The effect of pre-emergent herbicides on germination and early growth of broadleaved species used for direct seeding

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Summary

Weed control is essential for successful new woodland creation by direct seeding, particularly in the first year after germination. Currently, herbicides probably offer the most practical way of achieving this in UK conditions, although successful direct seeding offers the potential for reductions in total overall herbicide use compared with conventional establishment using transplants. There is a need to identify post-sowing pre-emergence herbicides that might control emerging weed seedlings without significantly affecting tree seedling germination and growth. Seed of ash (*Fraxinus excelsior*), cherry (*Prunus avium*), oak (*Quercus robur*), sycamore (*Acer pseudoplatanus*), rowan (*Sorbus aucuparia*), chestnut (*Castanea sativa*), beech (*Fagus sylvatica*), Norway maple (*Acer platanoides*), field maple (*Acer campestre*), birch (*Betula pendula*), hazel (*Corylus avellana*), dogwood (*Cornus sanguinea*), hawthorn (*Crataegus monogyna*) and crab-apple (*Malus sylvestris*) were sown in pots in glasshouses and treated with post-sowing pre-emergence herbicides including diflufenican, isoxaben, lenacil, metamitron, metazachlor, napropamide, pendimethalin, propyzamide and simazine. Pendimethalin and napropamide, separately or in mixture, appeared to have potential for use on most species tested, in particular ash and sycamore. Applications to emerging seedlings were more damaging. Field trials are required to confirm these initial indications of tolerance.

Introduction

Direct seeding, also known as direct sowing, is an ancient method of woodland establishment. Recent Forestry Commission experiments investigated the practicality of the technique for new woodland creation (I. Willoughby, R.L. Jinks, G., Kerr and P.G. Gosling, unpublished). It was concluded that control of competing vegetation is essential for successful tree establishment using direct sowing. Hand weeding or the use of mulches is costly and often impractical amongst densely sown irregularly spaced young seedlings. In many situations, other than on a very small scale, it is likely that the use of herbicides offers the most cost-effective method of achieving adequate initial weed control. However, Willoughby (2002) suggests total overall herbicide inputs may be lower in direct seeded woodland due to denser initial tree spacing.

It is probable that weed competition is most damaging in the first year after sowing, when seedlings have very small root systems. The dense and irregularly spaced seedling emergence that results from direct seeding means that overall herbicide applications, possibly from mechanized sprayers, are usually the most practical weeding option. On fertile ex-agricultural sites, good pre- and post-cultivation weed control (Willoughby, 2002) will limit but not avoid the occurrence of damaging weed invasions in the first year after sowing. Willoughby (1996) suggested applying a broad-spectrum herbicide post-sowing but before tree seedling emergence, to control any germinating weeds. This is effectively a modified nursery stale seedbed technique as described in Williamson and Morgan (1994). However, if non-dormant or pre-treated seed is sown in the autumn or early spring to reduce the risk of re-imposed thermodormancy from warm temperatures (Piotto, 1994), then tree seeds may germinate before weeds, so preventing the use of the stale seedbed technique. Conversely, later sowing at warmer temperatures would favour the control of rapidly germinating weeds, but increases the risk of reduced germination of the tree seed due to thermodormancy.

To allow the early sowing of tree seed in order to maximize potential germination, while still achieving adequate weed control, would require the identification of a suitable soil-acting pre-emergence herbicide. Such a herbicide would need to be applied after sowing in winter or early spring to a weed-free site, and be capable of giving control of germinating weed seedlings for several months, without impacting on tree seedling germination and growth. Pre-emergence herbicides with this type of action are used in conventional nursery production of conifer seedlings (Williamson and Morgan, 1994). However, information on their effect on broadleaved species is limited. Large-seeded species such as oak (*Quercus* sp.), beech (*Fagus sylvatica* L.) and sweet chestnut (*Castanea sativa* Mill.) are listed by Williamson and Morgan (1994) as tolerating applications of 2.0 kg a.i. ha^{-1} simazine, and there are also reports of this herbicide being used in direct-sown oak (*Quercus robur* L.) in field conditions (Kramarev, 1973). This tolerance is probably a result of the depth of soil covering the seeds (around 25 mm) reducing herbicide movement down to seed level.

For smaller-seeded species, Williamson *et al.* (1990) suggested that there may be some potential for the use of repeat low doses of chlorthal-dimethyl on birch and alder, or propyzamide or metamitron on alder only, but adequate weed control in these cases relies on seedbed sterilization, which is not practical outside a nursery. Clay *et al.* (1988) suggested that chlorthal-dimethyl and isoxaben may warrant further testing in alder and birch seedbeds, whilst Richardson and Turner (1980) identified the potential for napropamide, finding that *Nothofagus procera* (*Nothofagus alpina* (Poepp. & Endl.) Oerst), sycamore and birch were tolerant. Cooper (1984) found that chlorthal-dimethyl was severely damaging to maple (*Acer* sp.), alder and birch, but that beech, *Laburnum anagyroides* Medik. and *Robinia pseudoacacia* L. were tolerant. Work in the USA suggested the potential for the use of napropamide, oxadiazon and chlorthal-dimethyl on seedbeds of species such as chokeberry (*Prunus virginiana* L), olive (*Elaeagnus angustifolia* L.), Kentucky coffee tree (*Gymnocladus dioica* (L.) K.Koch.), black locust (*Robinia pseudoacacia* L.), black alder (*Alnus glutinosa* L.) and red oak (*Quercus rubra* L.) (Graunke and Gouin, 1983; Hall *et al.*, 1986; Long and Geyer, 1989; Porterfield *et al.*, 1993; White and Rolf, 1982). (Nomenclature follows Stace (1997), Halliday and Beadle (1983) and Krüssmann (1986).)

The lack of clear consistent evidence for herbicides that may be safe for use in the direct sowing of broadleaved species led to the series of glasshouse pot experiments reported here. An experiment in 1996 was designed to test eight herbicides, which previous evidence and experience suggested might have some potential as post-sowing pre-emergent treatments, over five broadleaved tree species that might be used in direct sowing (I. Willoughby, R.L. Jinks, G., Kerr and P.G. Gosling, unpublished). Experiments in 1997, 1998 and 1999 were repeated for species that had failed to germinate successfully, and extended the range of species tested to include tree and shrub components which could be used to create new native woodlands (Rodwell and Patterson, 1994). An additional experiment in 1999 investigated the effectiveness of tank-mixing two promising herbicides, as well as testing whether tree seedling emergence soon after treatment increased the likelihood of herbicide injury.

Materials and methods

1996 experiment

On 16 April 1996, a compost mixture of 6 parts loam, 1 part peat and 3 parts grit plus 3.3 g l^{-1} slow release Osmocote fertilizer was used to fill 9-cm diameter pots (15-cm diameter pots for oak). Five broadleaved tree species were sown – ash (*Fraxinus excelsior* L.), beech, cherry (*Prunus avium* L.), oak (*Quercus robur* L.) and sycamore (*Acer pseudoplatanus* L.). Ash was subjected to warm and cold pre-treatment (Jinks *et al*., 1995), and sycamore, cherry and beech were given the appropriate cold pre-treatment (Gordon and Rowe, 1982) to break dormancy. Acorns are non-dormant and so did not require pre-treatment. Seed was purchased from Forestart seed merchants. The seedlot quality was tested at the British Official Seed Testing Station in accordance with International Seed Testing Association Rules (ISTA, 1985). Based upon these viability and germination data, seed were counted into batches designed to produce approximately six plants per pot (ash, 12; beech, 10; cherry, 12; oak, 9; and sycamore, 9). For example, it was estimated that approximately 50 per cent of the ash seeds were viable, hence 12 seeds were sown to produce six plants. Seed was sown over a 2-day period onto the surface of the pots, then covered with compost to the same depth as the seed. Species were kept separate and analysed as separate experiments. For each species there were nine herbicide treatments (including one control) at three rates. There were five replicates per treatment, arranged in a randomized block design, making 135 pots (plots) in total per species. Herbicide treatments were sprayed on 18 April using a laboratory track sprayer fitted with an 800-15E flat fan nozzle, and a pressure of 210 kPa, in a spray volume of 475 l ha^{-1}. Treatment details are given in Table 1. Rates were based on a one-third, recommended and three times the recommended rate for weed control among transplants. After spraying, the pots were placed in an unheated glasshouse and watered as necessary to prevent the pots from drying out. Shoot fresh weight was recorded approximately 6–12 weeks after treatment depending on the speed of emergence. Analysis of the number of plants per pot and health scores gave very similar results as shoot fresh weight, and hence these data are not presented for reasons of brevity.

1997 experiment

The 1996 experiment was repeated the following year with sweet chestnut, Norway maple (*Acer platanoides* L.), rowan (*Sorbus aucuparia* L.) and sycamore, the latter being included as emergence of this species in the 1996 experiment had been poor. Norway maple and sycamore had an appropriate cold pre-treatment, and rowan a short warm followed by a cold pre-treatment (Gordon and Rowe, 1982). Chestnut is considered to be non-dormant. Seed was sown on 23 April 1997 in 9-cm diameter pots (15-cm diameter pots for chestnut). Based upon seedlot quality, seven rowan, eight maple, eight sycamore and five chestnut seeds were sown per pot and covered with a seed's depth of compost. Herbicide treatments were sprayed on 24 April 1997 using a laboratory track sprayer fitted with an 800-15E flat fan nozzle at a pressure of 252 kPa and a spray volume of 430 l ha^{-1}. Treatment details are given in Table 2. The three species were treated separately. For each species there were nine treatments (including one control) at three rates. There were five replicates per treatment, arranged in a randomized block design, making 135 pots (plots) in total per species.

1998 experiments

Emergence of beech was poor in 1996, and chestnut and Norway maple was poor in 1997, hence these species were trialled again in 1998 at two sowing dates to improve their chances of good germination. Beech and chestnut seeds (eight and five seeds per pot, respectively, based upon viability tests) were sown on 2 December 1997 into 15-cm diameter pots. Seeds were covered with a seed's depth of compost, lightly watered from overhead and placed in a cold, gauze-sided glasshouse to overwinter. At the end of February, the chestnuts were carefully moved into deeper pots and covered with compost. The winter-sown beech had not received a cold pre-treatment, as it was not required. However, spring-sown maple and beech did receive the appropriate pre-treatment before sowing (Gordon and Rowe, 1982). At the end of March 1998, another batch of beech and chestnut seeds were planted as before, and maple seeds were sown in 9-cm diameter pots using the same compost mixture. Eight seeds were planted per pot, wings being removed before

Table 1: Treatment details, numbers of plants, and fresh weights, 1996 experiment

				Shoot fresh weight (g/pot)		
Active ingredient	Product	Formulation (kg ha^{-1} a.i.)	Rate	Ash, harvested 19/6/96	Cherry, harvested 7/6/96	Oak, harvested 7/8/96
Isoxaben	Flexidor 125	125 g l^{-1} SC	0.042	10.2	16.5	27.9
			0.125	8.4	15.0	29.6
			0.375	2.2	1.0	32.9
Lenacil	Venzar	80% w/w WP	0.59	9.1	13.7	29.9
			1.76	0.8	2.1	29.4
			5.28	0.0	0.1	18.6
Metamitron	Goltix WG	70% w/w WG	1.17	11.6	9.6	26.6
			3.5	10.2	3.1	27.3
			10.5	4.2	1.2	32.7
Metazachlor	Butisan S	500 g l^{-1} SC	0.21	7.2	9.2	34.5
			0.625	0.1	2.6	33.2
			1.875	0.1	0.2	24.7
Napropamide	Devrinol	450 g l^{-1} SC	0.33	11.3	19.0	36.3
			0.99	14.1	18.9	31.9
			2.97	14.7	11.8	24.9
Pendimethalin	Stomp 400 SC	400 g l^{-1} SC	0.3	15.9	17.8	27.8
			1.0	12.2	11.2	31.2
			3.0	14.5	4.3	35.7
Propyzamide	Kerb Flo	400 g l^{-1} SC	0.25	13.8	13.3	33.5
			0.75	8.1	4.5	32.8
			2.25	1.5	0.4	28.5
Simazine	Gesatop 500 SC	500 g l^{-1} SC	0.7	7.5	11.6	29.1
			2.0	2.6	1.4	29.1
			6.0	0.0	0.0	29.4
Untreated control				13.8	17.6	31.4
P (control versus treated)				<0.001	<0.001	0.468
SED				1.51	2.04	3.87
d.f.				106	106	106
$t(P = 0.05)$				1.98	1.98	1.98
LSD				2.99	4.04	7.68

SC = suspension concentrate; WG = wettable granules; d.f. = residual degrees of freedom; WP = wettable powder: a.i. = active ingredient; SED = standard error of difference of means, for individual herbicide rate comparisons; LSD = least significant difference at $P = 0.05$.

planting. Herbicides were applied on 27 March 1998 using the same equipment as the 1997 experiment – details are contained in Table 2. Species were treated separately. For each species (winter- and spring-sown chestnut were treated as separate species) there were nine herbicide treatments (including one control) at three rates. There were eight replicates per treatment arranged in a randomized block design, giving a total of 216 pots (plots) per species.

1999 experiments

On 26 March 1999, 10 field maple seeds (*Acer campestre* L.), 20 birch seeds (*Betula pendula* Roth.), five hazel seeds (*Corylus avellana* L.), eight dogwood seeds (*Cornus sanguinea* L.), eight hawthorn seeds (*Crataegus monogyna* Jacq.) and eight crab-apple seeds (*Malus sylvestris* (L.) Mill.) were sown in 15-cm diameter pots. All seed was subject to an appropriate pre-treatment regime

Table 2: Treatment details, numbers of plants and fresh weights, 1997 and 1998 experiments

Active ingredient	Product	Formulation	Rate (kg ha^{-1} a.i.)	Shoot fresh weight (g/pot) Rowan harvested 16/6/97	Sycamore harvested 16/6/97	Chestnut sown Dec. harv. 20/5/98	Chestnut sown March harv. 9/7/98	Beech sown Dec. harv. 17/6/98	Norway maple harvested 17/6/98
Diflufenican	AmazonTP	500 g l^{-1} SC	0.04	0.6	11.0	6.7	9.4	5.8	6.6
			0.10	0.6	10.9	4.9	6.6	6.5	5.5
			0.30	0.0	12.3	4.8	6.8	6.7	4.4
Isoxaben	Flexidor 125	125 g l^{-1} SC	0.04	1.6	11.2	4.9	6.8	7.3	6.9
			0.12	1.9	12.7	5.2	9.7	6.3	6.8
			0.37	1.5	9.8	4.8	7.9	6.0	4.7
Metamitron	Goltix WG	70% w/w WG	1.19	0.9	10.1	3.5	3.3	6.5	6.6
			3.50	0.0	12.2	4.1	6.2	6.3	4.5
			10.50	0.0	11.1	3.6	4.2	7.0	3.9
Metazachlor	Butisan S	500 g l^{-1} SC	0.21	1.2	14.1	4.8	5.8	6.8	5.1
			0.62	0.1	12.0	3.7	3.4	6.7	5.4
			1.87	0.1	6.1	2.0	2.1	7.4	1.4
Napropamide	Devrinol	450 g l^{-1} SC	0.33	2.6	11.5	3.4	9.0	6.3	3.3
			0.99	2.1	12.2	2.6	6.9	6.7	4.9
			2.97	2.1	12.2	1.1	5.0	6.9	3.4
Pendimethalin	Stomp 400 SC	400 g l^{-1} SC	0.33	2.0	11.8	4.6	6.8	6.8	5.8
			1.00	0.6	13.3	5.7	8.2	6.8	6.1
			3.00	0.1	10.4	3.4	7.6	6.5	3.4
Propyzamide	Kerb Flo	400 g l^{-1} SC	0.25	1.2	9.6	4.8	5.0	5.9	4.0
			0.75	0.4	12.0	3.3	8.5	6.6	3.0
			2.25	0.0	6.7	2.6	4.3	5.0	0.9
Simazine	Unicrop	500 g l^{-1} SC	0.65	3.1	11.4	5.3	6.6	6.2	2.6
		Simazine	2.00	0.3	8.9	4.5	7.3	6.9	2.9
		Flowable	6.00	0.3	3.8	5.9	6.7	6.8	0.3
Untreated control				2.4	11.1	6.0	9.8	6.3	4.6
P (control versus treated)				<0.001	0.561	<0.001	<0.001	0.478	0.701
SED				0.38	1.29	0.85	2.01	0.60	1.17
df				106	106	184	184	184	184
$t(P = 0.05)$				1.98	1.98	1.98	1.98	1.98	1.98
LSD				0.75	2.55	1.67	3.94	1.19	2.32

SC = suspension concentrate; a.i. = active ingredient; d.f. = residual degrees of freedom; LSD = least significant difference at $P = 0.05$; WG = wettable granules; SED = standard error of difference of means, for individual herbicide rate comparisons.

(Gordon and Rowe, 1982). Pots were sprayed on 26 April using a laboratory track sprayer fitted with an 800-15E flat fan nozzle, at a pressure of 252 kPa and in a spray volume of 430 l ha^{-1}. Treatments are given in Table 3. Each species was treated separately. There were two herbicide treatments at three rates, plus two controls. There were eight replicates per species arranged in a randomized block design, giving 64 plots in total per species.

A second experiment in 1999 used ash seed pre-treated to overcome dormancy (Jinks *et al.*, 1995). Ash was sown (six seeds per pot, based on viability tests) on 8 April into 12-cm diameter pots, with the same soil mix and irrigation treatments as in previous experiments. Herbicides were applied as above. Herbicide treatments are summarized in Table 4. Seed was stratified into two groups: (1) germinating at the time of sowing, and (2) no germination apparent. This effectively enabled applications to be made at four growth stages: post-sowing (8 April), seed germination (8 April), first seedlings emerging (29 April) and most seedlings emerging (4 May). Assessments were as in previous experiments. There were two herbicide treatments at three rates at four application timings plus three untreated controls. Eight replicates of these treatments were arranged in a randomized block design, giving a total of 216 pots (plots).

Data from all experiments were subject to analysis of variance using GENSTAT (Genstat, 1993). The *P* value presented gives the level of probability for the comparison between the control and treatment means, the null hypothesis of no effect of treatments was rejected at the $P = 0.05$ significance level. In other words, *P* values of 0.05 or less indicate a >95 per cent probability that the treatments had an effect. Tests for control versus treated, main effects and interaction were carried out. However, for simplicity, only control versus treated *P* values and SEDs for individual means are presented. Data were then subjected to Fisher's least significant difference test (Snedecor and Cochran, 1967) – those treatment means differing by more than the LSD given are significantly different at the $P \leq 0.05$ level (i.e. there is a >95 per cent probability that the difference in the means could not have occurred by chance).

Results

1996 experiment

Table 1 gives shoot fresh weights for each treatment at the time of harvesting for the 1996 experiment. The beech failed to germinate and sycamore (data not presented) emergence was poor. Generally, the oak was least affected by the herbicides, followed by sycamore, with ash and cherry being more sensitive. Oak was resistant to most of the herbicide treatments. Only the highest rates of lenacil, metazachlor and napropamide (the latter two not significant, but causing a 20 per cent reduction in growth) significantly reducing shoot fresh weight. Ash growth was suppressed by most herbicides at medium and high doses, except for napropamide and pendimethalin. Shoot growth of cherry was affected by most herbicides, but medium doses of napropamide and isoxaben did not reduce growth.

1997 experiment

Germination of chestnut and maple was very poor generally – no assessments were possible. Rowan and sycamore growth was satisfactory (Table 2). Napropamide appeared to be safe on both species, with no significant reductions in growth at any dose. All other herbicides either severely reduced growth or resulted in the death of rowan, except for low rates of pendimethalin or simazine. Sycamore was unaffected by applications of napropamide, diflufenican (after initial chlorosis), metamitron or pendimethalin. Growth was largely unaffected by applications at low and medium doses of isoxaben, metazachlor, propyzamide and simazine, but was significantly reduced at the highest dose rates.

1998 experiment

Table 2 also shows the results of the 1998 experiment. Germination was variable – only 40 per cent of the March-sown chestnut germinated, and March-sown beech failed completely. With the December-sown chestnut, some shoots were emerging at the time of spraying. For March treatments, on chestnut, isoxaben and pendimethalin appeared to have least effect (no significant growth reductions). Diflufenican and simazine also gave no significant effects, although

Table 3: Treatment details, numbers of plants and fresh weights, 1999 experiment

Active ingredient	Product	Formulation	Rate (kg ha^{-1} a.i.)	Shoot fresh weight (g/pot) Field maple harvested 2/6/99	Birch harvested 15/6/99	Hazel harvested 15/6/99	Dogwood harvested 21/6/99	Hawthorn harvested 15/6/99	Crab-apple harvested 15/6/99
Napropamide	Devrinol	450 g l^{-1} SC	0.99	13.2	3.6	3.4	1.7	6.1	7.8
			2.97	6.8	0.2	1.0	0.9	3.7	7.3
			4.05	10.1	0.1	1.4	0.6	3.7	6.9
Pendimethalin	Stomp 400 SC	400 g l^{-1} SC	0.60	14.5	2.4	4.4	1.1	7.4	6.2
			2.00	5.0	0.1	5.0	0.7	2.6	2.0
			3.00	6.2	0	0.7	0.3	2.2	2.1
Untreated control				12.8	7.6	7.2	1.6	5.3	9.0
P (control versus treated)					0.005	<0.001	0.002	0.016	0.267
0.011									
SED				1.78	0.66	2.02	0.43	1.38	2.07
d.f.				50	50	50	50	50	50
t				2.00	2.00	2.00	2.00	2.00	2.00
LSD				3.58	1.32	4.05	0.86	2.77	4.16

SC = suspension concentrate; a.i. = active ingredient; SED = standard error of difference of means for individual herbicide rate comparisons; d.f. = residual degrees of freedom; LSD = least significant difference at $P = 0.05$.

Table 4: Treatment details, number of plants and shoot weight, 1999 ash sowing date experiment

				Shoot fresh weight (g/pot)			
Active ingredient	Product	Formulation	Rate (kg ha^{-1} a.i.)	Ash, post sowing harvested 21/6/99	Ash, seed germinating harvested 21/6/99	Ash, seedlings emerging harvested 21/6/99	Ash, seedlings emerged harvested 21/6/99
Napropamide	Devrinol	450 g l^{-1} SC	0.99	9.5	15.2	7.6	7.4
			2.97	9.4	15.1	8.0	5.3
			4.05	8.7	12.6	8.5	4.8
Pendimethalin	Stomp 400 SC	400 g l^{-1} SC	0.60	7.2	12.5	8.6	5.5
			2.00	7.5	11.2	3.3	2.0
			3.00	6.8	8.5	3.1	1.4
Napropamide + Pendimethalin	Devrinol + Stomp 400 SC	450 g l^{-1} SC + 400 g l^{-1} SC	0.99 + 0.60	9.1	–	–	–
			2.97 + 2.00	6.8	–	–	–
			4.05 + 3.00	7.0	–	–	–
Untreated control				12.1	12.1	12.1	12.1
P (control versus treatment)				<0.001	<0.001	<0.001	<0.001
P (control versus treatment × date interaction)				<0.001	<0.001	<0.001	<0.001
SED				1.14	1.14	1.14	1.14
d.f.				79	79	79	79
t				2.00	2.00	2.00	2.00
LSD				2.28	2.28	2.28	2.28

SC = suspension concentrate; a.i. = active ingredient; SED = standard error of difference of means for individual herbicide rate comparisons; d.f. = residual degrees of freedom; LSD = least significant difference at $P = 0.05$.

growth was reduced by around 30 per cent. For other herbicides the effects were variable, but all caused significant reductions in growth at the highest rates. Some herbicides were more damaging to December-sown than to March-sown chestnut, for example napropamide and pendimethalin. Beech was unaffected by most of the treatments – only the highest rate of propyzamide gave any significant reduction in shoot growth. Norway maple growth was only significantly reduced by propyzamide, simazine and metazachlor. However, whilst not statistically significant, the highest rates of napropamide and pendimethalin also reduced growth by around 25 per cent.

1999 experiment

Table 3 shows the results for the 1999 experiment. With germination being generally poor, only a small number of plants were obtained for most species. However, results with most of the species, except possibly dogwood and hazel, give an indication of likely response in the field. Hawthorn and crab-apple appeared to tolerate napropamide well, and were unaffected by any of the doses of napropamide. Growth of field maple was significantly reduced by the medium dose, but not the highest dose. Dogwood tolerated the lower doses but growth was significantly reduced by the highest dose. Napropamide was not well tolerated by either hazel or birch, where severe reductions in growth were shown from all doses, most of which was statistically significant. Pendimethalin was not tolerated by any of the species at the highest dose – birch and hazel were particularly badly affected, with virtually no growth remaining. Growth of dogwood, hazel and hawthorn was not statistically significantly reduced by the two lowest doses, although there were appreciable reductions in growth from the medium (recommended) dose. Field maple and crab-apple were severely damaged by the two higher doses, and growth of crab-apple was reduced, albeit not significantly, by the lowest dose. Growth of birch was severely restricted by all doses.

1999 sowing date experiment

Overall emergence and growth of ash was good. There were significant differences between dates and treatments ($P < 0.001$). Generally pendimethalin caused slightly more damage than napropamide (Table 4), but the greatest differences in performance were observed between the dates of applications rather than between herbicides and doses, with the second application 'date' (to just chitted seed) resulting in the least damage. Mixtures of napropamide and pendimethalin applied at the first date gave results generally little different from the values for the individual herbicides.

Discussion and conclusions

Overall germination and emergence of some species was variable, despite using pre-treated seed. Hence, even with good replication, there were some anomalous situations where this led to apparently more damage being caused by lower than higher application rates. In addition, variable emergence led to situations where considerable reductions in growth (up to 20 per cent in some cases) did not result in statistically significant results. This problem could be mitigated in future experiments by further increasing replication. An attempt to give a practical measure of susceptibility is given in Table 5. Further caution must be used when interpreting these results, due to the fact that trees grown in pots are likely to be more susceptible to soil-acting herbicides, as roots are more restricted to herbicide-treated soil than in field-grown trees. Conversely, the peat contained in the compost mixture could have potentially reduced residual herbicide efficacy, as occurs in soils with high organic matter contents (Willoughby and Dewar, 1995), although there was no evidence of this from the results.

Some herbicides, in particular napropamide and pendimethalin, which appeared to have some potential in the early trials, proved to be surprisingly damaging to December-sown chestnut. This probably resulted from herbicide application during the main period of seedling emergence. Many of the herbicides tested can be absorbed through a sensitive hypocotyl, and this probably caused the observed damage – by the time the March-sown chestnuts were emerging, herbicide concentrations would have been lower, and there was less damage. Emergence of tree seeds soon after herbicide application could therefore be

Table 5: Tolerance of broadleaved tree species to preemergence post sowing herbicides

Herbicide	Product	Formulation	Rate. kg ha^{-1} a.i	Rate l ha^{-1} product	Ash	Cherry	Oak	Syca-more	Rowan	Chest-nut[†]	Beech	Norway maple	Field maple	Birch	Hazel	Dog-wood	Haw-thorn	Crab-apple
Diflufenican	Amazon TP	500 g l^{-1} SC	0.30	0.6	–	–	–	R (0)	S (100)	MS (31)	R (0)	R (4)	–	–	–	–	–	–
Isoxaben	Flexidor 125	125 g l^{-1} SC	0.375	3.0	S (84)	S (94)	R (0)	MR[‡] (22)	MS (39)	MR[‡] (19)	R (5)	R (0)	–	–	–	–	–	–
Lenacil	Venzar	80% w/w WP	5.28	6.6	S (100)	S (100)	MS[**] (41)	–	–	–	–	–	–	–	–	–	–	–
Metamitron	Goltix WG	70% w/w WG	10.50	15.0	S (70)	S (93)	R (0)	R (0)	S (100)	S (57)	R (0)	MR[¶] (15)	–	–	–	–	–	–
Metazachlor	Butisan S	500 g l^{-1} SC	1.88	3.75	S (100)	S (99)	MR (21)	MS (45)	S (96)	S (79)	R (0)	R (0)	–	–	–	–	–	–
Napropamide	Devrinol	450 g l^{-1} SC	2.97	6.6	R (0)	MS1 (33)	MR1 (21)	R (0)	MR (12)	MS (49)	R (0)	MS[*] (26)	MR[††] (21)	S (98)	S (86)	MS[*] (44)	MS[*] (30)	MR (19)
Pendimethalin	Stomp 400 SC	400 g l^{-1} SC	3.00	7.5	R (0)	S (76)	R (0)	R (6)	S (96)	MR (22)	R (0)	MS[§§] (26)	S[‡‡] (52)	S (99)	S (90)	S (81)	S[‡‡] (58)	S (77)
Propyzamide	Kerb Flo	400 g l^{-1} SC	2.25	5.6	S (89)	S (98)	R (9)	MS[§] (40)	S (100)	S (66)	MR[§] (21)	S (83)	–	–	–	–	–	–
Simazine	Unicrop Simazine FL	500 g l^{-1} SC	6.00	12.0	S (100)	S (100)	R (6)	S (66)	S (87)	MS (32)	R (0)	S (93)	–	–	–	–	–	–

Figures for actual control in experiments given in parentheses.

S = >50 per cent reduction in growth compared to the untreated control (based on shoot fresh weight, 2 months after application); MS = 26–50 per cent reduction in growth; MR = 11–25 per cent reduction to tree growth; R = Resistant (<10 per cent reduction in survival and growth).

[*] Resistant at 0.99 kg a.i. ha^{-1} napropamide

[†] Results are for less susceptible March sowing

[‡] Resistant at 0.125 kg a.i. ha^{-1} isoxaben

[§] Resistant at 0.75 kg a.i. ha^{-1} propyzamide

[¶] Resistant at 3.50 kg a.i. ha^{-1} metamitron

[**] Resistant at 1.76 kg a.i. ha^{-1} lenacil

[††] At 4.05 kg ai ha^{-1} napropamide

[‡‡] Resistant at 0.6 kg ai ha^{-1} pendimethalin

[§§] Resistant at 1.0 kg ai ha^{-1} pendimethalin problematic – herbicides may need to be applied earlier in the year (February to early March, as opposed to late March) to avoid crop injury. The ash sowing-date experiment in 1999 was set up to examine this further. It used pre-treated ash seed which was expected to germinate very rapidly and allow seedling emergence within 3 weeks of sowing. All herbicide treatments apart from those applied to chitted seed caused some growth reduction, particularly at the higher doses. However, there was clear evidence that the later application to emerging seedlings caused more damage. It is likely with these herbicides that uptake could occur through actively growing hypocotyl and seed leaves, which restricted growth. However, the application to chitted seed, which emerged very quickly, caused least damage. This is probably due to these selected plants being more vigorous than others, as shown by the values for the lower napropamide doses being significantly higher than the untreated. In retrospect it would have been useful to have had separate control treatments for this sowing date. The separation of chitted and unchitted seed to give different treatment dates was necessitated by the condition of the seed on receipt. If the experiment is to be repeated, seed should be procured when it is all unchitted, then split randomly into different emergence-date treatments.

The absence of any increase in damage from the mixtures of napropamide and pendimethalin compared with the herbicides alone may indicate that mixtures in the field do not increase the possibility of damage. These results are in contrast to a previous experiment where mixtures of napropamide with diphenamid and chlorthal-dimethyl caused appreciably more damage than napropamide alone when applied to Sitka spruce and birch, although these results were not statistically significant. Larch suffered no greater damage (J. Lawrie and D.V. Clay, unpublished results).

Based on the screening trials from 1996 to 1999, Table 5 summarizes the relative tree tolerance to the various herbicides tested. Based upon this information, isoxaben, napropamide and pendimethalin were judged to have the most potential for use on direct-sown ash and sycamore. Subsequent field trials (data not presented) have confirmed the safety of napropamide and pendimethalin used with direct-sown ash and sycamore. Other herbicide/species combinations have not been tested in field conditions, but nevertheless it is possible from these trials to make the following provisional recommendations.

Ash, sycamore or beech may tolerate applications of up to 6.6 l ha^{-1} of napropamide (as Devrinol). Rowan is only moderately resistant at this rate. Cherry, oak and Norway maple may tolerate applications of napropamide (as Devrinol) at 2.2 l ha^{-1}. Pendimethalin (as Stomp) may be safe to apply up to 5 l ha^{-1} to ash, oak, sycamore and beech. Chestnut is moderately resistant. Norway maple may be tolerant of up to 2.5 l ha^{-1} of pendimethalin (as Stomp), whereas field maple and hawthorn may tolerate applications of up to 1.5 l ha^{-1} pendimethalin (as Stomp). Tank mixes of pendimethalin and napropamide appear to be as safe as the products alone, and offer better weed control than using the herbicides separately. Oak or beech appear to tolerate applications of simazine (as Unicrop Simazine FL) at up to 4.0 l ha^{-1}. Other herbicides, such as diflufenican (if available), isoxaben, metamitron, metazachlor and propyzamide, may have potential on a more limited range of species (see Table 5), and may be worth considering if the expected weed spectrum warrants their use. Results with some species, in particular dogwood and hazel, were affected by poor germination and growth and the experiments need to be repeated.

The 1999 sowing date work suggests that it is prudent to ensure that at least 2 weeks elapse between treatment and subsequent tree seed germination. Precise treatment timings will therefore depend on sowing date and ground conditions, but in general, for autumn sowings, mixtures of napropamide and pendimethalin should be sprayed in November–February. For other herbicides, if napropamide is not used, after either spring or autumn sowings, the aim should be to spray in late February to mid-March. Tree seeds should be covered with soil as per normal practice, i.e. to approximately the same depth as the size of the seed itself.

These conclusions are provisional only and are based primarily on glasshouse or small-scale field trials. Small field trials need to be carried out by users before adopting these recommendations on a large scale. Even herbicides shown to be safe in the potentially more damaging situation of pot trials may still result in delayed emergence or increased tree seedling mortality in field conditions. However, any effects are likely to be minor, and unlikely to be as damaging as mortality resulting from competition from untreated weed vegetation. Damage may be greater in light-textured nursery soils with little organic matter.

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