view, the need to understand the ecology of dormancy and germination of seeds in the soil seed bank is obvious.

A significant contribution to seed bank ecology was the demonstration that many buried seeds exhibit periodicities in their germination requirements, i.e., they are not in a continuous "germination-ready" state, even when exposed to light (Courtney, 1968; Schafer and Chilcote, 1970; Taylorson, 1970). The fact that buried seeds can change from endogenous to exogenous dormancy and back was included by Schafer and Chilcote (1969, 1970) in their conceptual model of the factors involved in the persistence and depletion of buried seeds. When Roberts (1972) modified the Schafer-Chilcote model, he recognized the three types of dormancy (innate, enforced, induced) suggested by Harper (1957).

It is important to realize that the model developed by Schafer and Chilcote (1969, 1970), and as modified by Roberts (1972), is for seeds that exhibit physiological dormancy. Physiological dormancy is one of the five types of seed dormancy recognized by Nikolaeva (1977), and it is due to low growth

potential of the fully developed embryo. Seeds with physiological dormancy undergo changes in their dormancy state, and a high percentage of weed seeds exhibit this type of dormancy. Thus, many buried weed seeds undergo changes in their dormancy states. In some weedy species (e.g., those of the Leguminosae, Malvaceae and Geraniaceae), dormancy is due to the presence of an impermeable seed coat (physical dormancy), and hard seeds of a few species also have a physiologically dormant embryo (combination dormancy). Relatively few species (e.g., those of the Ranunculaceae and Umbelliferae) of arable land have morphological dormancy (i.e., an underdeveloped embryo that is not physiologically dormant) or morphophysiological dormancy (i.e., an underdeveloped embryo that is physiologically dormant).

To look at the changes in dormancy states that can occur in seeds with physiological dormancy, let us start with a freshly matured seed that is fully dormant (D)-i.e., one which will not germinate under any set of normal environmental conditions. As the dormant seed comes out of dormancy (afterripens), it exhibits a continuum of germination responses (Baskin and Baskin, 1985a), gradually acquiring the capacity to germinate over a wider and wider range of conditions until it becomes fully nondormant (ND), in which state it can germinate over the widest range of conditions possible for that seed. This transitional state between dormancy and nondormancy is known as conditional dormancy (CD), and there are many phases of it. If the afterripened, nondormant seed is prevented from germinating, it may re-enter dormancy. During re-entrance into dormancy, the seed will exhibit a continuum of germination responses in the opposite direction to those of afterripening. In addition to the annual D/CD/ND/CD/D cycle described above, seeds of some species have D/CD/ND/CD/ND, CD/ND/CD/D/CD/D or perhaps other cycles. Seeds of still other species are dormant or conditionally dormant at maturity, and they become nondormant and remain nondormant; they do not cycle (Baskin and Baskin, 1985b).

The purpose of this paper is to examine the environmental factors that cause changes in dormancy states in seeds with physiological dormancy. We will deal primarily with seeds buried in the soil because the majority of seeds in persistent seed banks are buried (Thompson and Grime, 1979).

ENVIRONMENTAL FACTORS CAUSING CHANGES IN DORMANCY STATES

Temperature

Some of the best examples of temperature-induced changes in dormancy states are found in buried seeds of annuals. Dormant and conditionally dormant seeds of obligate (germinate only in autumn) and facultative (germinate in autumn and in spring) winter annuals afterripen fully at high (25/15, 30/15, 35/20 C) summer temperatures, but they do not afterripen or only partially afterripen at low (5, 15/6 C) winter temperatures (Baskin and Baskin, 1986). In obligate winter annuals such as Lamium purpureum L. (Baskin and Baskin, 1984a), low winter

temperatures induced nondormant seeds into dormancy, while spring and autumn (15/6, 20/10 C) temperatures did not. Nondormant seeds of facultative winter annuals such as Lamium amplexicaule L. (Baskin and Baskin, 1984b) are induced into conditional dormancy by low winter temperatures, but not by spring and autumn temperatures. However, exposing nondormant seeds of the facultative winter annual Capsella bursa-pastoris (L.) Medic. sequentially to simulated March (15/6), April (20/10) and May (30/15 C) thermoperiods caused them to enter into a deeper phase of conditional dormancy than seeds kept continuously at 5 C. Seeds kept at 30/15 C did not enter conditional dormancy at all (Baskin and Baskin, unpubl.).

Dormant seeds of summer annuals such as Ambrosia artemisiifolia L. and Polygonum pensylvanicum L. that germinate in spring afterripen fully at low (5, 15/6) winter temperatures but little, or none, at high (25/15, 30/15, 35/20 C) summer temperatures (Baskin and Baskin, in press). The same requirements for afterripening of dormant seeds are found in Panicum dichotomiflorum Michx. (Baskin and Baskin, unpubl.), which retains the capacity to germinate throughout the growing season (Baskin and Baskin, 1983). A portion of the fresh seeds of some spring- and summer-germinating summer annuals such as Chenopodium album L. and Amaranthus hybridus L. exhibit conditional dormancy, germinating at 25/15, 30/15 and/or 35/20 C. While seeds of these two species afterripen best at low (5 and/or 15/6 C) temperatures, they also afterripen some at high temperatures. At high temperatures, the seeds rapidly gain the ability to germinate to high percentages at high, but not at low temperatures.

The temperatures that induce seeds of summer annuals into dormancy are correlated with germination phenology of the species. Nondormant seeds of spring-germinating summer annuals such as Ambrosia artemisiifolia (Baskin and Baskin, 1980) are induced into dormancy by increasing temperatures in the field in late spring-early summer. In some spring/summer germinating summer annuals such as Panicum dichotomiflorum (Table 1), seeds begin to enter conditional dormancy in early to mid summer (8 weeks at 30/15 C), and the depth of conditional dormancy increases as seeds are exposed to October (20/10) and November (15/6 C) temperatures during autumn. However, the depth of conditional dormancy in seeds kept at 30/15 for 20 weeks does not differ from that in seeds exposed sequentially to 30/15 for 12 weeks, 20/10 for 4 weeks and 15/6 C for 4 weeks. In seeds of other summer annuals such as Amaranthus hybridus that retain the capacity to germinate throughout the growing season, neither summer (30/15) nor autumn (20/10, 15/6 C) temperatures induce nondormant seeds into conditional dormancy (Baskin and Baskin, unpubl.).

TABLE 1

Germination percentages (mean ± SE) of nondormant buried seeds of Panicum dichotomiflorum exposed sequentially to September (30/15), October (20/10) and November (15/6 C) thermoperiods.

Treatment	Test temperatures (C) 20/10	25/15	30/15	35/20
Nondormant seeds	100	100	100	100
Placed at 30/15 C				
4 weeks	99±1	87±1	100	100
8	47±2	99±1	100	100
12	7±3	85±5	100	100
16	0	32±3	96±2	88±2
20	1±1	8±5	66±4	77±2
30/15 C (12 w) → 20/10 C				
4	1±1	45±2	98±2	95±2
8	0	16±3	61±3	77±2
30/15 C (12 w) → 20/10 (4 w) → 15/6 C				
4	1±1	12±1	83±7	99±1

Buried seeds of biennials and of monocarpic and polycarpic perennials have not received the same amount of attention as those of annuals; thus, we do not know much about changes in their dormancy states. Buried seeds of the monocarpic perennials Verbascum thapsus L. and V. blattaria L. undergo an annual CD/ND/CD cycle (Baskin and Baskin, 1981). Vanlerberghe and Van Assche (1986) demonstrated that seeds of V. thapsus show increases and decreases in degree of dormancy when incubated at high (20 C) and low (4 C) temperatures, respectively. They showed conclusively that the changes in dormancy states were due to temperature and not to some other factor(s) associated with the burial environment. Seeds of various monocarpic and polycarpic perennials sown in soil that was plowed regularly exhibited periodicity of germination (e.g., Roberts, 1979; Roberts and Chancellor, 1979), implying that seeds undergo changes in their dormancy states.

Other factors of the soil environment

Although temperature is the major environmental factor causing changes in the dormancy state of buried seeds in temperate regions, it does not operate independently, and it is not the only factor that can cause changes in dormancy states. Temperature frequently interacts with other environmental factors in the induction of dormancy. Inhibition of germination during the season(s) when temperatures are favorable for germination of nondormant seeds is a prerequisite for dormancy induction. Many nondormant seeds in the seed bank have a light requirement for germination (Wesson and Wareing, 1969). Thus,

since soil attenuates light very effectively (Tester and Morris, 1987), seeds buried more than a few millimeters deep are in complete darkness and can not germinate. Although the red/far-red photon flux ratio is lowered as light passes through soil, soil-filtered light has been shown to stimulate rather than inhibit germination (Tester and Morris, 1987). Other factors that may prevent germination of buried seeds until they are induced into dormancy by temperature are oxygen and carbon dioxide levels in the soil (Popay and Roberts, 1970a), volatile metabolites from the seeds themselves (Holm, 1972), low soil water potential, (Oomes and Elberse, 1976), flooding (Pons, 1982), allelopathic influences of vegetation (Jackson and Willemsen, 1976) and a low amplitude of diurnal temperature fluctuations (Thompson and Grime, 1983).

Darkness is a factor associated with the burial environment that has been shown to cause a change in the dormancy state of seeds; however, its effects are temperature dependent (e.g., Arnold, 1973). Imbibed seeds of Lactuca sativa L. (Powell et al., 1983), Rumex crispus L. (Samimy and Khan, 1983a), Kalanchoe blossfeldiana v. Poelln. (Rethy et al., 1983) and Lamium amplexicaule (Taylorson and Hendricks, 1976) held in darkness were induced into conditional dormancy -i.e., made light-requiring for germination. In R. crispus, the degree and rate of dormancy development increased with temperature, with the maximum speed of induction occurring around 25 C, and in L. amplexicaule seeds held in darkness at 15 and 25 C showed a greater loss of sensitivity to the plant hormone gibberellic acid than those held at 5 C. Nondormant buried seeds of Ambrosia artemisiifolia subjected sequentially to increasing temperature regimes of 5, 15/6, 20/10 and 30/15 C entered secondary dormancy, whereas those held continuously at 5 C did not enter secondary dormancy (Baskin and Baskin, 1980).

It generally is agreed that oxygen is required for the breaking and induction of dormancy in seeds. Nondormant seeds of Ambrosia trifida L. embedded in agar, which restricted oxygen supply, developed dormancy slower than seeds exposed to air (Davis, 1930). Oxygen also is required for dormancy induction in seeds of Lactuca sativa (Vidaver and Hsiao, 1975) and Rumex crispus (Le Deunff, 1973). Seeds have been shown to require oxygen to afterripen. For example, seeds of. A. artemisiifolia stratified at 5 C in nitrogen failed to afterripen, whereas those stratified in air afterripened normally (Brennan et al., 1978). In the aquatic species Scirpus juncoides Roxb. (Pons and Schroder, 1986) and Zizania aquatica L. (Simpson, 1966), low oxygen tensions promoted afterripening. Germination of dormant seeds of Trifolium subterraneum L. (seeds have a hard seed coat and a physiologically dormant embryo) is greatly improved if imbibed seeds are stored at low oxygen concentrations for several days and then transferred to either normal air or 100% oxygen (Ballard and Grant Lipp, 1969).

Evidence that levels of carbon dioxide in the soil influence changes in dormancy states of seeds is limited. Embryo dormancy in imbibed seeds of Trifolium subterraneum was

broken by 0.3 to 5.0% (by volume) carbon dioxide (Ballard, 1958), and an increase in carbon dioxide concentration promoted afterripening of dormant seeds of Polygonum scandens L. (Justice, 1941). The levels of carbon dioxide in the soil may play a secondary role in overcoming dormancy of some seeds. In seeds of Lactuca sativa (Negm et al., 1973), Xanthium pensylvanicum Wallr. (Katoh and Esashi, 1975) and Spergula arvensis L. (Jones and Hall, 1979), dormancy is broken by ethylene only if carbon dioxide is present.

Soil water potential via its effects on tissue water potential can cause changes in dormancy states of some seeds. Seeds of Corylus avellana L. are only partially dormant at maturity but become completely dormant during dry storage of intact fruits (Shannon et al., 1983). Drying partially reimposed dormancy in stratified seeds of Pyrus spp. (Westwood and Bjornstad, 1968), and stratified seeds of Polygonum spp. entered dormancy when stored dry at room temperature (Justice, 1941). However, air drying stratified seeds of Ambrosia artemisiifolia did not cause them to become dormant (Bazzaz, 1970). Low water potentials obtained with solutions of polyethylene glycol 6000 have been used to induce dormancy in seeds of Chenopodium bonus-henricus L. (-8.6 bars) (Khan and Karssen, 1980) and Rumex crispus (-15.7 bars) (Samimy and Khan, 1983a). Alternate wetting and drying at alternating temperatures broke dormancy in seeds of R. crispus, while the same treatments at constant temperatures were ineffective (Vincent and Cavers, 1978). Depth of dormancy was reduced in seeds of Lactuca sativa and Phacelia tanacetifolia Benth. when substrate hydration level was low during exposure of seeds to environmental conditions that normally induce dormancy (McDonough, 1968). In Sisymbrium officinale (L.) Scop., a higher percentage of the seeds entered dormancy at high than at low soil moisture (Karssen, 1980/81a).

Nitrate and nitrite ions are present in the soil and have been shown to break dormancy and stimulate germination in seeds of many species (e.g., Hendricks and Taylorson, 1974). In Sisymbrium officinale nitrate is required for afterripening of seeds even at low (2 C) temperatures, and in both S. officinale and Polygonum persicaria L. the presence of nitrate prevents induction of nondormant seeds into dormancy at 2 C (Karssen, 1980/81b). Nitrate promoted germination of dormant seeds of Avena fatua L. in darkness, but the stimulatory action decreased with increases in temperature (Saini et al., 1985a). In dormant seeds of Chenopodium album, the dormancy breaking action of ethylene was dependent on the availability of nitrate (Saini et al., 1986); however, the presence of nitrate masked the interaction between light and ethylene (Saini, 1985b). Popay and Roberts (1970b) observed a seasonal increase in the level of nitrate in the soil which was correlated with a peak of germination in Capsella bursa-pastoris. However, applications of nitrates to the soil have been shown to stimulate germination in seeds of some species (Sexsmith and Pittman, 1963) but not in others (Hurtt and Taylorson, 1986). In seeds of some species, nitrite is more effective than nitrate in breaking dormancy (Cohn et al., 1983).

VEGETATION EFFECTS ON CHANGES IN DORMANCY STATES

Sunlight filtered through leaves has a low red/far-red photon flux ratio (R/FR) (Smith, 1982), and thus it inhibits the germination of seeds of many species (e.g., Gorski, 1975; Gorski et al., 1977; Fenner, 1980a,b). Significantly, Gorski (1975) showed that dark-germinating Lactuca sativa seeds exposed to leaf-filtered light for a few days became light requiring in the usual phytochrome mediated manner, and Fenner (1980b) showed the same thing for seeds of Bidens pilosa L. In Cirsium palustre (L.) Scop. (Pons, 1983) and Plantago major L. ssp. major (Pons, 1986), however, a low R/FR ratio was much less effective in inhibiting stratified than nonstratified seeds, and in Plantago major ssp. major the effectiveness of a low R/FR ratio in inhibiting germination was dependent upon other environmental factors, including temperature, nitrate and osmotic potential (Pons, 1986). Germination of the seeds of some species is not inhibited by a low R/FR ratio (Gorski et al., 1977; Fenner, 1980a). In fact, in seeds of some species FR has been shown to promote germination (Downs, 1964) and R to inhibit it (Hilton, 1984).

In addition to altering the quality of sunlight, vegetation can play other, often indirect, roles in causing dormancy changes in seeds in the seed bank. The amplitude of daily temperature fluctuations in the surface layer of soil is considerably less under plant canopies than in adjacent openings (Vazquez-Yanes and Orozco-Segovia, 1982), and thus germination of seeds with impermeable coats may be prevented. High daily fluctuations of temperature can overcome dormancy by rupturing the seed coat in many hard seeded species (Quinlivan, 1971; Vazquez-Yanes and Orozco-Segovia, 1982). It was noted above that nitrate and nitrite break dormancy in seeds of many species. Thus, since the activities of plant roots and soil microbes help determine the concentrations of these ions in the soil, vegetation may directly or indirectly cause a change in the dormancy states of buried seeds. Plants produce ethylene (Smith, 1976) which alone (Schonbeck and Egley, 1980) or in combination with carbon dioxide (Negm et al., 1973) or nitrate (Saini et al., 1986) stimulates breaking of dormancy in seeds of some species. The plant root exudate strigol stimulates germination of the obligate root parasitic weed Striga asiatica (L.) Ktze. (Cook et al., 1966). Respiration of plant roots undoubtedly contributes to decreased oxygen and increased carbon dioxide concentration in the soil atmosphere, and these changes may cause dormancy break in some seeds (e.g., Justice, 1941; Ballard and Grant Lipp, 1969).

SIGNIFICANCE FOR WEED POPULATION MANAGEMENT

Since (1) there is a large reserve of viable seeds in most agricultural soils, only a fraction of which may germinate in any one year, and (2) conventional weed control practices do not kill ungerminated seeds, lack of germination of buried dormant, conditionally dormant and nondormant seeds is a major reason that weeds are so difficult to control. Learning how to break

dormancy and to stimulate germination of these buried seeds by application of chemicals to the soil would be a major technological advancement for weed control (Chancellor, 1981).

It has been demonstrated that the sensitivity of seeds to light and plant growth regulators gradually decreases as they enter dormancy (Bewley, 1980), and it is supposed that the seeds' sensitivity to these factors gradually increases as they come out of dormancy. Thus, information on the dormancy states of seeds in the soil seed pool would allow one to apply chemicals to the soil when they would be most efficient in stimulating seeds to germinate, or when entrance into dormancy would be prevented. A good example of using chemicals to control the dormancy state of weed seeds, and thereby causing a reduction in the number of buried seeds in the soil, is the study by Samimy and Khan (1983b) on Ambrosia artemisiifolia. Application of a mixture of the plant growth regulators kinetin, ethephon (ethylene releasing) and gibberellin A_4 + A_7 to soil containing seeds of A. artemisiifolia prevented nondormant seeds from entering dormancy in spring. By the second spring, only 20% of the seeds in the treated soil were viable, whereas in the nontreated soil 89% were viable. Apparently, the nondormant seeds were lost from the seed pool through decay and germination (Samimy and Khan, 1983b).

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SURVIVAL AND FATE OF WEED SEED POPULATIONS : INTERACTION WITH CULTURAL PRACTICE

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ABSTRACT

Factors affecting the fate and survival of weed seeds following dissemination and the influence of cultural practice on weed seed persistence are discussed. Particular emphasis is given to the fate of seeds post-harvest, as influenced by soil disturbance and depth of burial. Consideration is also given to the effect of other agronomic factors on seed decline, including crop rotation and use of herbicides. The seed population dynamics of three major annual grass-weeds Avena fatua, Alopecurus myosuroides and Bromus sterilis are compared in relation to cultivation and straw-disposal regimes. It is concluded that, although of great importance to the success of annual broad-leaved weeds, the production of seeds of potentially long-lifespan is of lesser importance to the success of annual grass-weeds.

INTRODUCTION

The ecological roles of seeds are i) to carry species to new habitats, ii) to provide resources for initial growth and iii) to enable the offspring to survive unfavorable conditions for growth. Successful regeneration depends on the dispersal of seeds to situations suitable for germination and establishment. Situations where such conditions may be met are referred to as 'safe-sites' (Harper 1977). A 'safe-site' may be envisaged as providing the necessary stimuli required for the breakage of dormancy, the conditions required for the germination process to proceed and the resources which are consumed during the course of germination and establishment. In addition a 'safe-site' should be free from specific hazards such as predators, pathogens, competitors and allelochemicals. Although the size of a single species population is ultimately dependent on the seed supply, it is initially determined by the availability of 'safe-sites'.

The size of a seed population on a soil surface for a given area in time depends on i) the rate of recruitment from seed rain, ii) rate of emigration and immigration of seeds from the soil profile and surface surrounding area iii) rate of germination and iv) rate of loss through seed mortality and predation. Clearly any discussion of the dynamics of seed populations must concern itself with the parameters of such a flux. In a recent essay on seed demography it is suggested that the fate of a given plant population may be decided by the pattern of mortality exhibited by its seeds and that losses through seed mortality greatly exceed losses at any other stage of plant development (Cavers 1983).

LOSSES FROM THE SOIL SURFACE

Following dissemination, retention of seeds on the soil surface may be of remarkably short duration, even in the absence of cultivation. Seeds do not necessarily remain where they land after dispersal. The hygroscopic awns of grasses many serve to facilitate lateral seed movement into suitable microsites for germination, although, the presence of soil cracks may prove essential to effect self burial (Stamp 1984, Somody et al 1985). By means of mark and recapture technique, Mortimer was able to show that seed losses from the soil surface during the space of one year may be considerable, many of which become buried (Mortimer, 1976). Opportunities for seed burial were high for Poa annua (50%) and Plantago lanceolata (30%) but less likely for Holcus lanatus (13%) and Dactylis glomerata (8%). Thus, whereas 37% of H. lanatus gave rise to seedlings in the year of sowing, only 7% of P. annua produced seedlings. In general the probability of burial increased with habitat disturbance and invertebrate activity. The rate of seed loss was substantially reduced in a closed sward. Similarly, Williams, (1984) monitoring changes in the size and composition of the seed bank beneath permanent pasture over a period of three years, concluded, that in the absence of grazing the chances of seeds becoming permanently incorporated were slight. However, when plots were mown infrequently, allowing considerable seed shed, numbers of Cerastium fontanum ssp glabrescens showed a marked transient increase while approximately 20% of Agrostis capillaris became more permanently incorporated.

McRill (1974) has implicated earthworms in the incorporation of weed seeds. Seed ingested by earthworms may pass through the gut in a viable state and become deposited within the cast. In particular large numbers of seeds have been associated with worm casts in grassland, the position of the cast within the soil profile being dependent on the species of earthworm. Considerable selectivity in weed species preference may occur, for 66% of Veronica persica seeds offered to Lumbricus terrestris were ingested whereas only 1% of Ranunculus repens were taken. The number of viable seeds egested may vary also. Thus, whereas over 80% viable seeds of Sonchus spp were recovered, only 50% of Poa spp and 0% of Agrostis capillaris were retrieved.

Losses from predation by vertebrates may also be considerable. The fate of seed of three species of buttercup, Ranunculus acris, R. bulbosus and R. repens sown onto the soil surface of a grazed pasture were monitored over a period of 15 months (Sarukhan 1974). Predation was mainly by rodents which accounted for between 38-54% loss of R. repens, 32-35% of R. bulbosus and 20-25% of R. acris seeds. Despite the greater predation of R repens, the rate of seed decline was slower than for the other two species. Seed mortality during dispersal can also be influenced by seed size. For example, whereas seeds of Polygonum lapathifolium and P. persicaria pass through the alimentary tract of cottontail rabbits in a viable condition, the larger seeds of P. pensylvanicum were totally destroyed (Staniforth & Cavers 1977).

LOSSES AT HARVEST

Agrestal weeds have poorly developed abiotic methods of dispersal and rely exclusively on man the agriculturalist for their dissemination. The

role of harvesting equipment in seed dispersal has been investigated by Petzold (1979) and Fogelfors (1982). In Argentina, Ballaré et al (1987) have demonstrated that only a small proportion of Datura ferox seeds were shed prior to harvesting soybeans. Greater than 90% of capsules were collected by the combine harvester and in two experiments between 7 and 40% of seeds were returned to the field, the viability unaffected by passage through the combine.

Of particular importance is the spread of agrestals as contaminants of crop seed. Despite improvements in seed cleaning, crop contamination remains an important means of weed dissemination. Improvements in seed cleaning were responsible for the demise of Agrostemma githago which lacks seed dormancy and is of short lifespan, necessitating repeated introduction. Thus, the success of arable weeds is primarily attributed to the persistence of seeds in the soil, itself a function of dormancy and potentially long lifespan. Consequently, two questions are particularly pertinent to the study of weed seed biology; when do they germinate? and for how long can they persist?

SEED LONGEVITY

When flowering plants are compared with respect to the fate of their seeds two contrasting groups may be recognised. In one, most if not all of the seeds germinate soon after release, whilst in the other group many become incorporated into a bank of dormant seeds which is detectable in the habitat at all times during the year and may represent an accumulation of many years. (These two groups represent two extremes of seed bank behaviour, and between them, there are species and populations in which the seedbank, although present throughout the year, shows pronounced seasonal variation in size. It has been found convenient to refer to these two groups as transient and persistent (Thompson, 1987). There exists between species great variation in the lifespan of their seeds.

Essentially two approaches to the study of seed longevity have been adopted. The first involves long-term burial of species in containers, subsequently exhumed at various intervals to determine percentage viability (Egley & Chandler 1983). The former include the classic studies of Dr Beal initiated in 1879 and continued for 100 years (Kivilaan & Bandurski, 1981). Of the 23 spp included, three species Rumex crispus, Oenothera biennis and Verbascum blattaria showed viability even after burial for 80 years. However, caution should be exercised in interpretation of results for species which exhibit cyclic changes of dormancy or restricted germination periodicities may escape detection from sampling at a single time of year. The seeds of Ambrosia artemisiifolia germinated once only during the period of study, forty years after burial. A possible explanation of this relates to the restricted germination pattern of this species, such that only at the 40 year period were assessments carried out early enough in spring to detect seeds in a non-dormant state (Baskin & Baskin 1977). The second approach involves exhumation of seeds from soils that have remained undisturbed for long periods (Chancellor 1986). Confirmation of considerable longevity of weed seed populations has been obtained from examination of seedbanks beneath pastures of known age. For example viable weed seeds have been detected beneath soils not disturbed for 58 years (Brenchley 1918).

A major limitation of both approaches is that they involve determination of seed lifespan under comparatively atypical conditions, for such seeds are not subject to cultivation which may result in exposure to light, greater diurnal amplitude of temperature fluctuation and modification of gaseous environment, factors known to influence dormancy loss and seed germination. To some extent these problems have been mitigated by the comprehensive studies of H.A. Roberts and co-workers. Typically, they have mixed seed to various depths in soil contained in open ended cylinders and monitored subsequent seedling emergence. Periodically, the soil has been disturbed to simulate cultivation and at the end of a specified period, survival of remaining viable ungerminated seed determined (Roberts & Neilson 1980, 1981a, Roberts & Boddrell 1983a, 1983b). Seed decline was found to be exponential. In addition, not only does the seed population decline in this manner but, so too, individual species decline at specific rates. For example in one experiment the annual decline of Fumaria officinalis was 26% whereas that of Veronica arvensis was 60%. The rate at which a population of viable seeds decline depends on several factors including dormancy characteristics, depth of seed incorporation, frequency, timing and depth of cultivation.

LOSSES OF BURIED SEEDS

Depth of burial

Typically seed decline is more rapid following shallow rather than deep burial (Dawson & Bruns 1975). For example Thomas et al, (1986) have shown that less than 1% of Setaria viridis seed sown on the soil surface was viable after six years, whereas buried seeds remained viable up to 17 years (Thomas et al, 1986). Likewise, seed of Sorghum halepense survived six years at a depth of 22.5 cm in undisturbed soil but less than 2 years when buried less deep. Seed survival in disturbed soil was less than 2.5 years (Leguizamon 1986). Conversely seeds of Bromus diandrus enforced into dormancy on the soil surface persisted for six months whereas seeds buried at 5 or 15 cm germinated or lost viability within one month (Harradine 1986). Likewise, seeds of Raphanus raphanistrum on the soil surface developed induced dormancy whereas shallow burial enhanced dormancy loss (Cheam 1986).

Depth of burial had little influence on the survival of populations of Avena fatua in Colorado (Zorner et al., 1984). However the mode of disappearance was closely related to depth. Loss through germination in situ increased with depth of burial whereas depletion as a consequence of non-viability increased with decreasing depth.

Effect of cultivation

Roberts & Feast (1973a) incorporated seed of 20 species to a depth of 15 cm. In the absence of disturbance seed decline of the entire population was 12% per annum, with a range of 6-21% for individual species. In contrast where soil was disturbed, mean seed decline was 32% per annum with a range of 20-26% for Chamomilla suaveolens, Matricaria perforata, Fumaria officinalis and Papaver rhoeas to 44-48% for Senecio vulgaris, Veronica hederifolia and Veronica persica. The mean numbers of seeds remaining viable after six years amounted to 5.9% of those initially sown in cultivated soil and 27.5% for undisturbed soil. In a similar experiment in which seeds were incorporated to depths of 2.5, 7.5 or 15 cm seedling emergence was 75, 65 and 54% respectively for cultivated soil and

58, 36 and 21% for uncultivated soil. The corresponding number of viable seeds remaining were 2.3, 4.0 and 7.7 for cultivated and 6.8, 16.5 and 31.6% for uncultivated soil (Roberts & Feast 1972).

Frequency of cultivation

Over a period of six years the rate of decline recorded for viable seed within a natural population was 22% per annum in the absence of cultivation, 38% when dug twice and 36% when dug four times (Roberts & Dawkins 1967). In a subsequent study numbers of naturally occurring seeds in the top 23 cm of soil declined at rates of 34% on plots which were undisturbed but left bare, 31% and 32% respectively for mulched or grassed down plots, 42% where dug twice and 56% where dug seven times (Roberts & Feast 1973b). Elsewhere, even after seven years 50% of Brassica Kaber seeds remained viable under undisturbed soil (grass or chemical fallow) compared with 3% following intensive cultivations which involved ploughing three times per annum plus additional cultivation (Warnes & Andersen 1984).

VERTICAL DISTRIBUTION OF SEEDS

The distribution of seeds with depth depends very much on when the soil is examined in relation to cultivation and time of seed production. Mouldboard ploughing may result in a particularly uneven distribution of seed (Rottele & Koch 1981). However, Fay & Olson (1978) report a more even distribution of wild oat seeds with mouldboard than chisel ploughing. Thus, with mouldboard ploughing 43% of seeds were in the top 0-5 cm, 37% in the 5-10 cm layer and 20% in the 10-18 cm layer whereas with chisel ploughing no seeds were buried below 10 cm and 60% of all seeds were located in the top 0 - 25 cm. Vertical distribution of seed within the soil profile has important implications for subsequent infestation, particularly where minimal tillage is practiced and freshly shed seeds are located at or near the soil surface. Using a mark and recapture technique, Naylor (1972) was able to demonstrate that the majority (90%) of blackgrass seedlings were derived from freshly shed seed in the top 2.5 cm of soil.

RELATIONSHIP BETWEEN SEED NUMBER AND SEEDLING EMERGENCE

Although the size of the seedbank may be considerable, comparatively few seeds contribute to the annual seedling recruitment. For example Roberts & Feast (1973b) reported that only 6% of viable seeds per annum emerged as seedlings. Similarly, Roberts & Ricketts (1979) estimated that between 3 and 6% seeds per annum emerged as seedlings when moisture was adequate and the percentage was even lower when moisture availability was inadequate. However, rates of seed decline greatly exceed losses from successful seedling emergence. For example, the proportion of seed not accounted for either as seedlings or as viable seed remaining after six years ranged from 20-60% in cultivated soil to 33 - 70% in undisturbed soil (Roberts & Feast, 1973a). This apparent discrepancy has been attributed to post-germination mortality of seed in the soil, not resulting in successful seedling emergence. Confirmation of such a fate is provided by Schafer & Chilcote (1970) who reported 85% seed mortality of Lolium perenne spp perenne from germination at depth, whereas a comparative figure of 49% mortality was obtained for Lolium multiflorum. This supports the observations of Rampton & Ching (1970) that buried seeds of L. multiflorum could persist for seven years whereas only a trace of L. perenne remained after three years, and partly explains the greater

prevalence of L. multiflorum as a weed.

ONE YEARS SEEDING SEVEN YEARS WEEDING

Despite some forty years of intensive chemical control, the size of seedbanks remains vast with as many as 67000 seeds m^{-2} (Roberts & Chancellor 1986). Although seed replenishment has obviously occurred, the composition of the seedbank is also indicative of seed persistence. Nonetheless, Schweizer & Zimdahl (1984) report seed decline over a period of 6 years of 99 and 94% for Amaranthus retroflexus and Chenopodium album, but when weed control was discontinued at the beginning of the fourth year the weed seed burden reached 50% of its original value after only three years. Similarly, Burnside et al (1986) reported that a weed seed population declined by 95% over five years in the absence of seed return but recovered to 90% of its original value following a single year of non-weed control. Consequently, there is considerable evidence for the adage one years seeding, seven years weeding. Nonetheless, despite a 98% reduction of Amaranthus palmeri over a six year period, some 18 m seeds ha^{-1} remained (Menges, 1987).

EDAPHIC FACTORS

The influence of soil type on seed persistence has received little attention. However, Lewis (1973) observed that seed deterioration occurred more rapidly in acid peat than in loam soil. In Nebraska, buried seeds of Sorghum bicolor lost viability more rapidly in fine sandy loam as compared with silt loam or clay loam (Burnside et al., 1977). In Finland, Pessala (1978) observed that during the first two years of burial, decline of Avena fatua was more rapid in sandy than clay soil. Such results may be related to soil moisture retention, for Lewis demonstrated the importance of waterlogging in enhancing seed survival. Consequently, it is likely that soil drainage would reduce seed persistence and hence facilitate seed decline. Information concerning the effect of soil fertility on seed decline is similarly scant. Banks et al (1976) recorded least number of weed seeds on nutrient deficient plots. In contrast Pulcher & Hurle (1984) observed reduction in seed density of plots receiving high intensities of nitrogen fertilizer.

AGRONOMIC FACTORS

Crop rotation

The season in which a crop is planted is probably the main factor determining weed flora composition, but although species composition is likely to be somewhat similar for autumn and spring-sown crops, their relative contribution will differ greatly. Hence, in the absence of seed return, seed decline will be influenced by the crop sown. Beuret (1980) reported that five times as many Apera spica-venti seedlings emerged in an autumn-sown wheat crop as compared with spring-sown barley. Total seed numbers declined more rapidly following continuous maize then either continuous small-grain cereals or rotational cropping, indicative of more efficient chemical control in maize. In contrast, following eight years of continuous rape, the seedbank was considerably greater. Similarly, Zawislak (1980) reported an increase of weed seed density of 46% in continuous rape and of 101% in continuous field beans, whereas seed density increased less markedly for rotational sequences. Elsewhere, decline of Brassica kaber was more rapid in a corn-soybean rotation than

for continuous wheat; and has been attributed to greater use of tillage in the former situation (Warnes & Andersen, 1984).

Herbicides

Hurle (1974) estimated seed numbers after various weed control measures. Greatest number of seeds were present on plots subject to mechanical weed control measures and least following herbicide treatments. Similarly, seed number after seven years monoculture of winter wheat were highest for hand-weeded plots and lowest for plots receiving a combination of herbicide treatments (Pulcher & Hurle 1984). A greater than ten-fold increase of weed seed number was recorded over eight years of regular cultivation in a raspberry plantation, whereas plots receiving simazine treatment showed no such increase (Clay & Davison 1976). Although there may be little change in the overall size of the seedbank, repeated application of the same herbicide may substantially affect species composition (Hurle, 1974). Nonetheless, Roberts & Neilson (1981b) found little qualitative effect of repeated herbicide application on species composition despite quantitative differences between treated and untreated plots.

FATE OF ARABLE GRASS-WEEDS

Detailed investigations of seedbank dynamics of major annual arable grass-weeds have been conducted by staff of the former Weed Research Organization and include Avena fatua, Alopecurus myosuroides and Bromus sterilis. The fate of seeds of these species may be considered in relation to the regulatory factors already discussed.

Avena fatua

Losses of A. fatua seeds as contaminants of grain and straw will be related to the degree of shedding at harvest (Wilson 1970). Although most seeds will shed prior to harvesting winter wheat, contamination of winter barley may be severe. For example in one trial 77% passed though the combine but only 21% of these were recovered from the grain tank.

Substantial seed losses have been observed post-harvest when seed remain on the soil surface throughout the autumn. Losses of between 76 and 85% have been reported between harvest and December (Wilson 1972). Such losses can not be attributed to predation or microbial decay, but more likely, seeds suffer post-germination mortality. In contrast, shallow incorporation of seed by cultivation in early-autumn largely preserves seed (Wilson & Cussans 1972).

Freshly-shed seeds exposed on the soil surface are prone to destruction by stubble burning. Where straw was burnt in swathes, an overall reduction of 32% was obtained (Wilson & Cussans 1975) although losses through straw burning were considerably lower than for natural mortality. Thus seed decline was 32% where straw was burnt, 67% where cultivation was delayed and 73% where straw was burnt and cultivation delayed. In comparison with delayed cultivation there were twice as many seedlings in the following spring.

Greatest losses of seed through germination occurred in the second

spring giving typical rates of decline of 50% in the first year and 90% in the second. Losses from a seedbank of mixed aged are most likely to result from seeds greater than one year old (Wilson 1985). However, a relatively small proportion (11-14%) of seeds may give rise to seedlings and even less (0.4%) if deeply buried (Wilson 1981). Depth of burial may affect persistence, for seeds buried deeply were found to show greater survival.

Studies of seed longevity indicate a total eradication of the seedbank over three years of spring barley cut for arable silage, whereas some seeds persisted for six years under grass (Wilson & Phipps 1985). In a further study, viable seeds were still present after four years of winter barley cropping (Wilson 1985) while Peters (1986) observed that on average less than 1% viable seeds remained after five years in uncropped and undisturbed soil.

Type of cultivation influenced seed distribution in the soil profile and hence emergence pattern. It is suggested that with no herbicidal control, tine cultivation will lead to a more rapid build up of seeds than ploughing, but where seed production is prevented, seed decline will be more rapid (Wilson 1978, 1981). He concludes that persistence of A. fatua as a weed appears to be related to seed production by survivors rather than persistence of seed in the soil.

Alopecurus myosuroides

The early shedding habit of A. myosuroides reduces the likelihood of contamination during harvesting although perhaps only 50% of seed will have been shed prior to harvest of winter barley. However, seed viability tends to be lower at the beginning and the end of shedding than at its peak during late July/early August (Moss 1983).

As with Avena fatua considerable seed mortality may occur on the soil surface such that as little as 32% viable seed remained ten weeks after shedding (Moss 1980a). Straw burning can cause substantial losses of seeds on the soil surface (Moss 1980b), the magnitude of loss (61-94%) being dependent on the amount of straw burnt and hence temperature attained. Moss reports a 16 fold reduction compared with baled plots. In previous studies considerable variation in seed mortality following straw burning has occurred (Moss 1978, 1979, 1980c). Also the level of control will be influenced by subsequent cultivation regime such that the reduction in seed number following straw burning may be nullified by ploughing up old seed reserves.

In contrast to A. fatua, seed decline is most rapid in the first year after shedding (Moss 1985). At two sites sown to winter wheat, the mean annual decline of an artificially established population was 73-88% over a 2 or 3 year period. At five sites with natural populations, seed numbers declined to an average of 3% of the original amount present after three years and to 1% after four years. However, despite the low proportion surviving after four years, appreciable numbers of seed remain (Moss 1985). Rates of seed decline under grass were similar to arable cropping. Rate of decline is similar irrespective of cultivation system, although where seeds are ploughed down and crops subsequently direct-drilled, rate

of decline may be impaired.

Bromus sterilis

Despite the early maturation of B. sterilis, contamination of winter barley may be considerable. As with the other two species germination losses from the soil surface may be substantial (Froud-Williams 1983). For example a decline of 85% occurred between July and August, 41% which suffered post-germination mortality, and by December only 6% viable seed remained.

Straw burning too, may destroy a large proportion of seeds, as many as 96% where straw was spread. Cultivations and seed burial serve to deplete the seedbank to a greater extent and more rapidly than retention on the soil surface. Thus shallow cultivations reduced seed numbers by a further 34%, while ploughing (to a depth in excess of 12 cm) resulted in total depletion of the seed bank.

CONCLUSION

Whereas the success of annual broad-leaved weeds has been partly attributed to an intrinsically high seed output, discontinuous germination and formation of persistent seedbanks; it is apparent that the success of annual grass-weeds; of relatively lower seed output, lack of inherent dormancy and of short seed lifespan, is largely a function of current agronomic systems. Seed survival is markedly influenced by cultural practice, albeit opportunities to effect seed decline will be greater for grass-weeds than broad-leaved species. Nonetheless, seed persistence may still be compounded by seed number.

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