A comparison of cover crops, direct seeding and herbicides in the establishment of ash trees (*Fraxinus excelsior* (L.)) in lowland Britain

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SUMMARY: The use of cover crops to suppress weed vegetation has been suggested as a potential approach for reducing herbicide use in new woodlands. An experiment on a woodland creation site tested the use of clover and of direct-sown tree seedlings grown as cover crops, on the growth of newly planted ash trees. The experiment also investigated the use of closer initial tree planting densities to control weed competition. Clover proved difficult to establish, slow to grow, required intensive chemical inputs and was not a practical option for reducing herbicide inputs. The close-spaced planting treatment was successful in establishing new woodland with reduced chemical inputs compared to conventional planting at 2 x 2m spacing, but was costly. Direct seeding was more successful than the use of cover crops or close spaced planted trees. However, the technique is likely to have more potential as a system in its own right for woodland creation on fertile lowland sites using reduced quantities of herbicides, than for use as a cover crop in suppressing weed invasion around planted trees.

Introduction

The use of herbicides remains a common method of controlling competing weed vegetation during the establishment phase of young trees in Britain, and inputs are usually highest on the most fertile, lowland sites. The UK Forestry Standard (Forestry Commission, 2004) and the UK Woodland Assurance Standard (UKWAS, 2006) require managers to reduce their reliance on herbicides, but non-chemical alternatives are often excessively costly or impractical (Willoughby et. al., 2004a).

One approach widely employed in agriculture to reduce herbicide and fertiliser inputs is the use of cover crops (Yenish et. al., 1996; Hartwig and Ammer, 2002). The cover crop is usually sown after ground preparation and an initial application of herbicide, and helps to reduce establishment of competitive weed species partly by pre-emptively occupying germination niches. In addition, cover crops made up of leguminous nitrogen-fixing species such as vetches, peas and clover can be beneficial in increasing soil nitrogen levels (e.g. Bowman et. al., 2000). In agricultural systems cover crops can also improve nutrient recycling, help regulate microclimates and hydrological processes, suppress undesirable organisms, and detoxify noxious chemicals (Altieri, 1999). Cover crops can also reduce soil erosion when planted in strips between tree rows in short-rotation hardwood plantations (Malik et. al., 2000), and also conserve soil moisture and protect water quality (Decker et. al., 1994).

The potential of cover crops for forestry situations has been reviewed by several authors (Jobidon, 1991; Dorworth and Glover, 1992; Markin and Gardner, 1993). Both detrimental and beneficial effects on tree growth have been reported (Ferm et. al., 1994; Thompson et. al., 1996; Hänninen, 1998). In some cases poor success of cover crops can be attributed to the presence of highly competitive shrubs or low germination rates (e.g. Coates et. al., 1993). However, the most widely reported disadvantage of cover crops is their ability to outcompete trees for limited soil water (e.g. for orchard trees, Merwin and Stiles, 1994; Foshee et. al., 1995). Hänninen (1998) found that perennial clover varieties reduced growth of red birch (*Betula pubescens* Ehrh. *f. rubra* Ulvinen *f. nova*) and caused reduced leaf area and size, an indicator of water stress (Larcher, 1995). Differences in growth response to different cover crops have been reported (Meyer et. al., 1992) probably due to the suitability of the cover crop for a specific site, and its relative competitiveness with a particular tree species.

In British forestry the ideal cover crop would be low and slow-growing, with a creeping habit, with the ability to establish and persist on a wide range of sites, and able to out compete more vigorous, invasive weeds without significantly impacting on tree growth. The use of cover crops in conjunction with weed-free strips maintained through the use of herbicides has been shown to be a practical technique for reducing the influx of noxious weeds on fertile, new woodland creation sites in lowland Britain (Williamson, 1992; Willoughby and MacDonald, 1999). However, investigations into a wide range of cover crop techniques on woodland creation sites showed that if weed-free strips were not maintained, most cover species were highly competitive, difficult to establish, expensive, chemically intensive, and impractical for use as alternatives to herbicides (Willoughby, 1999). White clover (*Trifolium repens* L.), however, was identified as having potential for suppressing weed vegetation without reducing tree growth (Willoughby, 1999, Figure 1).

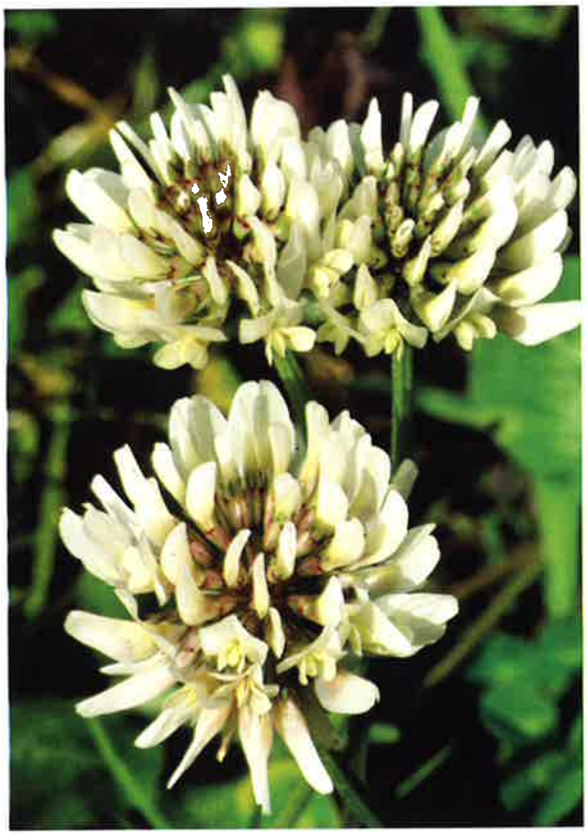

Figure 1. White clover has been widely used as a cover crop in agriculture.
(Photo: FC Picture Library, Laurie Campbell)

Willoughby (1999) reported that increasing planting densities, bringing forward the point of canopy closure and hence competitive exclusion of weed species, did show potential for achieving successful woodland creation using reduced quantities of herbicides. However, for the technique to have any practical application, the cost per tree would need to be significantly reduced. One method of achieving this might be through the use of direct seeding instead of planting (Willoughby et. al., 2004b). Direct seeding as a method of woodland establishment has a long history (e.g. Evelyn, 1670; Langley, 1728; Guillebaud, 1930; Stevens et. al., 1990). In recent years there has been renewed interest in the technique due to its potential silvicultural, environmental and economic advantages over conventional planting (Willoughby et. al., 2004b; Willoughby et. al., 2004c; Madsen and Löf, 2005; Jinks et. al., 2006; Willoughby and Jinks, 2009; Figure 2). However, high densities of tree seedlings established by direct seeding might also have potential for use as an alternative cover crop, helping to protect planted trees by reducing germination and growth of weed species. Unlike a conventional cover crop of herbaceous species, the direct sown trees themselves may also eventually form part of the woodland over-storey. This might allow cheap, fast-growing species to rapidly capture the site for trees, whilst slower-growing, potentially higher value timber species could be planted at lower densities. Higher overall stand densities may also help to improve the form and hence value of the planted, final crop timber species.

The experiment described here investigated the hypotheses that weed control and hence tree establishment for woodland creation on lowland arable sites could be improved by:

- The use of clover cover crops.
- The use of direct sown tree seedlings as a cover crop.
- The use of close-spaced planting densities.

Figure 2. Direct sowing has been shown to be a successful method of high quality native woodland creation on suitable sites.

Methods

The experiment was situated on a good quality woodland creation site on lowland arable land at Idsworth Farm, Hampshire (Latitude: 50° 56' N, Longitude: 0° 56' W). The site was 130m above sea level with a north westerly aspect, and moderately exposed to sea breezes (Detailed Aspect Method of Scoring 11, Quine and White, 1993). It received a mean annual rainfall of 705mm, had 1766 growing degree days (above 5°C) and a mean annual soil moisture deficit of 183mm (data from Pyatt et. al., 2001). Soil type according to Mackney et. al. (1983) was a brown rendzina, Andover 2 Association, with pH of 8.3.

The site had previously been used for cereal crops and was rotovated and weed-free before planting. Five different experimental treatments were applied to 18 x 18m plots. Treatments were randomised within four replicate blocks, giving twenty plots in total. In all treatments two year-old ash (*Fraxinus excelsior* L.) transplants, graded to 30-40cm height were planted at 2 x 2m spacing (except the close-spaced planting treatment, T3) in February 1999. Experimental treatments comprised:

T1 – no weeding control. No further weed control after planting.

T2 – direct seeding cover crop. Ash and sycamore (*Acer pseudoplatanus* L.) seed, pre-treated to overcome dormancy (Gordon and Rowe, 1982) was sown at a rate of 200,000 viable seeds ha^{-1} in February 1999 and incorporated into the soil with a light roller. Ash trees were planted, before applying 2.97 kg a.i. ha^{-1} napropamide (as Devrinol, 450 gl^{-1} napropamide; United Phosphorus) to control subsequently germinating weeds without damaging newly emerging tree seedlings (Willoughby et. al., 2004b).

T3 – close spaced trees. Ash trees planted at 1 x 1m spacing, followed by a single application of 2.0kg a.i. ha^{-1} pendimethalin (as Stomp 400 SC, 400gl^{-1} pendimethalin; BASF) to control subsequently germinating weeds. No further weeding took place.

T4 – clover cover crop. Kent wild white clover (*Trifolium repens* L.) was sown at a rate of 30 $kgha^{-1}$ in February 1999 onto a weed free site, immediately before tree planting. Clover plots were mown and treated with a tank mix of glyphosate at 4 lha^{-1} (1.44kg a.i. ha^{-1}, as Glyphogan, 360 gl^{-1} glyphosate; Makhteshim) and clopyralid at 1.0 lha^{-1} (0.2kg a.i. ha^{-1}, as Dow Shield, 200 gl^{-1} clopyralid; Dow AgroSciences) prior to re-sowing by hand in October 1999 due to poor germination rates. The plots were re-sown again in May 2000 at an increased rate of 3.9gm^{-2} (39 $kgha^{-1}$). Superphosphate fertiliser was applied to the clover plots in June 2000 at 50 $kgha^{-1}$.

T5 – chemical weed control. After ash trees were planted, 2.0kg a.i. ha^{-1} pendimethalin (as Stomp 400 SC, 400gl^{-1} pendimethalin; BASF) was applied to control subsequently germinating weeds. Further appropriate selective herbicide applications were made as required throughout the life of the experiment to maintain weed free conditions in these plots following Willoughby and Clay (1996).

All treatments except the no-treatment control had an application of graminicide and clopyralid during the first growing season to control grasses and thistle (*Cirsium arvense*) that were inadequately controlled by the pre-planting treatment.

Tree height, stem diameter at 5cm above ground level, and survival were recorded on 49 inner assessment plot trees, immediately after planting and at the end of each growing season for five years. For the first three years annual assessments were made of the percentage weed cover of the main vegetation types in ten randomly positioned 1 x 1m quadrats per plot. Direct sown tree seedling numbers, height and stem diameter at 5cm above ground level, were also recorded in these quadrats in the four direct-sown treatment plots for the first four growing seasons.

Statistical analyses

The final-year plot mean height and stem diameter increments were analysed initially using analysis of variance, and Fisher's Least Significant Difference test (LSD) then used to test for differences between treatments (GenStat, 2005). Covariates of initial height and stem diameter were not significant and so these were not included. Survival data were analysed using a binomial generalised linear model with a logit-link function (GenStat, 2005). Specific pairwise binomial contrasts were then used to test for differences in survival between treatments (GenStat, 2005).

Results

a) Germination and growth of clover cover crop

The initial clover sowing failed (Table 1) and plots were re-sown in October 1999. However, by January 2000 two of the four plots still had virtually no germination, despite laboratory germination test results of 94% for the seed batch. A second re-sowing operation took place in May 2000, and by July 2000 mean clover cover was 29%. By July 2001 this had increased to 68% (ranging from 55-82% across the four blocks).

b) Germination and growth of tree seedling cover crop

Tree seedling germination was successful with a total of 56,500 seedlings ha^{-1} of ash and sycamore surviving at the end of the first growing season (Table 2). By the end of the fourth growing season a total of 40,500 seedlings ha^{-1} survived, with an average four-year height of 48.5cm for ash, and 83.7cm for sycamore.

Table 1. Mean percentage vegetation cover.

Assessment	Vegetation type/species	T1 No weeding	T2 Direct seeding	T3 Close spaced	T4 Clover cover crop†	T5 Chemical weed control
October 1999	Bare ground	13.3	25.8	17.6	n/a	36.8
	Grass and cereal crop	27.3	4.9	8.8	n/a	2.2
	Planted *Fraxinus excelsior*	0	2.0	0.1	n/a	0
	Trifolium repens	0	0	0	n/a	0
	Other herbaceous	54.2	56.1	73.5	n/a	61.0
July 2000	Bare ground	6.6	18.7	16.3	10.1	94.2
	Grasses and cereals	21.9	11.0	12.0	2.8	0.1
	Planted *Fraxinus excelsior*	0.9	2.8	2.7	0.8	1.5
	Trifolium repens	0.4	0.0	0.0	28.8	0.0
	Other herbaceous	70.2	67.5	69.0	57.5	4.2
July 2001	Bare ground	6.0	9.4	7.0	0.8	80.6
	Grasses and cereals	48.3	24.6	39.3	10.8	0.3
	Planted *Fraxinus excelsior*	1.8	5.8	9.4	3.0	2.5
	Trifolium repens	0.0	0.0	0.0	68.4	0.0
	Other herbaceous	43.9	60.2	44.3	17.0	16.6

†Percentage vegetation cover was not assessed in the clover cover crop in 1999.

Table 2. Number, density, height (cm) and stem diameter (mm) of direct sown seedlings over four growing seasons.

	Ash seedlings				Sycamore seedlings			
Age (end of growing season)	Count	No. ha^{-1}	Mean height (cm)	Mean stem diameter (mm)	Count	No. ha^{-1}	Mean height (cm)	Mean stem diameter (mm)
1	125	31250	4.9	3.1	101	25250	9.0	3.1
2	83	20750	16.7	3.7	95	23750	30.0	5.8
3	82	20500	34.7	5.6	98	24500	58.0	8.5
4	81	20250	48.5	7.6	81	20250	83.7	11.3

c) Treatment effect on naturally occurring re-vegetation

Where no weeding took place (T1) the site was rapidly invaded by grasses, cereals and other arable weeds (Table 1). The repeated use of herbicides in the chemical weed control treatment (T5) resulted in a higher proportion of bare ground than other treatments. Within the close spaced tree plots (T3) by the third growing season species composition was broadly similar to the control plots, although with a lower proportion of grass and cereals and a higher proportion of herbaceous weeds. In the clover treatments (T4) over the first two growing seasons the herbicides used had more impact on reducing the amount of naturally occurring vegetation present than the cover crop itself, until the clover began to establish after the second re-sowing. The tree seedling cover crop (T2) offered some suppression of naturally occurring weed vegetation, with generally lower levels of grass cover present than in the no weeding control plots.

d) Growth and survival of the planted trees

Compared to the unweeded control, all treatments except the direct seeding cover crop resulted in significantly greater five-year height increment of the planted trees (Table 3). There were no significant differences in five-year height increment between direct seeding and close spaced trees cover crops, but the clover cover crop did result in a significant improvement in five-year height increment compared to the direct sown trees cover crop. Over five years height increment in the clover cover crop treatment was not significantly different to

Table 3. Mean height and stem diameter increment, and survival after 5 years, for ash trees planted at Idsworth Farm.

Treatment	Five-year total height increment (cm*)	Five-year total stem diameter increment (mm)	% survival (end of year year 5)
T1 - No weeding	81.8^{a}	13.39^{a}	96.4
T2 - Direct seeding	92.9^{ab}	17.98^{ab}	100†
T3 - Close spaced trees	121.8^{bc}	17.68^{ab}	99.3
T4 - Clover cover crop	134.8^{cd}	23.28^{b}	99.0
T5 - Chemical weed control	160.4^{d}	34.26^{c}	93.4
P-value	0.004	<0.001	0.014
S.E.D.	17.07	2.783	n/a
d.f	12	12	12
L.S.D.	37.20	6.063	n/a

Within a measurement type, treatments sharing a superscript letter are not significantly different from each other.
*13 tree heights (11 in the 2 x 2m spacing with residual herbicide treatment, 1 in the 1 x 1m spacing treatment and 1 in the no weeding control treatment) were excluded from the analysis due to die-back from other causes, possibly herbicide contact. Stem diameters were not excluded for these trees.
†indicates survival significantly higher than the chemical weed control treatment.
See main text for full treatment details.

that in the chemical weed control plots, although the clover plots were effectively kept weed free using herbicides applied at the end of the first growing season, prior to re-sowing of clover, and also received a fertiliser application after the second re-sowing. Analysis of year 3-4 height increment showed that trees in the clover treatment continued to maintain high growth rates during this time, despite the fact that no further herbicides were applied (data not shown).

Stem diameter increment after five years was significantly higher in the chemical weed control treatment than in all other treatments. The clover cover crop treatment also resulted in significantly higher stem diameter increment than the no weeding control, but there were no other differences between treatments (Table 3).

Five-year survival was greater than 90% overall, but was significantly affected by treatment (Table 3). Survival of planted trees was marginally higher in the direct sown cover crop treatment than in the chemical weed control treatment.

Discussion

Five-year height and stem diameter increments were highest for the chemical weed control treatment, conforming with results from many other studies in lowland Britain (e.g. Davies, 1987). This is probably due to effective removal of competitive vegetation and the associated greater availability of resources such as soil moisture and light (Truax et. al., 2000; Bloor et. al., 2008). The five-year height increment recorded for chemically weeded ash trees is comparable with those in other studies in lowland Britain (e.g. Kerr, 2003).

Five-year height and stem diameter increment of trees in the clover treatment was significantly higher than in the no weeding control. However, germination and establishment of the clover took nearly three years, and considerable intervention was required. The first growing season has been found to be critical in terms of the impacts of vegetation on tree growth, and subsequent competition from weeds invading after year 3 can have relatively low additional impact (Willoughby and Jinks, 2009). Therefore, in the case of the clover cover crop treatment, the benefits to tree growth evident at the end of year 5 may have already been largely established (as a result of the weeding carried out in the first growing season, and the fertiliser application in the second growing season) before the clover came to dominate the plots. Further work using trees planted through well established cover crops would be required to confirm the effects of clover on the growth of young trees.

The close spaced planting treatment was successful in establishing a new woodland with reduced chemical inputs compared to conventional planting at 2 x 2m spacing. Although herbicide costs are reduced, the extra costs of planting at higher density and possible need for respacing (pre-commercial thinning) at an earlier age are likely to outweigh this (Willoughby, 1999) and the cost of planting trees at such high densities is usually prohibitive.

Direct sowing of tree seed has been reported as a potentially viable technique for high quality woodland creation, provided suitable silvicultural practices are adopted (Willoughby et. al., 2004c). However, in our work investigating the use of the technique as a potential cover crop for planted trees, for the first three growing seasons the direct seeding treatment did not prevent the establishment of weed vegetation (although cover of grasses and cereals was reduced), and growth of planted trees was no different from the no weeding control. Survival was marginally higher than the chemical weed control plots, but this might be due in part to herbicide damage to trees in the weeded plots. Therefore although relatively successful in this experiment, unless the planted species are to comprise genetically improved stock or species that cannot be seeded cost effectively, direct seeding probably has more potential for use as a stand alone woodland creation system, rather than use as a cover crop for planted trees.

Although clover has been widely used as a cover crop in agriculture, it has been less successful in forestry situations (Trowbridge, 1989; Ferm et. al., 1994). Coates et. al. (1993) reported poor germination of clover which they attributed to low viability or non species-specific *Rhizobium* innoculant (Trowbridge, 1989). However, in our work initial field germination was negligible, with reasonable establishment (68% cover) only achieved after two re-sowings, and applications of herbicide and fertiliser. Poor germination was also observed in two subsequent experiments to study the effect of clover cover crops on tree growth on upland and lowland restock sites (Forest Research, unpublished). A range of red and white clover varieties and pelletised seed, identified in conjunction with the Institute of Grassland and Environmental Research, were trialled on these sites, but despite high germination rates in an informal greenhouse test field germination was poor and plants did not thrive. White clover can fail due to pests, diseases, adverse environmental and soil conditions such as compaction, lack of adequate moisture and inappropriate sowing depth. Slow emergence in combination with low soil moisture may expose young seedlings to a range of pests and diseases, and those that do germinate often die (Murray and Clements, 1993). Soil moisture contents recorded on the Idsworth site from mid-June 1999 to July 2000 using ML1 soil moisture probes (Delta-T Devices Ltd., Cambridge, UK) did not exceed 0.4 m^3m^{-3} (data not shown), well below the optimum of 0.56-0.60 m^3m^{-3} recommended by Murray and Clements (1993), and hence may have limited germination and survival.

Sowing rates were up to ten-fold higher than those cited in the literature (3-6 $kgha^{-1}$, e.g. Frankow-Lindberg, 1993; Ovalle et. al., 2008) and are unlikely to be the cause of poor germination. Although broadcast sowing has sometimes been found to be more successful than drilling (Laidlaw and McBride, 1992), incorporation to a depth of 5-10mm is usually recommended (British Seed Houses, 2009). The surface sowing method used in our experiments may have reduced the ability of newly emerged seed to access soil moisture, and increased risk of predation. Spring sowing has generally been reported to produce higher clover yields during the first year compared to autumn sowing (Younie et. al., 1985), which is consistent with the failure of the October 1999 re-sowing. In addition to poor germination, any clover that did germinate did not grow well. This suggests that even with adequate germination, clover may take 1-2 seasons to establish sufficiently to form a successful cover crop.

Conclusions

Chemical weed control was the most effective treatment having the largest beneficial effect on tree growth. Although some of the alternatives evaluated did achieve a reduction in chemical use, there was a trade off in tree growth for all treatments. Clover proved difficult to establish, slow growing and required intensive chemical inputs; it was not a robust, simple or practical option for reducing herbicide inputs. The use of clover cover crops is only likely to have potential on sites where it can be established with minimal herbicide inputs prior to planting, and even in these cases its impact on tree growth remains unproven, with reports of both positive and negative effects. The use of mixtures of leguminous species may have more potential for reducing herbicide inputs than attempts to utilise a single species (Frochot et. al., 2009; Balandier et. al., 2009).

Although the use of close spaced planting resulted in good establishment with reduced herbicide input, the high cost means that this would rarely be a practical option. As a system for woodland creation on fertile lowland sites using reduced quantities of herbicides, direct seeding appears to have far greater practical potential than the use of clover cover crops or close spaced planted trees.

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