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Tolerance of broadleaved tree and shrub seedlings to preemergence herbicides

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Abstract Control of competing vegetation is essential for the successful establishment of tree seedlings in nurseries and direct-sown woodland; this usually requires potentially expensive hand weeding or post-sowing preemergence herbicides. In order to identify suitable herbicides, two container experiments tested the response of 12 broadleaved tree and shrub species to napropamide and pendimethalin applied preemergence. Most species tolerated rates adequate for controlling many annual weed species although *Rhamnus cathartica* L. (buckthorn) and *Alnus glutinosa* (L.) Gaertn. (alder) were damaged by all rates of napropamide. A study of application date of napropamide and pendimethalin applied post-sowing to *Fraxinus excelsior* L. (ash) in containers showed that pendimethalin was damaging if applied when seeds were germinating or seedlings emerging, but napropamide was tolerated at all growth stages. A field experiment tested the tolerance of ten species sown in seedbeds to napropamide alone and in mixture with pendimethalin. Results generally confirmed the indications of tolerance from the container experiments. Applications of 2 kg a.i. ha^{-1} napropamide plus 2 kg a.i. ha^{-1} pendimethalin appeared to be safe on *Corylus avellana* L. (hazel), *Fagus sylvatica* L. (beech), and *F. excelsior*, provided tree seeds were sown to the correct depth and at least 2 weeks elapsed between herbicide treatment and tree seed germination. The mixture of 2 kg a.i. ha^{-1} pendimethalin plus 1.0 kg a.i. ha^{-1} of napropamide was tolerated by *Acer pseudoplatanus* L. (sycamore) and *Crataegus monogyna* Jacq. (hawthorn). Applications of 1.0 kg a.i ha^{-1} napropamide alone were moderately tolerated by *Carpinus betulus* L. (hornbeam) and *Cornus sanguinea* L. (dogwood).

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Introduction

The out-planting of seedlings raised in tree nurseries is the principal method for establishing woodlands in the United Kingdom (UK) where the use of natural regeneration is not viable. This is partly because the problems of seed predation and weed competition are more easily addressed in an intensively managed nursery site (Willoughby et al. 2004a). However, recent studies have shown that direct seeding, where tree seed is sown in the actual location to be afforested, is worth considering in certain limited situations (Willoughby et al. 2004b). In both nursery production and direct seeding systems, weeds can compete with tree seedlings for light, moisture and nutrients, which can kill small, recently emerged seedlings. Hand weeding is possible in nurseries although costly, but is not a practical option on extensive direct-seeded sites (Willoughby 1996). In both systems, the use of herbicides is attractive as a cost-effective option for many managers.

Vegetation management is probably most important in the first season after tree seedling emergence since small trees are least able to compete with vigorous, faster growing weed species. For direct sown trees, Willoughby et al. (2004b) recommend preparing the ground using a modified stale seedbed technique involving removal of existing vegetation with contact herbicides in the year before sowing, followed by cultivation, and then the use of contact herbicide to control germinating weeds prior to sowing. However, to control weeds that germinate immediately after tree seedling emergence in the spring, suitable post sowing, preemergence herbicides need to be identified. Williamson and Morgan (1994) give details of post-sowing preemergence herbicides for use over conifers in forest nurseries in the UK, but there is only limited information on tolerance of broadleaved species. In glasshouse experiments, Willoughby et al. (2003) identified a number of herbicides that could control newly germinating weed seed, whilst allowing broadleaved tree seed to germinate unharmed. Of the herbicides tested, napropamide and pendimethalin appeared to offer the greatest potential. Work in the USA has also highlighted the potential for the use of napropamide on seedbeds of broadleaved species (Warmund et al. 1980, 1983; South 1984; Geyer and Long 1988; Long and Geyer 1989; Sumaryono and Crabtree 1989; Warren and Skroch 1991; Porterfield et al. 1993).

In Experiment 1 reported here, we investigated the herbicide tolerance of a range of native tree and shrubs species that can be used in direct seeding, but about which there appears to be little published information. Previous work suggested that tree tolerance to herbicides might be reduced if applications are made close to the time of seedling emergence (Willoughby et al. 2003). Therefore, in Experiment 2, the tolerance of *Fraxinus excelsior* L. seeds to different application timings (pre, during and post-seedling emergence) of napropamide and pendimethalin was investigated. In Experiment 3, where the objective was to investigate the herbicide tolerance of a number of previously untested native tree and shrub species, larger containers were used to increase the volume of growing medium available per seedling since there is some evidence that susceptibility to test-applications of herbicide is increased in small pots (Copping et al. 1990). Experiment 4 took place in a nursery to confirm herbicide tolerance under field conditions and test tolerance to mixtures of napropamide and pendimethalin. Mixtures of residual herbicide are often required to control the wide range of weed species occurring on recently afforested land.

Materials and methods

Experiment 1: Tolerance of shrub species to napropamide and pendimethalin applied over newly sown seed

Experiment 1 took place in a glasshouse at Long Ashton Research Station, near Bristol, UK (51°25′N, 2°40′W). This location receives an average annual precipitation of 870 mm and 1,922 growing degree days (above 4°C). Seed of *Alnus glutinosa* (L.) Gaertn. (alder), *Carpinus betulus* L. (hornbeam), *Cornus sanguinea* L. (dogwood), *Prunus spinosa* L. (blackthorn), *Sorbus aria* (L.) Crantz (whitebeam), pretreated as necessary to break dormancy (Gordon and Rowe 1982) was sown at rates of 19, 16, 16, 16 and 20 seeds per pot, respectively. Seed numbers were adjusted to take account of anticipated germination rate based on seed lot viability. The 12.5 cm diameter × 9 cm depth, 1 l pots contained a medium of 3:2:1:1 steam sterilised loam, peat, Cornish grit and perlite. Osmocote® fertiliser (3–4 months duration, 14% N, 14% P_2O_5, 14% K_2O) at 4.5 g l^{-1} and magnesium limestone at 3.3 g l^{-1} were added to the medium. Seed was surface sown on 2 February 2000, except for *A. glutinosa*, which was sown on 22 February. Seeds were covered with their own depth of medium and watered lightly overhead prior to herbicide application on the same day. All seeds were ungerminated at the time of sowing except *C. betulus* and *P. spinosa* where between 10 and 15% of seeds had emerged radicles. For each species there were five replicates of nine treatments (consisting of two herbicides × three rates, plus three untreated controls) for a total of 225 pots (45 for each species).

Napropamide as Devrinol®, 450 g a.i. l^{-1} SC (United Phosphorous Ltd., Warrington, UK) at 1.0, 3.0 and 4.05 kg a.i. ha^{-1}, and pendimethalin as Stomp 400 SC®, 400 g a.i. l^{-1} SC (Cyanamid Agriculture UK) at 0.6, 2.0 and 3.0 kg a.i. ha^{-1} were sprayed after sowing using a laboratory track sprayer fitted with an 80015E flat fan nozzle, at a pressure of 252 kPa and in a spray volume of 430 l ha^{-1}. Pots were lightly watered overhead 24 h after spraying to incorporate the herbicide and then set out in randomised blocks with the species being kept separate.

Plant vigour was estimated visually at intervals using a score of 0–7; where 0 = no growth, 4 = 50% reduction compared with the best untreated and 7 = as best untreated. Shoot fresh weight per pot was recorded at the end of the experiment. Data were subjected to Analysis of Variance using Genstat® (Genstat 5 Committee 1993), and then Fisher's Least Significant Difference test was performed at the $P \leq 0.05$ level (Snedecor and Cochran 1967). LSD's given are for control versus treatment (individual herbicide and rate combinations) comparisons.

Experiment 2: Tolerance of *Fraxinus excelsior* to napropamide and pendimethalin applied at different stages of seedling emergence

Location, containers, compost, sowing, herbicide application and assessment details were the same as Experiment 1 but pots were set out 24 h after spraying on outdoor sand beds with capillary irrigation. Non-germinated *F. excelsior* seed, pretreated to break dormancy by controlling storage moisture content and temperature (Jinks et al. 1995), was sown at a rate of 16 seeds per pot on 2 March 2000 onto the medium as described for Experiment 1 and watered lightly overhead after sowing. The first herbicide application was made immediately after sowing on 2 March, the second on 22 March when there were 2–3 seeds germinating per pot together with an occasional radicle present. The third application was made on 4 April when there were 2–4 seedlings per pot with cotyledons emerged, and an occasional seedling with a fully expanded first pair of leaves. At each of the three application dates there were nine herbicide treatments (two herbicides × three rates plus three untreated controls) with five replicates of each treatment giving a total of 135 pots. These were set out in randomised blocks, with application dates kept separate.

Assessments and statistical analysis were the same as for Experiment 1.

Experiment 3: Tolerance of four species grown in large troughs to preemergence applications of napropamide and pendimethalin

Location, sowing, herbicide treatment and assessment details were the same as Experiment 2, but rigid plastic troughs $60 \times 15 \times 15$ cm^3 were used, with one species sown on each half of a trough. Each trough contained a growing medium of 4:2:1 sterilised loam, peat and Cornish grit, prepared on 30 January 2001. Osmocote fertiliser (5–6 months duration, 14% N, 14% P_2O_5, 14% K_2O) at 4.5 g l^{-1} and magnesium limestone at 2.7 g l^{-1} were also added to the medium. Seed of *Corylus avellana* L. (hazel), *Euonymus europaeus* L. (spindle), *Rhamnus cathartica* L. (buckthorn) and *Viburnum lantana* L. (wayfaring tree), pretreated where necessary to break dormancy (Gordon and Rowe 1982), was sown onto the surface on 31 January and 1 February at 32, 149, 129 and 195 seeds per half trough, respectively. Seeds were then covered with their own depth of soil and lightly watered overhead. After sowing, the troughs were set outdoors on walled capillary beds, which offered partial protection from wind and frost.

Herbicides were sprayed on 7 March 2001; applications were preemergence to bare soil, except for *E. europaeus* where there were occasional cotyledons emerging. There were four replicates of nine herbicide treatments (two herbicides × three rates plus three untreated controls) giving a total of 108 troughs (36 troughs each with two species). Troughs were set out in randomised blocks.

Assessments and statistical analyses were the same as for previous experiments except that for *C. avellana* and *E. europaeus*, because a non-destructive assessment was needed, shoot height was recorded but not shoot fresh weight.

Experiment 4: Tolerance of seven tree species to napropamide and pendimethalin

Experiment 4 was sited within a fenced enclosure at Headley Research Nursery, Hampshire, UK (51°08′N, 1°51′W), which receives an average annual precipitation of 804 mm and 1,798 growing degree days (above 4°C). Soil type according to Mackney et al. (1983) was a humic–ferric podzol, Shirrell Heath 1 series. Soil was pretreated with Basamid® (97%w/w dazomet; Certis). Seedbeds 1.1 m wide were prepared, and plots 10 m long marked for the herbicide treatments, with the tree species forming 1 m sub plots. A 0.5 m buffer was left between sub plots. A base dressing of 475 kg ha^{-1} 0: 24: 24 ($N: P_2O_5: K_2O$) fertiliser was applied before sowing, and three top dressings of 100 kg ha^{-1} 25: 0: 15 ($N: P_2O_5: K_2O$) fertiliser were applied during the growing season, with irrigation being applied if no rainfall occurred within 24 h of application. Seeds of *Acer pseudoplatanus* L. (sycamore), *C. avellana, C. betulus, Crataegus monogyna* Jacq. (hawthorn), *C. sanguinea, Fagus sylvatica* L. (beech) and *F. excelsior*, pretreated where necessary to break dormancy (Gordon and Rowe 1982), were sown in drills at a rate of 20 viable seeds per m length of drill on 8–14 May 2001. Sowing depths were 4 cm for hazel, and 2 cm for the remaining species. Drills were back filled and firmed down, and a thin covering of light grit was applied that was lime-free. Immediately after sowing, one of three herbicide treatments: 1.0 kg a.i. ha^{-1} napropamide, 1.0 kg a.i. ha^{-1} napropamide plus 2.0 kg a.i. ha^{-1} pendimethalin, or a mixture of 2.0 kg a.i. ha^{-1} napropamide plus 2.0 kg a.i. ha^{-1} pendimethalin were applied with a CP3 Knapsack Sprayer®, at a volume rate of 200 l ha^{-1}, using a green Polijet® nozzle delivering 1,200 ml min^{-1} at a pressure of 100 kPa. Seedbeds were then netted against birds, and mice were controlled with baited snap-traps. Irrigation after sowing was applied (6 mm over 2 h), and the same rate subsequently through the growing season when soil moisture tension at 15 cm depth fell to 50 kPa. For each of the seven species there were three replicates of the four treatments (three herbicide plus one control treatment), giving 12 sub plots per species arranged in a randomised block split plot design, with 84 sub plots in total.

Seedling emergence, height and stem diameter at the soil surface were assessed at the end of the first growing season (February 2002). The proportion of seedlings that emerged for each species was analysed using a generalised linear model with binomial error distribution and logit link function. The significance of the herbicide treatment was tested using a chi-squared test of the deviance, except when over dispersion was present when an *F*-test was used. Seedling height and diameters were subject to Analysis of Variance using Genstat® (Genstat 5 Committee 1993), and then Fisher's Least Significant Difference test was performed at the $\alpha = 0.05$ level. (Snedecor and Cochran 1967).

Results

Experiment 1: Tolerance of shrub species to napropamide and pendimethalin applied over newly sown seed

Napropamide was generally well tolerated at all rates by *P. spinosa*; however, it was damaging to the other four species with significant reductions in shoot fresh weights of *C. betulus* and *S. aria* from the two higher rates (3.0 and 4.05 kg a.i. ha^{-1}), and significant reductions in growth of *A. glutinosa* and *C. sanguinea* at all rates (Table 1).

Pendimethalin was well tolerated by *P. spinosa*. *S. aria* was only damaged by the highest rate (3.0 kg a.i. ha^{-1}). Although *A. glutinosa* showed significant reduction in plant vigour in June from the middle (2.0 kg a.i. ha^{-1}) and higher rates (data not shown), final shoot weight was only significantly reduced at the highest rate (Table 1). *C. betulus* was damaged by the two higher rates throughout

Table 1 Effect of herbicides on shoot fresh weight (g pot^{-1})—Experiment 1

Herbicide	Rate (kg a.i. ha^{-1})	3 July 2000 *A. glutinosa*	29 June 2000 *C. betulus*	29 June 2000 *C. sanguinea*	8 June 2000 *P. spinosa*	3 July 2000 *S. aria*
Napropamide	1.0	1.85*	13.4	13.9*	20.9	3.01
Napropamide	3.0	0.23*	9.4*	14.2*	15.2*	1.12*
Napropamide	4.0	0.10*	9.7*	9.4*	17.3	0.97*
Pendimethalin	0.6	6.27	16.6	15.8*	25.5	2.95
Pendimethalin	2.0	5.31	9.0*	10.6*	21.7	2.07
Pendimethalin	3.0	1.86*	4.6*	5.2*	18.1	0.71*
Untreated control		8.03	14.4	23.2	20.6	3.24
S.E.D. (control versus treated) (residual *df* = 34)		1.44	1.95	2.68	2.46	0.89
S.E.D. (treated versus treated)		1.77	2.39	3.28	3.02	1.09
L.S.D. (control versus treated) ($\alpha = 0.05$)		2.93	3.97	5.44	5.01	1.81
L.S.D. (treated versus treated) ($\alpha = 0.05$)		3.59	4.86	6.66	6.14	2.21
P (control versus treated, from overall ANOVA)		<0.001	0.002	<0.001	0.598	0.013

*Values significantly different from untreated control at $\alpha = 0.05$

the experiment; *C. sanguinea* was the least tolerant species and was significantly damaged at all rates.

Experiment 2: Tolerance of *F. excelsior* to napropamide and pendimethalin applied at different stages of seedling emergence

Napropamide appeared to be tolerated, even when applied to emerging seedlings (Table 2). Pendimethalin was largely tolerated when sprayed immediately after sowing although there were some indications of adverse tree vigour effects (data not shown). The later applications at higher rates (2.0 and 3.0 kg a.i. ha^{-1}) resulted in vigour reductions in June (data not shown); shoot weight was significantly reduced by the highest rate applied when the seeds were germinating, and by both of the higher rates when applied to emerging seedlings (Table 2).

Experiment 3: Tolerance of four species grown in large troughs to preemergence applications of napropamide and pendimethalin

Napropamide and pendimethalin were tolerated by *V. lantana* at all rates (Table 3). *C. avellana* and *E. europaeus* showed significant reductions in plant vigour in June from the highest napropamide rate of (4.05 kg a.i. ha^{-1}) (data not shown), but there was no evidence of an effect on height (Table 3); the lower rates of napropamide and all pendimethalin rates were safe on these species. *R. cathartica* was the least tolerant species with all napropamide rates and the highest pendimethalin rate causing significant reductions in shoot fresh weight (Table 3).

Table 2 Effect of herbicides on shoot fresh weight (g pot^{-1}) of *F. excelsior* on 3 July 2000—Experiment 2

Application date Application stage of growth		2 March (Post-sowing)	22 March (Seeds germinating)	4 April (Just emerging)
Herbicide	Rate (kg a.i ha^{-1})			
Napropamide	1.0	24.4	20.7	16.6
Napropamide	3.0	23.0	20.8	18.8
Napropamide	4.0	20.2	19.5	19.9
Pendimethalin	0.6	17.4	22.8	18.5
Pendimethalin	2.0	16.6	16.2	7.4*
Pendimethalin	3.0	17.1	10.5*	9.7*
Untreated control		20.6	18.2	19.2
S.E.D. (control versus treated) (residual *df* = 34)		3.30	3.16	3.22
S.E.D. (treated versus treated)		4.05	2.58	3.95
L.S.D. (control versus treated) ($\alpha = 0.05$)		6.71	5.24	6.55
L.S.D. (treated versus treated) ($\alpha = 0.05$)		8.22	6.42	8.02
P (control versus treated, from overall ANOVA)		0.695	0.082	0.051

*Values significantly different from untreated control at $\alpha = 0.05$

Experiment 4: Tolerance of seven tree species to napropamide ± pendimethalin

There were appreciable differences in survival between treatments, especially for *C. sanguinea, C. monogyna, C. betulus* and *A. pseudoplatanus* (Table 4). However, the low and variable survival for *C. betulus* from all treatments, were not significant. The higher rate of napropamide plus pendimethalin (2.0 + 2.0 kg a.i. ha^{-1}) reduced seedling survival in *C. monogyna* by ~70%. Both rates of the napropamide plus pendimethalin reduced *C. sanguinea* numbers by 70–90%. *A. pseudoplatanus* survival was reduced by around 30% by 1.0 kg a.i. ha^{-1} napropamide and the higher rate of napropamide plus pendimethalin (2.0 + 2.0 kg a.i. ha^{-1}), but not by the lower rate mixture (1.0 + 2.0 kg a.i. ha^{-1}).

The only significant effect on tree height (Table 5) was with *C. sanguinea*, where both herbicide mixture rates reduced seedling growth, mirroring the effects on survival. Heights of *C. betulus* and *C. monogyna* were reduced by the high-rate napropamide and pendimethalin mixture by around 20 and 25%, respectively, again corresponding to the survival data, but these differences were not statistically significant.

There were no significant reductions in stem base growth (Table 6) compared to the untreated control, although the application of napropamide to *C. avellana* reduced diameter growth by around 13%.

Table 3 Effect of herbicides on mean plant height (cm) or shoot fresh weight (g pot^{-1}) on 26 June 2000—Experiment 3

Herbicide	Rate (kg a.i. ha^{-1})	Mean height (cm)		Fresh weight (g)	
		C. avellana	*E. europaeus*	*R. cathartica*	*V. lantana*
Napropamide	1.0	153	112	16.3	26.2
Napropamide	3.0	148	103	5.1*	20.7
Napropamide	4.0	131	114	3.4*	25.9
Pendimethalin	0.6	157	154	18.1	23.1
Pendimethalin	2.0	146	137	18.8	21.1
Pendimethalin	3.0	151	135	13.2*	26.6
Untreated control		151	114	23.0	27.1
S.E.D. (control versus treated) (residual *df* = 26)		17.9	30.9	3.13	3.95
S.E.D. (treated versus treated)		21.9	37.8	3.84	4.84
L.S.D. (control versus treated) (α = 0.05)		36.7	63.5	6.50	8.20
L.S.D. (treated versus treated) (α = 0.05)		45.0	77.7	7.96	10.04
P (control versus treated, from overall ANOVA)		0.756	0.535	<0.001	0.200

*Values significantly different from untreated control at α = 0.05

Table 4 Total number of live seedlings in February 2002, 9 months after sowing and application—Experiment 4

Herbicide	Rate (kg a.i. ha^{-1})	*A. pseudo-platanus*	*C. betulus*	*C. avellana*	*C. monogyna*	*C. sanguinea*	*F. sylvatica*	*F. excelsior*
Napropamide	1.0	42^{b}	26^{a}	102^{a}	222^{a}	189^{a}	244^{a}	24^{a}
Napropamide + pendimethalin	1.0 + 2.0	$47^{a,b}$	8^{a}	109^{a}	226^{a}	87^{b}	262^{a}	40^{a}
Napropamide + pendimethalin	2.0 + 2.0	22^{c}	5^{a}	90^{a}	67^{b}	28^{b}	266^{a}	33^{a}
Untreated control		61^{a}	45^{a}	97^{a}	229^{a}	245^{a}	260^{a}	39^{a}

Values sharing the same letter (a, b or c) are not significantly different at the *P* = 0.05 level within species

Discussion

Napropamide is an acetamide herbicide that is absorbed by the roots and inhibits microtubule formation in the roots of germinating plants. Pendimethalin is a dinitroaniline herbicide that is absorbed by roots and leaves, and disrupts microtubule formation (Tomlin 1997; Reade and Cobb 2002). Both are used as preemergence herbicides to control germinating weeds. Any tolerance exhibited by specific tree species to these herbicides is probably due to either rapid metabolism of the active ingredient, or to insufficient quantities of herbicide reaching the plant.

Table 5 Mean height (cm) of seedlings in February 2002, 9 months after sowing and application–Experiment 4

Herbicide	Rate (kg a.i. ha^{-1})	*A. pseudo-platanus*	*C. betulus*	*C. avellana*	*C. monogyna*	*C. sanguinea*	*F. sylvatica*	*F. excelsior*
Napropamide	1.0	21.5	12.5	30.4	15.8	19.4	20.8	8.1
Napropamide + pendimethalin	1.0 + 2.0	46.0	8.6	37.6	17.9	9.12	25.2	17.4
Napropamide + pendimethalin	2.0 + 2.0	33.3	6.2	37.5	10.1	7.8	21.6	11.5
Untreated control		20.8	8.0	30.7	15.6	15.9	23.0	8.9
S.E.D. (treated versus treated) (residual *df* = 6)		10.56	2.72	3.38	3.08	2.23	4.53	2.96
L.S.D (treated versus treated) (at α = 0.05)		25.84	6.66	8.27	7.54	5.46	11.08	7.24
P (treated versus treated, from overall ANOVA)		0.15	0.27	0.12	0.17	<0.01	0.78	0.07

Table 6 Mean stem diameter (mm) of seedlings in February 2002, 9 months after sowing and application—Experiment 4

Herbicide	Rate (kg a.i. ha^{-1})	*A. pseudo-platanus*	*C. betulus*	*C. avellana*	*C. monogyna*	*C. sanguinea*	*F. sylvatica*	*F. excelsior*
Napropamide	1.0	5.8	3.1	6.2	2.6	2.9	4.4	4.0
Napropamide + pendimethalin	1.0 + 2.0	9.6	3.2	8.1	3.8	2.8	5.1	7.7
Napropamide + pendimethalin	2.0 + 2.0	8.4	2.9	8.6	3.5	3.1	4.8	5.8
Untreated control		5.7	2.5	7.1	2.8	3.0	4.6	4.5
S.E.D. (treated versus treated) (residual *df* = 6)		1.62	0.97	0.54	0.38	0.29	0.55	1.06
L.S.D (treated versus treated) (at α = 0.05)		3.96	2.37	1.32	0.92	0.71	1.35	2.59
P (treated versus treated, from overall ANOVA)		0.13	0.89	0.02	0.06	0.66	0.60	0.05

Results from our experiments confirmed earlier work (Willoughby et al. 2003) indicating that napropamide and pendimethalin may be safe to use as preemergence residual herbicides on certain direct-sown tree and shrub species. Willoughby et al. (2003) also suggested that delaying application of pendimethalin until tree seeds were germinating or emerging might reduce tree tolerance. This was confirmed with *F. excelsior* in our experiment, but applications of napropamide to germinating or emerging seedlings were tolerated. In practice, application of napropamide in the drier, warmer conditions of late spring, at a time of year when it is most likely that tree seed might be germinating, would require irrigation to incorporate the herbicide into the soil to avoid the risk of rapid chemical degradation. Such additional irrigation might theoretically reduce tree seed tolerance if it led to herbicide moving further down into the soil profile than might normally occur with naturally occurring rainfall. However, Sumaryono and Crabtree (1989) suggest that napropamide may resist leaching and largely remain within the top 2 cm of soil. They also suggest tolerance might be increased by sowing seed to at least 2 cm depth, a practice adopted for all the species in our experiments. Sowing at these depths may not be possible with some other smaller seeded broadleaved species such as *Betula* spp. (birch) (Willoughby et al. 2004b). Tolerance of *C. avellana*, *F. excelsior*, *A. pseudoplatanus* and *F. sylvatica* to the herbicides when applied post-sowing confirms previous results (Frochot and Pitsch 1981; Richardson and Turner 1980; Willoughby et al. 2003). However, work elsewhere suggests that a rate of up to 2.97 kg a.i. ha^{-1} napropamide alone (Willoughby et al. 2003) or in mixture with 2.0 kg a.i. ha^{-1} pendimethalin is well tolerated by *A. pseudoplatanus* (R. Jinks personal communication). In the latter case, on one site with sandy soil, one application at this higher rate of napropamide appeared to cause a 25% reduction in survival. Reductions in survival of up to 50% in sandy or silty loam soils from applications of napropamide at 1.1 kg a.i. ha^{-1} to *Gymnocladus dioicus* (L) K. Koch (Kentucky coffeetree) seed were reported by Long and Geyer (1989), but not for *Gleditsia triacanthos* L. (honey locust) (Geyer and Long 1988). This implies that despite our results in the field experiment on a sandy soil, it may still be prudent to use the lower maximum rate of 1.0 kg a.i. ha^{-1} napropamide for applications to *A. pseudoplatanus* sown in light textured, sandy soils (Willoughby et al. 2004b).

With other species there was slightly less damage from field compared with container applications, as was anticipated from earlier work (Copping et al. 1990). The glasshouse results give good indications of likely tolerance in the field. *C. sanguinea* was damaged by all treatments in the pot experiment and suffered some reduction in survival from the napropamide and pendimethalin mixtures in the field trial. Warren and Skroch (1991) also found that napropamide was damaging on *Cornus florida* L. *C. betulus* was damaged by all except the lowest herbicide rates in the pot experiment and there were (non-significant) indications of possible survival and growth reductions in the field experiment. Other treatments found undamaging in the pot experiments, but not tested in field conditions, were napropamide and pendimethalin at up to 4.05 and 3 kg a.i. ha^{-1}, respectively, on *V. lantana*, and 3 and 3 kg a.i. ha^{-1} respectively, on *E. europaeus* and *P. spinosa.* Porterfield et al. (1993) also reported tolerance of *Euonymus* and *Prunus* species to preemergence applications of napropamide plus chlorthal-dimethyl in mixture. *A. glutinosa* and *R. cathartica* differed from other species in herbicide response in the pot trial being damaged by all rates of napropamide but not by the lower rates of pendimethalin. Similarly, Clay et al. (1988) found preemergence applications of napropamide very damaging on *Alnus rubra* Bong. *S. aria* was damaged by the higher rates of napropamide and pendimethalin in the pot trial, and in earlier work *Sorbus aucuparia* L. was also reported as being damaged by higher rates of pendimethalin but not by napropamide (Willoughby et al. 2003).

More field trials are needed to confirm the relative tolerance indicated by glasshouse work of these species to preemergence application of napropamide and pendimethalin. However, this work does suggest that applications of up to 2.0 kg a.i. ha^{-1} napropamide plus 2.0 kg a.i. ha^{-1} pendimethalin appear to be safe to use as post-sowing preemergence herbicides to control germinating weeds in direct seeding and nursery situations on seed of *C. avellana*, *F. sylvatica* and *F. excelsior*, provided seed is buried to 2 cm (4 cm for *C. avellana*) and at least 2 weeks elapse between treatment and germination (Willoughby et al. 2004b). Applications of up to 1.0 kg a.i. ha^{-1} napropamide plus 2.0 kg a.i. ha^{-1} pendimethalin appear to be safe on seed of *A. pseudoplatanus* even on sandy soil, and on *C. monogyna*. Applications of 1.0 kg a.i. ha^{-1} may be moderately tolerated by *C. betulus* and *C. sanguinea.*

Details of weed susceptibility for these two herbicides are given in Willoughby and Clay (1996). Detailed guidance on their potential use for weed control in direct seeding situations is given by Willoughby et al. (2004b).

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