Future alternatives to the use of herbicides in British forestry

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Abstract: Weed control is often crucial for successful tree establishment in British forestry. Herbicides currently offer the most cost-effective means available for achieving this, but research into alternatives is required. Recent experiments have been conducted by the Great Britain Forestry Commission investigating the use of 19 alternative ground cover and silvicultural treatments for newly planted ash (*Fraxinus excelsior* L.) and Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco) established on fertile lowland ex-agricultural sites. Most ground cover treatments proved difficult to establish and were more competitive to trees than naturally occurring vegetation. White clover (*Trifolium repens* L.) showed some potential for suppressing weed vegetation without reducing tree growth. Closer initial tree planting densities appeared to offer a practical means of reducing herbicide inputs, whilst still permitting good rates of growth. It is concluded that a comprehensive review of other alternative methods of weed control is now required to set a framework for future Great Britain Forestry Commission research in this field.

Résumé : Le contrôle de la végétation est souvent crucial pour que les arbres réussissent à s'établir dans le contexte de la foresterie britannique. Les herbicides offrent présentement le moyen d'atteindre cet objectif au meilleur coût possible mais il est nécessaire de faire de la recherche pour trouver des alternatives. L'utilisation de 19 couvertures de sol différentes et de traitements sylvicoles a récemment été étudiée par la commission de foresterie de Grande-Bretagne dans le cas de nouvelles plantations de frêne commun (*Fraxinus excelsior* L.) et de sapin de Douglas (*Pseudotsuga menziesii* (Mirb.) Franco) établies sur des sites agricoles des basses terres fertiles. La plupart des couvertures de sol se sont avérées difficiles à établir et compétitionnaient avec les arbres plus que la végétation naturelle. Le trèfle blanc (*Trifolium repens* L.) a montré une certaine capacité pour supprimer la végétation indésirable sans réduire la croissance des arbres. Une plus forte densité initiale, au moment de la plantation des arbres, pourrait constituer un moyen pratique de réduire l'apport d'herbicides tout en permettant de bons taux de croissance. L'auteur conclut qu'il est maintenant nécessaire de faire une revue complète de toutes la autres méthodes de contrôle de la végétation pour établir le cadre des futurs travaux de recherche de la commission de foresterie de Grande-Bretagne.

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Introduction

The control of competing vegetation is probably the single most important silvicultural operation required to establish or regenerate woodlands in Great Britain. It is particularly critical on the drier and more fertile sites in the lowlands of England, where moisture and not nutrient competition is the key factor.

Herbicide application is the most common method of weed control carried out (Hibberd 1991), as this is by far the most cost-effective technique currently available. Typically a 1-m diameter spot, or 1 m wide band around the tree is maintained weed free through directed sprays from hand-held, ground-based applicators (Willoughby and Dewar 1995).

Stringent environmental controls are exerted by the Ministry of Agriculture, Fisheries and Food through the Pesticides Safety Directorate (National Association of Agricultural Contractors (NAAC) and National Turfgrass Council (NTC) 1991) and internal controls are operated within the Great Britain Forestry Commission. Best practice recommendations have been published for the whole U.K. forest industry (Willoughby and Dewar 1995; Great Britain Forestry Commission 1993). Pesticide use within the forest industry is very low compared with agriculture; although forestry covers 11% of the land area of Great Britain, it only accounts for an estimated 1% of the total amount of active ingredient used (Willoughby 1999). Wagner (1993) highlights a worldwide trend towards restricting herbicide use, despite scientific evidence to demonstrate the human and environmental safety of such practices. Indeed, demands for reducing herbicide use in forestry continue despite much wider scale use on amenity areas in towns and on the food we eat. The recent certification initiative in Britain has confirmed this trend. A group of interested organisations including industry representatives and environmental nongovernmental organisations have been working towards building upon the commitments to sustainable forest management included in the Forest Stewardship Council Certification Criteria and the U.K. Forestry Standard (Great Britain Forestry Commission 1998). The aim is to provide a protocol that allows certification of woodlands against certain environmental and sustainability criteria. Although not yet finalized it looks likely that a commitment to a reduction in the amount of pesticides used on a per hectare basis within U.K. woodlands will be included.

It seems prudent, therefore, to investigate methods of reducing herbicide inputs in British forestry. The use of mulches, cutting, pulling, rolling, and cultivation can all be

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effective methods of weed control in forestry (Davies 1987), but they are generally more expensive (Willoughby 1997) and less reliable than the use of herbicides. Cutting by itself has been shown to increase the vigour of grass weeds in particular, though it may be an effective method of control for annual weeds (Davies 1987), although even in this case, multiple passes throughout the year would be necessary. Cultivation is commonly used in restocking British woodlands to redistribute harvesting residues and create an improved microclimate for planting (Thomson 1984; Tabbush 1988). However, by itself, it is unlikely to give sufficient weed control to obviate the need to use herbicides except on the most infertile sites in the uplands (Hibberd 1991). On more fertile lowland new planting sites, cultivation by itself can often make problems worse (Willoughby and Moffat 1996). Considerable research has taken place in the agricultural sector (Ayres and Paul 1990) and overseas (Bassett et al. 1990; Jobidon 1991; Dorworth and Glover 1992; Markin and Gardner 1993) on biological weed control techniques, but to date, little research has taken place in these fields in the United Kingdom. Research has concentrated on lower cost and lower risk silvicultural approaches. Experiments with trees on new planting sites at wide spacings (3 × 3 m or greater) on ex-agricultural land has shown the value of sowing a desirable groundcover at planting (Williamson 1992; Willoughby and McDonald 1999). The sown vegetation outcompetes and suppresses the growth of invasive weeds and allows herbicide use to be confined to maintaining a 1 m wide weed-free band along the planting lines (30% of the total planting area). Typically, a low-productivity grass sward is the favoured ground cover, but wild flower swards are sometimes sown to improve biodiversity (Williamson 1992) or kale sown to provide cover for game birds (McCall 1988) very early in a woodland's life.

In 1994, the Great Britain Forestry Commission initiated research to take this principle a step further, by studying the practicality of establishing a desirable groundcover species, through which trees could be planted directly without the need for weed-free strips to be maintained. Herbicide inputs would be reduced and confined to establishing the groundcover prior to tree planting. For such a system to work, the sown vegetation must suppress highly competitive weed species, while exerting less of a competitive effect on the trees. Weed suppression would need to be maintained at least until trees are established and shading out ground vegetation, i.e., 3–10 years, depending on initial spacing. Ideally the species sown would form a low, slow-growing, creeping cover, that would prevent sites becoming available for ruderals or other vigorous perennials. Advice exists on the use of groundcovers in horticultural situations (Aspden 1992), forest gardens (Crawford 1997), and on man-made (Putwain and Evans 1992) and reclaimed sites (Moffat and McNeill 1994). Cover crops have also been used in other countries, for example in restocking situations (Coates et al. 1993), nurseries (Hanninen 1998), and in afforestation (Ferm et al. 1994; Babel 1995). Effects on tree growth were variable; Ferm et al. (1994) reported some reduction in tree growth compared with herbicide weeded areas, whereas Hanninen (1998) reported clovers (*Trifolium* sp.) as noncompetitive. Davies (1987) reported clover as being highly competitive in U.K. conditions. Clearly, site and nature of competition of weed species is important. There are few reported attempts to use cover crops in the afforestation of fertile farmland of the type found in the lowlands of the United Kingdom, where weeds compete predominantly for moisture, and there is little evidence on the effect on tree growth of not maintaining a weed free zone around the tree in the early years after planting.

Materials and methods

Two experiments were established by the Great Britain Forestry Commission: one in the winter of 1994 on arable land with loamy clay soil at 70 m above sea level at Radcot in Oxfordshire and one in the winter of 1996 on improved pasture land with a gleyed brown earth soil at 110 m above sea level at Perridge in Devon. Average annual rainfall was 1000 mm at Perridge and 700 mm at Radcot. Detailed moisture and nutrient analysis were not carried out, but experience with similar site types suggested nutrients would not be a limiting factor. Light competition is generally not as important a factor as moisture competition (and hence inhibition of trees ability to uptake nutrients) on these site types in the United Kingdom (Davies 1987). At both sites, all existing vegetation was killed with herbicides before complete cultivation and establishment of the treatments as follows:

Treatment T1 (control, no further vegetation management)

Weed vegetation was allowed to naturally colonize.

Treatment T2

All ground was kept completely weed-free through the use of herbicides throughout the experimental period. After planting, residual herbicides were applied in the winter to control germinating weeds. At Perridge, 3.75 $L \cdot ha^{-1}$ Kerb Flowable (propyzamide, 400 $g \cdot L^{-1}$) was applied, and at Radcot this was mixed with 2 $L \cdot ha^{-1}$ Flexidor 125 (isoxaben, 125 $g \cdot L^{-1}$). At Perridge, subsequent weed control was maintained during the growing season with applications of foliar-acting herbicide as necessary. Typically, one application of Harvest (glufosinate-ammonium, 150 $g \cdot L^{-1}$) at 3 $L \cdot ha^{-1}$ and one application of Roundup Pro Biactive (glyphosate, 360 $g \cdot L^{-1}$) at 3 $L \cdot ha^{-1}$ were made as carefully directed sprays to avoid tree contamination. Applications of 5 $L \cdot ha^{-1}$ Stomp (pendimethalin, 400 $g \cdot L^{-1}$) and 2.5 $L \cdot ha^{-1}$ Butisan (metazachlor, 500 $g \cdot L^{-1}$) were made in spring 1997. At Radcot, subsequent weed-free conditions were maintained through directed applications of 3 $L \cdot ha^{-1}$ Roundup Pro Biactive (glyphosate, 360 $g \cdot L^{-1}$) in the first year, and 3 $L \cdot ha^{-1}$ Challenge (glufosinate ammonium, 150 $g \cdot L^{-1}$) and 0.5 $L \cdot ha^{-1}$ Dow Shield (clopyralid, 200 $g \cdot L^{-1}$) in subsequent years. A tank mix of 3 $L \cdot ha^{-1}$ Challenge, 5 $L \cdot ha^{-1}$ Stomp, and 2.5 $L \cdot ha^{-1}$ Butisan was applied as overall sprays each spring.

Treatment T3

The standard recommendation for new planting was imposed, i.e., a 1 m wide band around tree rows was kept weed-free using herbicides, as detailed in treatment T2. Conventionally, this would be for 3–5 years after planting, but in these experiments, weed control was maintained throughout the life of the experiment. Between the weed-free bands, the vegetation was mown to encourage the development of a grass sward and prevent seeding of noxious perennial weeds.

Treatment T4

A 50:50 mix of sheep's fescue (*Festuca ovina* L.) and hard fescue (*Festuca longifolia* Thuill) was sown at a rate of 100 $kg \cdot ha^{-1}$. At Radcot, 1.5 $L \cdot ha^{-1}$ Falcon (propaquizafop, 100 $g \cdot L^{-1}$) was applied in May of the first growing season to selectively control invading grasses. In July of the first growing season, 0.5 $L \cdot ha^{-1}$ Dicotox Extra (2,4-D, 400 $g \cdot L^{-1}$) was applied to selectively control invading broadleaved weeds. Subsequently, no further herbicide applications were made.

Treatment T5

A 50:50 mix of selfheal (*Prunella vulgaris* L.) and sibwort plantain (*Plantago lanceolata* L.) was sown at a rate of 50 kg·ha^{-1}. At Perridge, in May of the first growing season, competing grasses were controlled through an application of 2.25 L·ha^{-1} Laser (cycloxydim, 200 g·L^{-1}). At Radcot, 1.5 L·ha^{-1} Falcon was applied in May of the first growing season to selectively control invading grasses.

Treatment T6

Kent wild white clover (*Trifolium repens* L.) was sown at a rate of 30 kg·ha^{-1}. At Radcot 1.5 L·ha^{-1} Falcon was applied in May of the first growing season to control invading grasses. At Perridge, in May of the first growing season, competing grasses were controlled through an application of 2.25 L·ha^{-1} Laser.

Treatment T7

Winter barley, cv. Fighter (*Hordeum vulgare* L. cv. Fighter) was sown at 125 kg·ha^{-1}, half normal agricultural rates. At Radcot, this was resown and treated with 1 L·ha^{-1} Falcon in May of the second growing season. At Perridge, in May of the first growing season, competitive grasses were controlled through an application of 2.25 L·ha^{-1} Laser.

Treatment T8

Kale (*Brassica oleracea* L. cv. Britain) was drilled at 4.5 kg·ha^{-1}. At Radcot, this was redrilled and treated with 1.5 L·ha^{-1} Butisan in May of the tree's second growing season, to give residual control of emerging weeds.

Treatment T9 (closely spaced trees treatment)

Trees were planted at 50 × 50 cm square spacing (40 000 stems / ha). At Radcot, 2 L·ha^{-1} Flexidor and 3.75 L·ha^{-1} Kerb Flowable was applied after planting. At Perridge, only Kerb Flowable was applied. No further herbicides were applied at either site.

The following treatments, T10–T19, were only established at Perridge.

Treatment T10

Plastic mulch mats, 1 m in diameter, were laid around the base of the trees after planting.

Treatment T11

A mixture of vernal woodland species, 50% bluebell (*Hyacinthoides non-scripta* L.), 30% cowslip (*Primula veris* L.), 20% wild garlic (*Allium ursinum* L.) were sown at a rate of 80 kg·ha^{-1}. In May of the first growing season, 2.25 L·ha^{-1} Laser was applied to selectively control competing grasses.

Treatment T12

A mix of woodland edge species, 25% red campion (*Silene dioica* (L.) Clairv.), 25% hedge woundwort (*Stachys sylvatica* L.), 25% wood avens (*Geum urbanum* L.), and 25% garlic mustard (*Alliaria petiolata* M. Bieb) were sown at a rate of 50 kg·ha^{-1}. In May, after sowing, 2.25 L·ha^{-1} Laser was applied.

Treatment T13

A mixture of woodland species, vernal, and woodland edge types was sown at a rate of 50 kg·ha^{-1}. This consisted of 40% bluebell, 20% cowslip, 5% wild garlic, 10% red campion, 10% hedge woundwort, 10% wood avens, and 5% garlic mustard. In May, after sowing, 2.25 L·ha^{-1} Laser was applied.

Treatment T14

A 50:50 mix of heath bedstraw (*Galium saxatile* L.) and selfheal (*Prunella vulgaris*) was sown at a rate of 50 kg·ha^{-1}. In May, after sowing, 2.25 L·ha^{-1} Laser was applied.

Treatment T15

Cotoneaster horizontalis Decne. were planted at a 75-cm spacing between tree rows. Only around 50% was planted in 1996, and the remainder, in 1997. In both seasons, 3.75 L·ha^{-1} Kerb Flowable was applied after planting.

Treatment T16

Hypericum androsaemum L. were sown, and 2.25 L·ha^{-1} Laser was applied after sowing.

Treatment T17

A mixture of 40% tree lupin (*Lupinus arboreus* Sims) and 60% everlasting pea (*Lathyrus sylvestris* L.) were sown; 2.25 L·ha^{-1} Laser was applied after sowing.

Treatment T18

A layered mix of covers were established. Treatments were sown as treatment T13, and in addition, privet (*Ligustrum vulgare* L.) and ground ivy (*Glechoma hederacea* L.) were planted at 1-m spacing between the tree rows. Laser (2.25 L·ha^{-1}) was applied after planting and sowing.

Treatment T19 (close spaced trees)

Treatments were as for treatment 9, except trees were planted at 1 × 1 m square spacing (10 000 stems / ha).

All sowing took place by hand. At Perridge, this occurred in October 1995 for all treatments except treatments 6, 7, and 9, which were sown in May 1996. At Radcot, sowing took place in September 1994, except for treatment T8 which was sown in June 1995. Supplementary sowing took place in April 1995 for treatments T5 and T6 at a rate of 50 kg·ha^{-1}, at Radcot. treatments T7 and T8 were completely resown in May 1996 at Radcot because of almost total failure.

At Radcot, ash (*Fraxinus excelsior* L.) was planted; at Perridge, ash and Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco) at 2 × 2 m spacing (except treatments 9 and 19) as 40- to 80-cm 2-year-old transplants. Plot size at Radcot was 6 × 34 m, consisting of 51 trees in which the central 30 trees were assessed. At Perridge, plots were 14 × 14 m, consisting of 49 trees in which the central 36 trees were assessed. Both sites had a randomized block design with two replicates. Height, diameter at 10 cm above ground level, and survival were measured at planting and the end of each growing season. For treatments T9 and T19, 36 (30 at Radcot) assessment trees were permanently marked. Assessments of percent vegetation cover of principal species were also made towards the end of each growing season at Perridge and at the end of 1997 at Radcot, using ten 1-m^2 quadrats placed randomly within each plot. A further assessment of ground cover in treatments T12, T13, and T18 was made in June 1997, but data (not presented) were very similar to assessments made later in the same season.

Notes on treatment choice

Grime et al. (1988) stratified common British species into three categories defining their competitive response to the environment. Ruderals occupy disturbance niches, competitors are typically perennial plants of very high potential growth rates, and stress tolerators persist at low growth rates under stress from, for example, low nutrient levels. In addition to the characteristics of an ideal ground cover detailed earlier, the species showing ordination towards

Table 1. Three-year growth increment, survival, and weed cover for ash at Radcot.

Treatment or statistics	Description	Height increment (cm)	Diameter increment (mm)	Survival (%)	Survival transformed to angles	Weed cover (%)
Treatment						
T1	Control, no weed management	59.9	7.7	100	90.0	100
T2	Bare ground	253.4	45.5	100	90.0	0
T3	Standard forestry treatment 1 m wide weed-free bands	197.8	31.0	100	90.0	50
T4	*Festuca ovina* + *F. longifolia*	66.7	8.9	98	84.7	65
T5	*Prunella vulgaris* + *Plantago lanceolata*	37.7	4.6	100	90.0	9
T6	*Trifolium repens*	87.2	7.4	100	90.0	91
T8	*Brassica oleracea*	83	8	97	82.4	97
T9	Closely spaced trees 50 × 50 cm, one herbicide application post-planting	106.9	11.7	96	82.1	85
Statistics						
p	All treatments	<0.001	<0.001		0.5	
SE	Standard error treatment means	11.97	1.422		5.18	
df		7	7		7	
t		2.36	2.36		2.36	
LSD	Least significant difference treatment means at $p = 0.05$	28.25	3.36		12.22	

stress tolerators were also favoured, as these seemed preferable to very fast growing or invasive species.

Treatments T5, T6, and T14 were chosen in the anticipation that they would form a low, creeping green cover, would thrive on fertile sites, and were relatively slow growing, with a fairly neutral competitor – stress tolerator – ruderal ordination. Treatment T4 was chosen as a low-productivity, stress-tolerating grass sward mix. Treatment T11 comprised stress tolerators with a vernal growth habit; it was anticipated that their period of maximum growth and spread would take place before the trees started to grow. The species in treatment T12 were anticipated to be more competitive than T11 but more likely to survive in the open, light conditions, whilst still not competing strongly throughout the tree's growing season. Treatment T13 had a mixture of species, and hence strategies, of treatments T11 and T12. Treatments T15 and T16 followed horticultural recommendations (Aspden 1992) for establishing shrubby ground cover that would exclude invasive competitive weeds. Treatment T17 comprised nitrogen-fixing lupin species commonly recommended for establishing woodland on very nutrient-deficient reclaimed sites (Moffat and McNeill 1994). Treatment T18 was intended to provide a layered mix of plants with different strategies, each providing ground cover less competitive than naturally occurring weeds. Treatment T8 has been successfully used in earlier trials with widely spaced trees as an interrow treatment between weed-free bands (Williamson 1992). It provides a broad, dense shade. Treatment T10 comprised a commonly recommended, effective (Hibberd 1989), but very expensive method of nonherbicidal weed control, the placing of 1-m diameter plastic mulch mat to shade out weeds around tree bases. Treatments T9 and T19 followed a slightly different principle. Rather than establishing an alternative ground cover, they utilised considerably increased planting densities of the crop tree species, in anticipation that rapid canopy closure would quickly shade out weed growth. The residual herbicide applied was intended to keep trees weed free for the critical first 3 months after planting during the first growing season. Once the trees have captured the site, other woodland flora could be introduced, or early selective thinnings made to open up the wood for recreation or biodiversity. Treatment T1 was a no-intervention control, with treatments T2 and T3 giving differing degrees of weed-free conditions. A second control treatment involving direct planting into the existing grass cover at Perridge, or stubble at Radcot, was not included as trees in such a treatment would not have benefitted from the same basal cultivation treatment as the rest of the experiment. The reinvading ground flora in the control (T1) was very similar to that in the external surroundings by the end of the first year. Indeed, from extensive previous research we would expect an untreated control treatment to give significantly reduced tree height and survival on these site types (Davies 1987).

Data was subject to analysis of variance using GENSTAT (Genstat 5 Committee 1993). The *p* value produced indicates the level of probability at which the overall variation in the means could not be produced by chance. Fisher's least significant difference (LSD) test was then performed; those treatment means differing by more than the LSD given are significantly different at the $p = 0.05$ level. Survival data were transformed to angles to allow the assumptions of normality for analysis of variance to be met.

Results

Radcot

At Radcot, after 3 years' growth, survival was good throughout (Table 1), and there were no significant differences between treatments. There were, however, significant differences in height and diameter increments. Both the herbicide treatments (T2 and T3) permitted significantly better height and diameter growth than the unweeded control (T1). Of the remaining treatments, only the closely spaced trees (T9) grew significantly better than the control, although they were poorer than in the multiple herbicide treatments. Although not quite significant at $p = 0.05$ level, the clover in treatment T6 allowed the ash to grow 40% more in height increment than the control, but diameter increment was little different. Treatment T5 grew significantly less than the control or any of the other ground cover treatments. Growth of the ground covers themselves were relatively poor. Table 1 also shows mean total plot weed covers at the end of the

Table 2. Two-year growth increment and survival for ash at Perridge.

Treatment or statistics	Description	Height increment (cm)	Diameter increment (mm)	Survival (%)	Survival transformed to angles
Treatment					
T1	Control, no weed management	32.5	4.7	98	84.2
T2	Bare ground	133.2	16.6	100	90.0
T3	Standard forestry treatment, 1 m wide weed-free bands	29.2	4.8	100	90.0
T4	*Festuca ovina* + *F. longifolia*	14.6	2.4	100	90.0
T5	*Prunella vulgaris* + *Plantago lanceolata*	13.2	1.2	100	90.0
T6	*Trifolium repens*	48.8	6.5	100	90.0
T7	*Hordeum* spp.	18.8	2.7	94	76.1
T8	*Brassica oleracea*	36.2	5.1	100	90.0
T9	Closely spaced trees 50 cm × 50 cm, one herbicide application post-planting	57.2	7.1	100	90.0
T10	1-m diameter mulch mats	40.8	6.2	100	90.0
T11	*Hyacinthoides non-scripta* + *Primula veris* + *Allium ursinum*	22.9	4.9	100	90.0
T12	*Silene dioica* + *Stachys sylvatica* + *Geum urbanum* + *Alliaria petiolata*	57.0	5.0	100	90.0
T13	T11 + T12	29.6	4.5	100	90.0
T14	*Galium saxatile* + *Prunella vulgaris*	20.4	3.3	100	90.0
T15	*Cotoneaster horizontalis* planted at 75-cm spacing	63.5	8.0	100	90.0
T16	*Hypericum androsaemum*	35.6	6.0	100	90.0
T17	*Lupinus arboreus* + *Lathus sylvestris*	48.0	5.5	100	90.0
T18	T13 + *Ligustrum vulgare* + *Glechoma hederacea*	24.9	4.3	100	90.0
T19	Closely spaced trees 1 m × 1 m, one herbicide application post-planting	53.3	7.5	100	90.0

1996 growing season, for each of the treatments. The control treatment (T1) was rapidly invaded by weeds dominated by black grass (*Alopecurus myosuroides* Hudson). Weeds were effectively controlled according to plan in treatments T2 and T3. Growth of the ground covers themselves was relatively poor. Treatment T8 initially established fairly well, but declined over the years. Treatments T4, T6, and T8 had an average weed cover of between 63 and 76% for the period. Only treatment T5 successfully outcompeted the weed vegetation. Treatment T9 was rapidly invaded by weeds after the effect of the winter residual herbicides wore off, but there were indications of some weed suppression by the end of the third growing season. Treatment T7 failed to establish successfully (data not shown).

Perridge

At Perridge, after 2 years' growth, there were significant differences in tree survival between treatments (Tables 2 and 3). For the ash, survival in the control treatment (T1) was significantly lower than all other treatments, except for T7 (barley), which was significantly lower than the control. Overall, survival was good throughout, with all treatments except T10 (mulch mats) in the Douglas-fir, giving greater than 94% survival.

For ash, the total weed control (treatment T2) gave considerably better growth than the control. Unexpectedly, treatment T3 in the ash, and both treatments T2 and T3 in the Douglas-fir, showed no significant growth advantage over the control. None of the other treatments gave significantly better tree growth than the control. Treatment T5 significantly reduced diameter growth in ash, and treatments T4, T10, and T14 significantly reduced height growth in Douglas-fir. However, suppression of weed vegetation was fairly poor, as at Radcot. At Perridge, of the sown ground covers, only treatments T5, T6, T8, T12, and T14 reduced weed cover by more than 50% at the end of 1997 (Table 4). Of these, treatment T5 significantly suppressed tree diameter growth compared with the control in the ash. Treatment T6 did, however, permit ash to grow 50% more in height than the control, but this was not statistically significant. Similarly, treatment T6 reduced height growth by 24% in the Douglas-fir but not significantly.

In the closely spaced trees, treatments T9 and T19, weed cover was being suppressed by the end of the second year. This was particularly so for the Douglas-fir, where weed cover fell to 25% in treatment T19. Although not quite significant at the $p = 0.05$ level, in ash, both treatments gave better height and diameter growth than the control. In the Douglas-fir, those trees in treatment T9 grew 30% more in height than the control or total herbicide treatments.

Treatment T15 had not fully established and was still receiving herbicide treatments at the time of the assessments, so results for it should be treated with caution.

Discussion

Both Radcot and Perridge were typical examples of sites being afforested in the lowlands of Great Britain. Ex-arable and improved grassland sites are highly fertile compared with traditional upland forest sites and can produce productive

Table 3. Two-year growth increment and survival for Douglas-fir at Perridge.

Treatment or statistics	Height increment (cm)	Diameter increment (mm)	Survival (%)	Survival transformed to angles
Treatment				
T1	89.5	13.8	100	90.0
T2	87.9	25.0	100	90.0
T3	67.8	13.3	100	90.0
T4	53.9	9.6	100	90.0
T5	71.6	10.6	100	90.0
T6	68.5	13.1	94	76.0
T7	79.5	13.2	98	84.2
T8	71.7	12.5	98	84.2
T9	101.6	14.1	100	90.0
T10	51.9	11.1	78	69.2
T11	63.0	12.2	96	81.8
T12	84.4	9.6	100	90.0
T13	85.7	13.7	94	79.9
T14	52.6	9.0	96	78.5
T15	76.3	15.6	98	84.2
T16	69.2	15.3	100	90.0
T17	62.7	10.5	94	79.9
T18	78.2	13	98	84.2
T19	78.1	13.8	100	90.0
Statistics				
p	0.154	0.008		0.686
SE	14.78	2.69		9.63
df	18	18		18
t	2.1	2.1		2.1
LSD	31.04	5.65		37.80

Note: See Table 2 for details of the treatments.

Table 4. Weed cover for both species at Perridge.

Treatment or statistics	Weed cover (%) 1996	Weed cover (%) 1997*	2-year mean
Treatment			
T1	100	100	100
T2	0	0	0
T3	50	50	50
T4	69	85	77
T5	17	7	12
T6	16	40	28
T7	74	100	87
T8	18	30	24
T9	100	60	80
T10	80	80	80
T11	65	85	75
T12	61	21	41
T13	76	56	66
T14	30	36	33
T15	65	87	76
T16	50	92	71
T17	74	54	64
T18	35	53	44
T19	85	43	64
Statistics			
p			
SE			
df			
t			
LSD			

Note: See Table 2 for the details of the treatments.
*T9, weed cover: ash, 70%; Douglas-fir, 50%. T19, weed cover: ash, 60%; Douglas-fir, 25%.

woodlands (Williamson 1992). However, their very fertility, combined with large weed seedbanks (Roberts 1982), makes for potentially profuse and rapid weed growth (Stott et al. 1992; Willoughby and Clay 1996; Williamson 1992). It is well established that weed growth can reduce tree survival and growth through competition for moisture and nutrients (Flint and Childs 1987; Davies 1987). Had no further management taken place after cultivation and initial weeding, the sites would have been rapidly invaded with highly competitive weed species (as in the T1 control treatments) that could reduce tree growth and survival (Williamson 1992).

The T1 control treatment suffered considerably reduced growth compared with the weed-free plots, as expected. What was surprising, however, was the poor growth from treatment T3 at Perridge, the standard forestry practice of maintaining a 1 m wide weed-free band. This result is difficult to explain but may indicate that, on this site type with the species planted, that a 1 m wide band is insufficient to significantly reduce the competitive effects of the weeds. This may add weight to the argument for research into improving our understanding of weeding thresholds and intensity across a range of species and sites in U.K. conditions. Increasing the precision of recommendations may be one practical approach for reducing herbicide inputs.

Both the results from Radcot, and the initial results from Perridge, demonstrate the difficulty of identifying less-competitive ground cover species that suppress such naturally occurring vegetation. Even after the site was prepared in a weed-free condition using herbicides, all the ground cover treatments required additional herbicide inputs to establish them. Even with this intensity of management, it proved impossible in most cases to adequately shade out competitive vegetation, without resorting to costly, impractical hand weeding. A notable exception to this was the ribwort plantain – selfheal mix, in which the plantain, at least, rapidly excluded and outcompeted weed vegetation. However, those ground covers that did establish proved as competitive as the naturally occurring vegetation. There may be a fundamental problem with attempting to establish slow-growing, stress-tolerating species in a niche that can be rapidly colonized by fast-growing competitive species. Increasing the sowing densities may be worth pursuing, but this would increase costs and may lead to increased competition with the trees. Few of the vernal species established successfully; site conditions were probably inappropriate, with light levels being too high. Woodland edge species fared better but, again, proved competitive with trees in the densities needed to exclude naturally colonizing vegetation on this very fertile site.

Vegetation competes with trees for moisture, particularly on these site types, and hence reduces tree growth (Davies 1987). On similar sites in the past, survival has also been significantly reduced (Willoughby and McDonald 1999), although this was not reflected in these two trials. The clear benefit for maximising tree growth under conditions of total weed control that has been found earlier (Williamson et al. 1992; Willoughby and McDonald 1999; Davies 1987) was again amply demonstrated. Given the expense and difficulty of establishing ground covers and the fact that they are a reduced, not a zero, herbicide option, any reduction in growth compared with the control makes them unacceptable. The only ground cover that established well, and showed potential for giving better tree growth rates than non-intervention, was the Kent wild white clover treatment T6. Earlier work has indicated the potential of clover as a ground cover species in forestry establishment, as it is known to be a nitrogen fixer (Halley and Soffe 1992), but past trials (Davies 1987) have also shown it to compete strongly for moisture. In the experiments reported here, however, any moisture competition was either offset by increased nitrogen availability, or more likely on these fertile sites, moisture competition was significantly greater from the naturally occurring vegetation in the control plot.

The poor response of trees to mulches may suggest larger diameters are required on such sites (Davies 1987). We would not normally expect the mulch mats themselves to reduce survival, although there is a possibility that, in very wet winters, anaerobic conditions are exacerbated beneath the mulches. Alternatively, it may be that 1-m diameter mats are insufficient to provide any degree of weed control, and instead simply provide good growing conditions for weeds to root under the mulches from the margins.

The closely spaced trees treatments did show some promise as a means of reducing herbicide inputs. The Douglas-fir in particular, at 50 × 50 cm spacing, was suppressing weed growth by the end of the second year. This effect was less pronounced with the lighter canopied ash trees. Vegetation suppression can take a considerably longer time in wider spaced trees (Willoughby and McDonald 1999). Individual trees were probably subject to less competition from weed vegetation, and hence grew better, than in the wider spaced controls. The closely spaced trees would have been subject to more competition from adjacent trees, but this can often promote rapid early height growth (Evans 1984). Weed vegetation can also promote height growth in trees, at the expense of diameter increment (Willoughby and McDonald 1999). However, within the closely spaced ash treatments at Radcot, and to a lesser extent at Perridge, diameter increment was also greater than the control. Clearly, there is potential for closely spaced planting of trees to reduce herbicide inputs. Herbicides are still required to kill off initial vegetation cover and stop the first year's flush of weeds, but subsequent canopy closure and weed suppression make repeat operations less critical. Other silvicultural advantages are also conveyed. Rapid canopy closure more quickly creates an environment for woodland flora, and high stocking densities encourage better quality and allow more choice of timber stems (Kerr and Evans 1993). More rapid tree growth and canopy closure helps to suppress invasive perennial weeds, which are hostile to tree growth and the development of true woodland ground flora (Francis et al. 1996). Denser plantations are also more robust and tolerant of neglect (Kerr 1993).

Closer initial spacing will have an impact on subsequent thinning regimes. Trees are thinned both to select for form and to maintain the overall vigour of the stand. Age of first thinning is usually determined with reference to the point at which canopy depth starts to reduce because of intraspecific competition between trees. With reducing canopy depth, stem volume, and therefore sawlog volume, decreases, so thinning aims to prevent this. Closer spaced trees will both encourage quicker height growth and bring on the onset of loss of canopy depth sooner than wider spaced trees. This may necessitate a respacing (pre-commercial thinning operation), earlier than the normal first thinning age (R. Matthews, personal communication). Information on the precise timing of this pre-commercial thinning in U.K. conditions is scarce. For ash, Kerr and Evans (1993) recommend respacing when trees reach 2–3 m in height (5–10 years old) to 2500 stems/ha. Subsequent first commercial thinning would take place when trees reach 8–10 m in height, 10–20 years after planting (Edwards and Christie 1981). Simply leaving trees to naturally respace will tend to favour individuals of good vigour rather than form, and reduce stem volume (Kerr and Evans 1993). Therefore, the long-term effect of closer initial spacing will be to provide a greater matrix of trees for selection of the final crop trees but also necessitate an early respacing operation at 5–10 years after planting.

Most of the trial treatments used to reduce herbicide inputs would be more costly than a conventional repeat herbicide regime on a field scale. The use of plastic mulches would cost a minimum of 38p per tree (£950/ha at a density of 2500 stems/ha), compared with 14p per tree (£370/ha) for band spraying as in treatment T3, or 28p per tree (£700/ha) for total weed control, on the most weedy sites such as Radcot. Conventional planting and the use of herbicides becomes and even cheaper option on less weedy sites. Depending on the species used, the cost of sowing alternative ground covers could range from £400 (for clover) to more than £3000/ha. Planting 10 000 stems / ha and weeding once as in treatment T19 would cost an extra £1400 for Douglas-fir or £2000 for ash compared with treatment T3. This includes the extra costs of planting more trees, respacing, but reduced herbicide costs. However, establishment of 10 000 – 50 000 stems / ha using direct sowing of tree seed would cost approximately £700/ha less then treatment T3 (Willoughby et al. 1996) The two treatments that show some promise for reducing herbicide inputs whilst not substantially increasing costs appear to be sowing clover or establishing dense plantations of trees using direct sowing. Both of these options should be investigated in future trials.

These trials point the way for further silvicultural research that may result in a reduction of herbicide inputs on fertile lowland new planting sites in Great Britain. They show the immediate potential for reducing herbicide inputs through closer planting densities. Further research is required using existing trials and new trials in different regions and in restocking situations. The use of higher planting densities also has potential on sites in the uplands, which are less fertile and subject to less-intense weed competition. Such research might form one strand of a silvicultural research programme into methods of reducing herbicide inputs in Great Britain. Research on other methods of weed control, and the development of approaches such as mycoherbicides, naturally synthesized herbicide products, alternative silvicultural systems such as continuous cover forestry using techniques of manipulating overstory canopies to suppress weed vegetation, or refining our understanding of required weeding intensity and thresholds, and determining onset of canopy closure and intraspecific competition for different species–site–spacing relationships will depend on a strategic review of anticipated costs, timescales, and likelihood of finding practical solutions.

Conclusions

The ground cover treatments tested proved difficult to establish despite repeated herbicide inputs and were costly. Most were very competitive and detrimental to tree growth, although the Kent wild white clover showed some promise. Closer spacing of trees appeared to show some suppression of weed vegetation by the end of the second and third growing seasons and allowed better tree growth than zero intervention. Longer term monitoring of these trials is required, but clear potential exists for reducing herbicide inputs compared with conventional establishment, through the use of planting densities of 10 000 stems / ha or greater. Closer initial spacing of trees is a costlier option than conventional establishment at 2500 stems/ha using repeat herbicide inputs.

A comprehensive strategic review covering both silvicultural and other alternative methods of weed control is now required to set a framework for future Great Britain Forestry Commission research in this field.

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References

Aspden, J. (*Editor*). 1992. Royal Horticultural Society encyclopaedia of gardening. Dorling Kindersley, 9 Henrietta Street, London.

Ayres, P., and Paul, N. 1990. Weeding with fungi. New Sci. **127**(1732): 36–39.

Babel, M. 1995. Afforestation of agricultural land under protective plant cover. Allg. Forst Z. **50**(20): 1085–1086.

Bassett, C., Whitehouse, L.J., and Zabkiewicz, J.A. (*Editors*). 1990. Alternatives to the chemical control of weeds. New Zealand Forest Research Institute, Private Bag 3020, Rotorua, Bull. No. 155.

Coates, K.D., Douglas, M.J., Schwab, J.W., and Bergerund, W.A. 1993. Grass and legume seeding on a scarified coastal alluvial site in northwestern British Columbia: response of native non-crop vegetation and planted Sitka spruce seedlings. New For. **7**(3): 193–211.

Crawford, M. 1997. Ground cover plants. Agroforestry Research Trust, 46 Hunters Moon, Dartington, Totnes, Devon, U.K.

Davies, R.J. 1987. Trees and weeds. G.B. For. Comm. Handb. 2.

Dorworth, C., and Glover, S.G. 1992. Biocontrol of forest weeds. Forestry Canada, Pacific Forestry Centre, 506 West Burnside Road, Victoria, B.C.

Edwards, P.N., and Christie, J.M. 1981. Yield models for forest management. G.B. For. Comm. Bookl. 48.

Evans, J. 1984. Silviculture of broadleaved woodland. G.B. For. Comm. Bull. 67.

Ferm, A., Hytonen, J., Lilja, A., and Jylha, P. 1994. Effects of weed control on the early growth of *Betula pendula* seedlings established on an agricultural field. Scand. J. For. Res. **9**: 347–359.

Flint, L.E., and Childs, S.W. 1987. Effect of shading, mulching and vegetation control on Douglas fir seedling growth and water supply. For. Ecol. Manage. **18**: 139–203.

Francis, J.L., Peterken, G.F., and Hill, D.A. 1996. Designing, managing and enhancing farm woods to maximise environmental benefits. Aspects Appl. Biol. No. 44. pp. 1–8.

Genstat 5 Committee. 1993. Genstat 5 release 3 reference manual. Clarendon Press, Oxford.

Grime, J.P., Hodgson, J.G., and Hunt, R. 1988. Comparative plant ecology. Unwin Hyman Ltd., London.

Great Britain Forestry Commission. 1993. Forests and water guidelines. 3rd ed.Great Britain Forestry Commission, Edinburgh.

Great Britain Forestry Commission. 1998. The UK forestry standard—the governments approach to sustainable forestry. Great Britain Forestry Commission, Edinburgh.

Halley, R.J., and Soffe, R.J. 1992. The agricultural notebook. Blackwell Scientific Publications, Oxford.

Hanninen, K.S. 1998. Effects of clovers as vegetative ground cover on the growth of red birch in nursery field production. J. Hortic. Sci. Biotechnol. **73**: 393–398.

Hibberd, B.G. (*Editor*). 1989. Urban forestry practice. G.B. For. Comm. Handb. 5.

Hibberd, B.G. (*Editor*). 1991. Forestry practice. G.B. For. Comm. Handb. 6.

Jobidon, R. 1991. Some future directions for biologically based vegetation control in forestry research. For. Chron. **67**: 514–519.

Kerr, G. 1993. Robust woodland establishment. Q. J. For. **87**: 302–304.

Kerr, G., and Evans, J. 1993. Growing broadleaves for timber. G.B. For. Comm. Handb. 9.

Markin, G.D., and Gardner, D.E. 1993. Status of biological control in vegetation management in forestry. Can. J. For. Res. **23**: 2023–2031.

McCall, I. 1988. Woodlands for pheasants. Game Conservancy, Fordingbridge, Hampshire, U.K., Advisory Guide No. 15.

Moffat, A., and McNeill, J. 1994. Reclaiming disturbed land for forestry. G.B. For. Comm. Bull. 110.

National Association of Agricultural Contractors and National Turfgrass Council. 1991. Code of practice for the use of pesticides in amenity and industrial areas. NAAC and NTC. HSE Books, Sudbury, Suffolk, U.K.

Putwain, P.D., and Evans, B.E. 1992. Experimental creation of naturalistic amenity woodland with fertilizer and herbicide management plus lupin companion plants. Aspects Appl. Biol. No. 29. pp. 179–186.

Roberts, H.A. (*Editor*). 1982. Weed control handbook: principles. British Crop Protection Council, Blackwell Scientific Publications, Oxford, U.K.

Stace, C. 1991. New flora of the British Isles. Cambridge University Press, Cambridge, U.K.

Stott, K.G., Clay, D.V., Rogers, D.G., and Davies, H.L.C. 1992. Effect of tree-base vegetation management on the establishment of

tree species in an agroforestry system. Aspects Appl. Biol. No. 29. pp. 401–406.
Tabbush, P.M. 1988. Silvicultural principles for upland restocking. G.B. For. Comm. Bull. 76.
Thomson, D.A. 1984. Ploughing of forest soils. G.B. For. Comm. Leafl. 71.
Wagner, R.G. 1993. Research directions to advance forest vegetation management in North America. Can. J. For. Res. **23**: 2317–2327.
Williamson, D.R. 1992. Establishing farm woodlands. G.B. For. Comm. Handb. 8.
Williamson, D.R., McDonald, W.G., and Nowakowski, M.R. 1992. Vegetation management during the establishment of farm woodlands. Aspects Appl. Biol. No. 29. pp. 203–210.
Willoughby, I. 1997. Weeding young trees—avoiding trouble. Farming Conserv. Mag. **3**(3): 27–30.
Willoughby, I. 1999. Herbicides in forestry—how are they approved and used? For. Br. Timber, **29**(2): 27–30.
Willoughby, I., and Clay, D.C. 1996. Herbicides for farm woodlands and short rotation coppice. Her Majesty's Stationery Office, London. For. Comm. Field Book No. 14.
Willoughby, I., and Dewar, J. 1995. The use of herbicides in the forest. G.B. For. Comm. Field Book 8.
Willoughby, I., and McDonald, H.G. 1999. Vegetation management in farm forestry—a comparison of alternative methods of inter row management. Forestry, **72**(2): 199–121.
Willoughby, I., and Moffat, A. 1996. Cultivation of lowland sites for new woodland establishment. Great Britain Forestry Commission, Edinburgh. G.B. For. Comm. Res. Inf. Note 288.
Willoughby, I., Kerr, G., Jinks, J., and Gosling, P. 1996. Establishing new woodlands by direct sowing. Great Britain Forestry Commission, Edinburgh. G.B. For. Comm. Res. Inf. Note 285.