Some biodegradable mulch materials provide effective weed control during establishment of ash (*Fraxinus excelsior* L.) on farm woodland sites

by Victoria Stokes

SUMMARY: Mulches are materials applied to the soil surface to control the growth of competitive weeds. The durability, practicality, and weed control efficacy of a range of mulch materials was tested for three years on a fertile ex-arable site planted with ash trees (*Fraxinus excelsior* (L.)) in southern England. Herbicides controlled weed growth effectively and resulted in the largest height and diameter increments for the lowest material cost. Biodegradable starch membrane mats, compressed wood fibre boards and hemp fibre mats did not control weed growth and did not improve height or stem diameter increment compared to the control. Hardboard and rubber mats both controlled weed growth and also significantly increased height and stem diameter increment. However, hardboard was difficult to handle on-site and rubber mats increased mortality, probably by reducing soil moisture availability. Costs of these treatments were high, partly due to small scale, experimental manufacture. Coir fibre mats with photodegradable membrane backing were durable, highly effective and practical. This was the only commercially available fully degradable material tested that resulted in a good growth response, comparable to that of non-biodegradable black plastic mats, which are often used on sites where herbicide use is not appropriate. On similar ex-agricultural sites, where a non-chemical approach is desirable, 1.2m x 1.2m coir mats with a photodegradable membrane are a practical alternative resulting in cost-effective growth benefits, although herbicides remain a cheaper, more effective option.

Introduction

Growth rate and survival of young forest trees can be severely reduced by competition with weeds for water and nitrogen (Davies, 1987; Potter, 1989; Balandier et al., 2006). Herbicides are commonly used to achieve weed control in forestry, and if used correctly they can be cheap, safe and effective. However, the UK Government and European Union policy encourages the reduction of chemical use within woodlands where practical (Willoughby et al., 2004; UKWAS, 2011).

One alternative to chemical herbicides is the application of mulch materials to the soil surface to prevent weed growth. Traditional mulches such as bark, wood chips and old carpet have been used by gardeners for many years, and although not widely used in European forestry, commercial mulch materials are increasingly used in roadside and arboricultural planting (van Lerberghe, 2004; Mc Carthy et al., 2011). Polyethylene or polypropylene mats have been used in forestry on a small scale for many years and can be highly effective in achieving long-term weed control. However, the material breaks down into fragments when exposed to ultra-violet light, requiring a costly clean-up operation after the trees are established (Shogren and Rousseau, 2005) or more commonly, plastic is left on site, forming a source of solid chemical pollution. There is also concern that the breakdown products may be bio-assimilated into living organisms and that these may be harmful (Vert et al., 2002).

There have been many advances in biodegradable mulch materials in agriculture. These products have been developed for large, flat areas, with mechanised application, and the crop is fast growing and short lived. The requirements of a mulch material for tree establishment are rather different. Trees are vulnerable to weed competition for three to five years during establishment (Wagner et al., 1999; Balandier et al., 2006) hence any mulch material used in forestry must be highly durable. It must eventually breakdown completely into harmless natural products, or be easily retrieved so that it does not cause pollution to the site. Potential site types range from new woodland creation on ex-farmland sites, to steep upland restock sites. Application is likely to be manual rather than mechanised, increasing labour costs, and so materials must be easy to handle and low in cost. The material must allow water to penetrate and reach the tree roots, while retarding evaporation water loss, and be opaque and dark so that weeds in the seed bank do not germinate (McDonald and Helgerson, 1990). Several recently developed mulch materials could satisfy some or all of these requirements. The most promising of these are soft plant fibre mats, hard plant fibre boards and biodegradable starch-based sheets.

Soft plant fibre mats, made of hemp, jute or coir, needle-punched together or onto a hessian backing, are completely biodegradable and so do not require retrieval from the site after use. Marketed products are usually round or square mats, with a slit to a central hole, allowing it to be fitted around a tree. They are suitable for a range of site types, particularly those with public access as they do not draw attention to the tree and have a natural appearance. They require no expertise to fit, although must be pegged down on windy sites, increasing the time and cost of fitting significantly (Samyn and de Vos, 2002). Manufacturers claim that soft fibre mats last between 1-3 years depending on material, thickness and environment and can provide good weed control while allowing water to penetrate to the tree roots. However, they can attract large populations of rodents that then cause damage to trees. Soft fibre plant mats are widely supplied although few manufacturers produce mats that are large enough for tree establishment. A 1m wide spot or band has been shown to be the minimum required for good tree establishment (Davies, 1987) although larger areas offer greater benefits, and Willoughby et al. (2004) recommend a minimum size of 1.2m x 1.2m for mulch mats.

Hard plant fibre boards are manufactured from recycled cardboard, green-waste or wood fibre (e.g. woodchips, sawdust, paper mill sludge). They are manufactured by impregnating the fibre with glue, or by compressing the fibre into a strong mat. The boards are usually square, 5-15mm thick and have a section that can be removed to allow fitting around a tree. Although initially rigid, fibre boards deform to the shape of the ground surface after wetting. Products have been trialled in Belgium and France and have been shown to have a beneficial effect on tree growth (Samyn and de Vos, 2002, Van Lerberghe, 2004). Hard plant fibre products may be more durable than soft-fibre mats and look more natural than plastic mats, but they may require time-consuming fixing to prevent them moving on windy sites causing damage to trees. Hard fibre boards are also attractive to mice and voles, which nest under the sheets and gnaw holes in the material. Hard fibre boards are not widely manufactured and have been little used. Hytönon and Jylhä (2005) and Jylhä and Hytönon (2006) reported that a 'particle board' treatment did not control weed growth on an agricultural afforestation site; there was no significant effect on growth or survival of Norway spruce, Scots pine or birch seedlings. However, the poor response may have been due to the small size of the boards used in the study (50 x 50cm), which has been shown to be insufficient for good tree establishment (Davies, 1987; Rose et al., 1999; Samyn and De Vos, 2002).

Biodegradable starch-based sheets are often known as 'biodegradable plastics' but are usually made from kraft paper. The material is usually marketed in a roll, designed for mechanised application, and may be impregnated with vegetable oils or herbicides to reduce weed growth (e.g. Olsen and Grounder, 2001; Shogren, 2001; Shogren and Rousseau, 2005). They have been developed for the salad crop market, and hence have low durability, often breaking down to constituent components in less than three months. Thicker corn-starch based sheet materials are now being developed with claimed durability of 1-2 years, which may provide some initial protection for establishing trees.

Although a range of biodegradable mulch materials is now available, their efficacy and practicality in forestry and tree establishment is unknown. The durability requirements are high, and the methods of application and securing used in agriculture may be unsuitable on forest sites. The materials may cause damage to growing trees and may be attractive to a range of mammals and birds, not encountered on agricultural sites.

The objectives of the study were:

- To identify potential biodegradable mulch materials for weed control on new planting sites.
- To quantify the durability, and economic and practical feasibility of the mulch materials.
- To evaluate the effects on survival and growth, in comparison with standard treatments.

Methods

The experiment was established on a rich, ex-arable lowland site at Jeskyns, in Kent, SE England (Latitude: 51°42'N, Longitude: 0°23'E). The site is 80m above sea level with a gentle slope to the south west; open ground surrounds the experiment which is relatively exposed. The bedrock is predominantly chalk, with small outcrops of clay and limestone, and the soil is predominantly an argillic brown earth (Frilsham Association 571j, Mackney et al., 1983). Mean annual rainfall is 728mm. The site was treated with a pre-planting overall spray of glyphosate at 5 lha^{-1} (1.8 kg a.i.ha^{-1}, as Clinic Ace, 360 gl^{-1} glyphosate; NuFarm) in September 2006, and was ploughed two weeks later before being sown with ryegrass (*Lolium perenne* (L.)).

Forty experiment plots of 12 x 12m (0.014ha) were laid out, comprising of four replicate plots of each of ten weeding treatments (unweeded control; compressed wood fibre board; hardboard; hemp fibre mat; coir fibre mat with photodegradable membrane backing; biodegradable starch-based membrane mat; black polythene mat (two sizes); rubber mat; spot weeding with herbicides). See Table 1 for full details of treatments. Ash (*Fraxinus excelsior* (L.)) seedlings graded to 25-30cm were planted at 2 x 2m spacing (16 per treatment plot; total 640 trees) in March 2007. Plants were protected by vole guards and the experiment area was fenced against rabbits.

Weed control treatments were applied immediately after planting. Mulch mats and boards were pegged with strong plastic pegs at the mid-point of each edge and at the slit/overlap (except for biodegradable starch-based mats and 1.2m polythene mats, which were not slit). The corners of each mat were tucked into a spade slot to a depth of 5cm. The exceptions were hardboard, which was pegged at the corners only, and compressed fibre boards, which were supplied in two halves and pegged individually with metal staples. The time taken to fix mulch mats and boards was recorded. A winter application of 3.75 lha^{-1} propyzamide (1.5 kg a.i.ha^{-1} propyzamide as Kerb Flowable; 400 gl^{-1} propyzamide; Dow Agrosciences) and 2.0 lha^{-1} isoxaben (0.25 kg a.i.ha^{-1} isoxaben as Flexidor 125; 125 gl^{-1} isoxaben; Dow Agrosciences) as a tank mix, and a summer application of glyphosate at 5 lha^{-1} (1.8 kg a.i.ha^{-1} glyphosate as Clinic Ace; 360 gl^{-1} glyphosate; NuFarm) were made to the weed-free spots of the herbicide plots annually for three years to maintain weed-free conditions.

Height (cm) of all trees was recorded immediately after planting. An assessment of survival, height (cm) and stem diameter at 5cm above ground level (mm) of all trees was made at the end of the first three growing seasons. Assessments of the mulch material condition and efficacy of weed control for all trees were carried out on seven occasions during the three-year experimental period. The same two assessors carried out all assessments according to a series of questions which could be answered only as 'yes', 'no' or 'not applicable to the treatment' for each treated area. The questions were:

- Are weeds rooted through the central hole?
- Are weeds rooted through the slit?
- Are weeds rooted through the material?
- Is the material still securely fixed?
- Has the tree been damaged by the material?
- Is vegetation rooted outside the treatment area flopping over the tree?

Each tree received a score of 1 (yes) or 0 (no) for each question and a total score for each plot (maximum score 16) was determined for each question.

The percentage cover of vegetation rooted within the treated area was also recorded for each tree in 10% classes (excluding the tree), and the mean vegetation cover per plot was determined. The type of breakdown occurring was also recorded for each mat (e.g. disintegration, tearing, cracking, animal ripping, bird damage) and the three dominant weed species competing with each tree were noted.

A time domain reflectometry soil moisture probe (Theta probe model SM2, Delta-T Instruments, Cambridge, UK) was positioned in the upper 5cm of the soil surface under one of the mats in each treatment of one block only. Volumetric soil moisture content was recorded hourly using a datalogger (DL2e, Delta-T Instruments).

At the end of the three year period the time taken to clean the remaining mulch materials from the site was recorded for the non-biodegradable treatments. Average 'management time' per tree was calculated for the trees in each treatment, incorporating any in-house manufacture time, treatment application or installation, and site clean-up time.

Statistical analysis

Plot mean tree height (cm) and stem diameter at 5cm above ground level (mm) at the end of the first, second and third growing seasons were analysed

Table 1. Cost and installation of weed control methods trialled at Jeskyn's Farm.

Weed control treatment	Size (m) & thickness (mm)	Installation time per plot (16 trees) and comments	Material cost per tree	Experimental time per tree (mins)†
Compressed wood fibre board[1]	1.2 x 1.2 10 mm	20 mins. Awkward to transport. Did not sit well over rough ground.	£4.40	1.25
Hardboard[2]	1.0 x 1.0 5 mm	10 mins. Heavy but easy to fix. Moulds to ground contours.	£3.70	14.69
Hemp fibre mat[3]	1.0 x 1.0 6 mm	30 mins. Moulds to ground contours, hard to pierce with pegs.	£3.04	1.89
Coir mat + photodegradable membrane[4]	1.2 x 1.2 12 mm	25 mins. Very easy to fix, moulds to ground contours.	£4.83	1.56
Biodegradable starch-based mat[5]	1.0 x 1.0 0.04 mm	40 mins. Extremely fragile and easy to tear.	Trial product (i.r.o £0.50)	2.5
Black polythene mat[6]	1.0 x 1.0 0.25 mm	40 mins. Application difficult in windy conditions.	£0.92	6.25
Black polythene mat[7]	1.2 x 1.2 0.25 mm	35 mins. Application difficult in windy conditions.	£1.00	5.94
EPDM rubber mat[8]	1.0 x 1.0 1.5 mm	20 mins. Heavy but easy to fix. Moulds to ground contours.	£6.40	2.25
Spot-weeding with herbicides[9]	1.0 x 1.0	4h 30 mins (45 mins each for 6 applications, incl. preparation & cleaning).	£0.17	16.88
No weed control	-	-	-	0

[1]'Isoplant' resin-free compressed wood fibre board, supplied by Florentaise Pro.
[2]Made in-house from 5mm thick hardboard. [3]Resin-free hemp fibre mat, supplied by Hemcore.
[4]Resin-free coir fibre mat with stitched underlayer of biodegradable membrane, supplied by Greenfix.
[5]Mater-bi product under development: CN605 thesis, 40µ thick corn starch-based biodegradable membrane, supplied by Novamont S.p.A.. [6]Acorn Planting Products. [7]LBS Horticulture.
[8]1.5 mm black commercial quality silk-insertion rubber mat, made for the trial by Atlantic Rubber Ltd.
[9]3 winter applications of residual herbicides and 3 summer applications of glyphosate by knapsack sprayer.
- Not applicable. Costs correct at time of purchase in late 2006, incl. VAT (at 17.5%) but not delivery. £0.30 per tree has been allowed for pegs. Material costs are *indicative only* as reductions are generally available for bulk purchases.
†Includes in-house manufacture (hardboard only), installation, application and site clean-up for small scale experimental plots. Costs are for comparison purposes only and are *unlikely to represent actual costs at field-scale.* Products currently supplied may differ from those tested.

using Genstat one-way Analysis of Variance (p 0.05; Payne, 2005). Initial height was found to be non-significant when used as a covariate, and was therefore excluded. Significant differences among treatments were tested using Fisher's least significant difference test (p 0.05; Payne, 2005). Survival data were not analysed due to the generally very high survival of trees in the experiment.

Results

Costs and installation

Material costs of the treatments ranged from £0.17 per tree for chemical herbicides (total for six applications made over 3 years) to £6.40 per tree for rubber mats (which are re-usable on other sites after seedling establishment) (see Table 1). Biodegradable starch-based mats had low material costs and management time per tree. The polyethylene mats also had low material cost but incurred a clean-up cost to remove residue from the site. This was estimated at around 3-4 minutes per tree, but varied due to the degree of breakdown, dispersion of the fragments and rate of incorporation to the soil and surrounding vegetation. Rubber mats also incurred a retrieval cost of approximately 1 minute per tree.

Plastic mats (both biodegradable and non-biodegradable) were time-consuming to fix, whereas the more robust materials (rubber mats, compressed fibre boards and hardboard) took less time to fix but were heavy to transport on site. Compressed fibre boards were difficult to install on uneven ground due to their rigidity. The hemp and the coir mats with photodegradable membrane (referred to hereafter as 'coir + membrane') were easy to

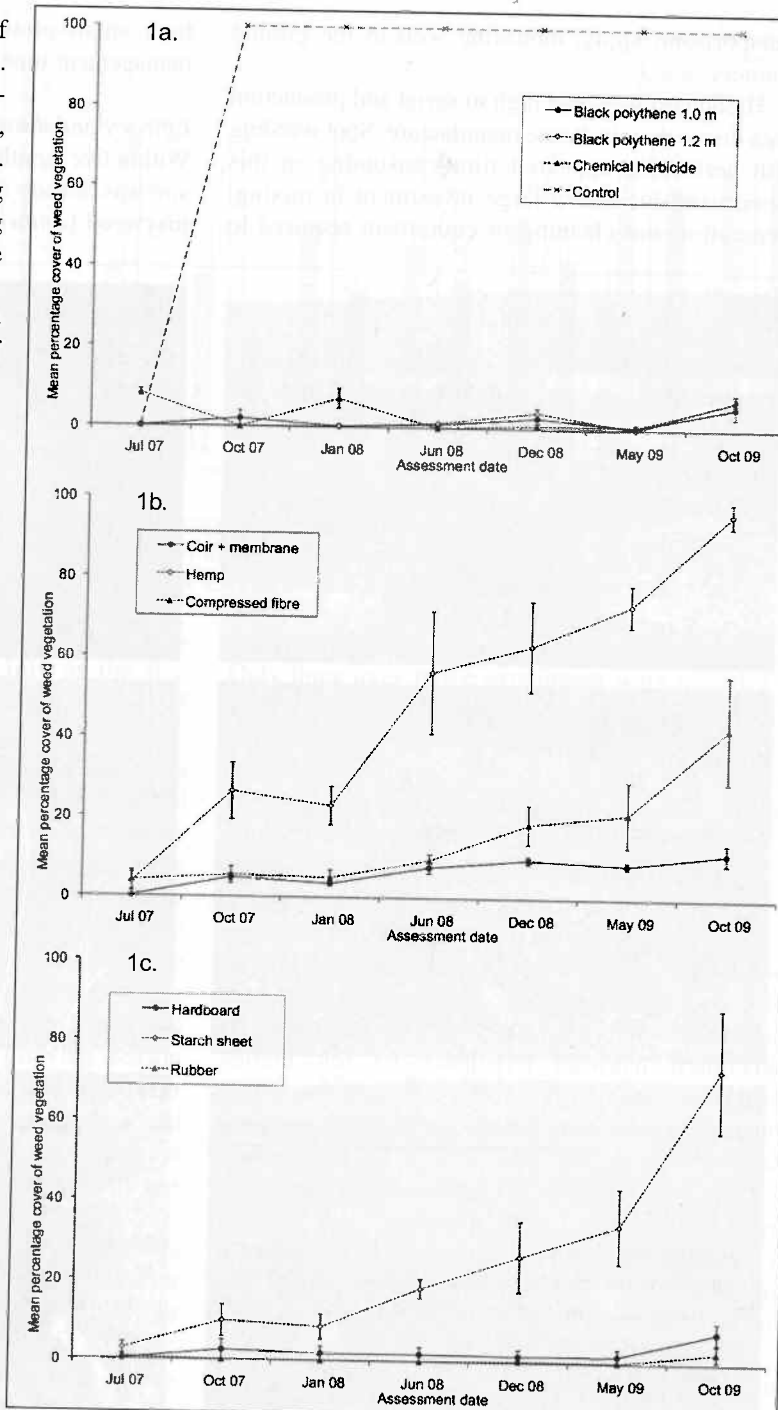


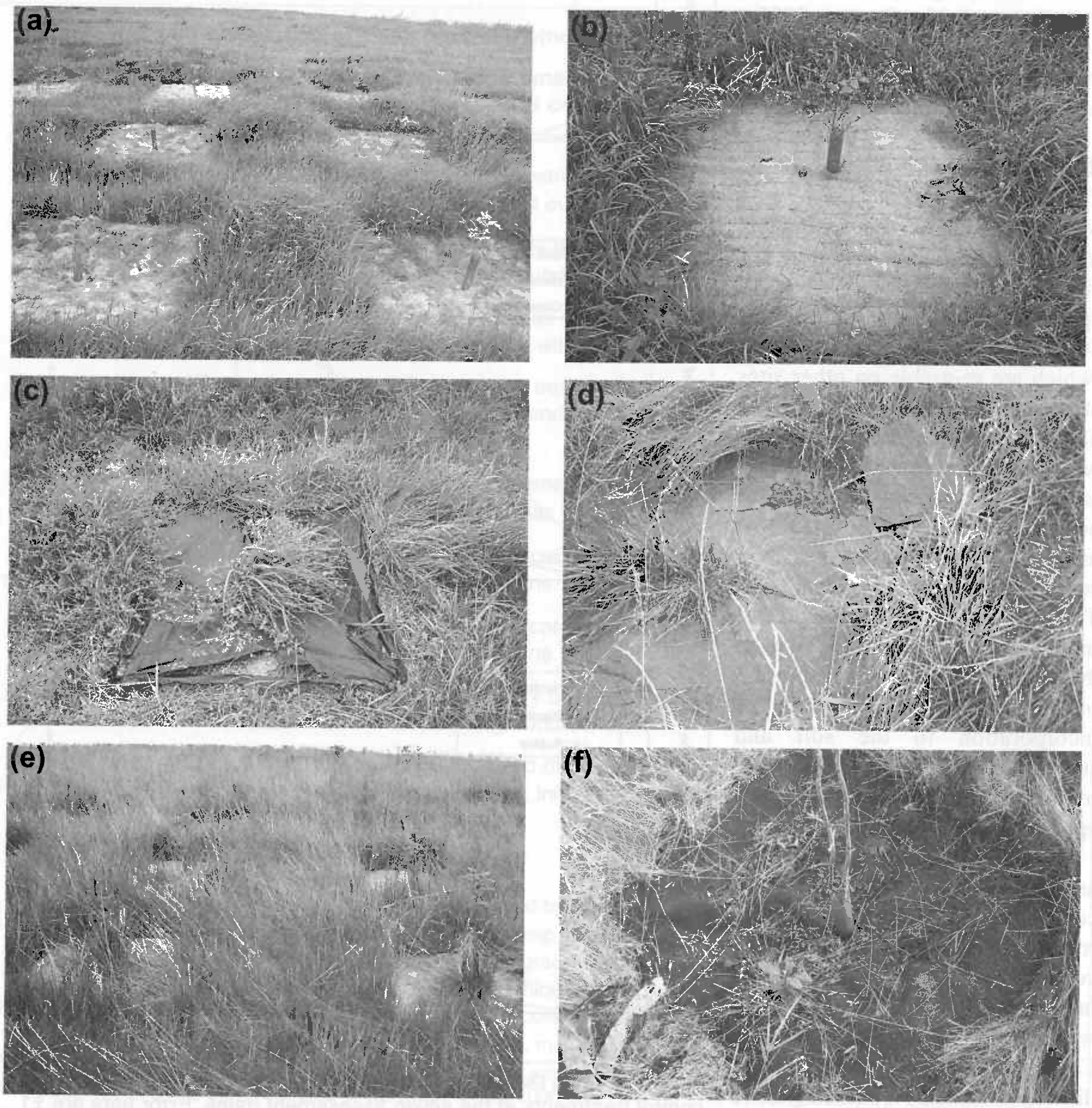
Figure 1. Mean percentage vegetation cover for each of the weed control treatments at the seven assessment dates. Error bars are ±1 standard error of the mean. (a) control, black polythene mat (1.0m), black polythene mat (1.2m), chemical herbicide, (b) coir + membrane mat, hemp mat, compressed wood fibre board, (c) hardboard, starch-based sheet, rubber mat.

transport and apply, moulding well to the ground contours.

Hardboard mats had high material and production costs due to their in-house manufacture. Spot weeding with herbicides appeared time-consuming in this experiment due to the large investment in mixing, preparation and cleaning of equipment required to treat small plots; however, at the field-scale the management time per tree would be much lower.

Efficacy and durability

Within five months of installation weed growth on the site was already strong, consisting largely of grasses, mayweed (*Anthemis* sp.) and wild oats (*Avena fatua*



Mulch treatments showing different stages of degradation: (a) herbicide treatment, (b) coir + photodegradable membrane, (c) biodegradable starch membrane all at 2 months after installation; (d) compressed wood fibre board at 7 months; (e) hardboard at 26 months and (f) rubber mat at 32 months after installation.

L.), with dock (*Rumex* sp.) becoming more dominant in the final year. The mean percentage cover of weed vegetation in the control plots was 100% by October 2007 (Figure 1). However, average weed cover in the herbicide, 1.0m and 1.2m black polythene mat, coir + membrane, hardboard and rubber mat treatments remained close to or below 10% throughout the three year period. The hemp, biodegradable starch membrane and compressed fibre-board treatments all became increasingly weed infested through the three year period (Figure 1).

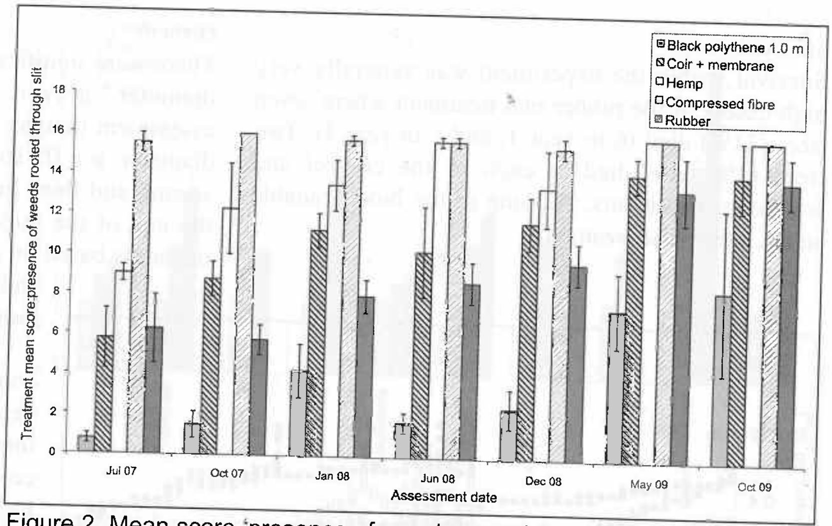


Figure 2. Mean score 'presence of weeds rooted through the slit' (max score 16) for each weed control treatments (which had a slit) at the seven assessment dates. Error bars are ±1 standard error of the mean.

Weeds colonised all mulch treatments very quickly via the central hole; by July of the first growing season mean score of all treatments was >15 maximum score 16), except for the rubber mat treatment which had a mean score of 13 (data not shown). Five of the treatments were slit to the central hole, and this slit also proved to be a weak point for weed colonisation. Compressed fibre boards were highly susceptible to weed ingress at the slit, while 1.0m black polythene mats, which had a 5cm overlap of material at the slit, were the least vulnerable (Figure 2). Heavy weed growth was recorded rooting through the material of the mats in the hemp treatment at the end of the first growing season (treatment mean score 15.75). The surface of the coir + membrane, biodegradable starch membrane and compressed wood fibre board treatments were also colonised by weeds, although more slowly (data not shown).

Vegetation rooted outside the treatment area was recorded flopping over the trees in all treatments with little difference between treatments, particularly in the spring and summer assessments. Almost all of the mats and boards remained well fixed; mean scores were 15-16 for all treatments throughout the assessment period. The dug-in corners and pegs used appeared to be effective. However while the pegs and corners of the hemp and the biodegradable starch membrane treatments remained firmly fixed, the central part of the mats degraded so that the material became loose and lost contact with the soil surface. Only three trees in the experiment were recorded as being damaged by the mulch material. These were in the 1.0m black polythene treatment, the coir + membrane treatment (in both cases the mat hole had not be positioned centrally around the tree) and the hardboard treatment (one board became detached in high winds in the first fortnight after installation).

Impact of treatments on soil moisture

As soil moisture content can be highly variable over very small distances and only one measurement point was sampled in each treatment, absolute values should not be compared between treatments. However, Figure 3 shows the response of soil moisture content underneath the mulch materials during a period of heavy rain in early summer 2008 (2nd growing season). The soil moisture content beneath those materials plotted on the first figure showed a clear increase during and after the period of heavy rainfall, indicating that water was able to pass through the material to the soil below. The soil moisture content beneath mulch materials plotted on the second figure did not increase during or after the period of rainfall, indicating that they can effectively intercept relatively heavy rainfall. The herbicide treatment, with little or no interception or uptake of water by weed vegetation, had particularly high soil moisture content (although comparison between treatments should be made with caution).

Survival
Survival within the experiment was generally very high except in the rubber mat treatment where seven trees (11%) died (6 in year 1, and 1 in year 2). Two trees (3%) also died in each of the control and hardboard treatments, and one in the biodegradable starch membrane treatment.

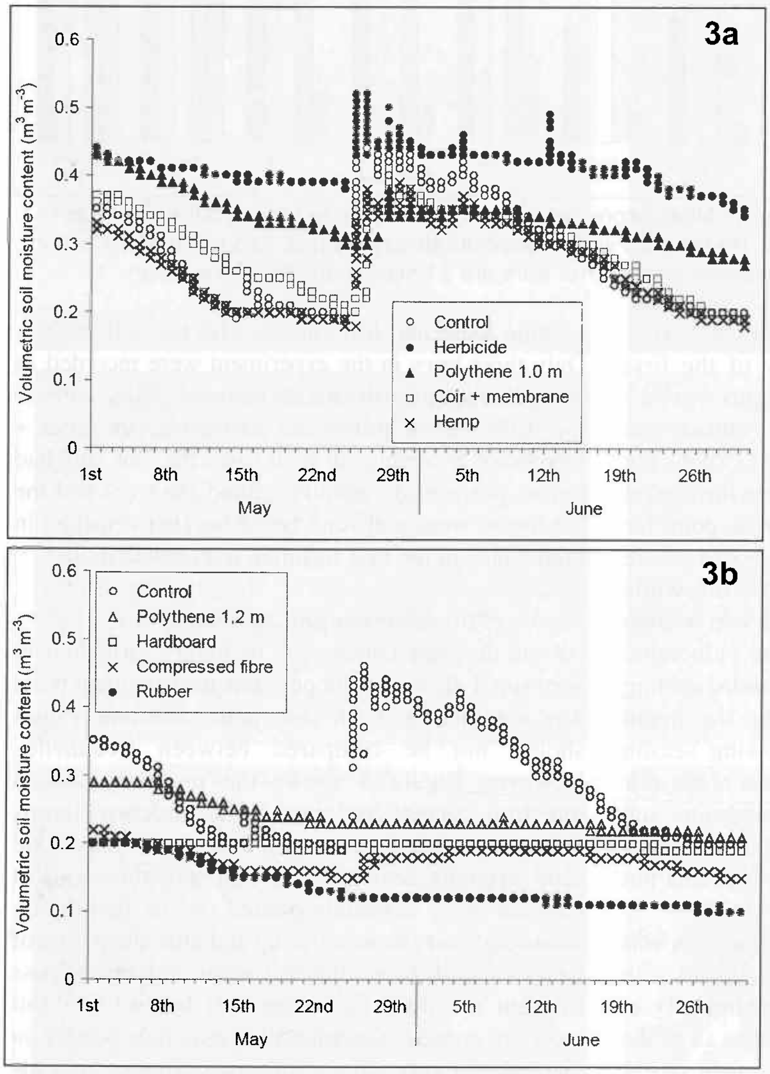


Figure 3. Soil moisture measurements under the different treatments during May and June of the second growing season (2008) showing the response to a period of heavy rainfall on the 25th of May. The control treatment is shown on both graphs; permeable and relatively impermeable materials have been shown on separate graphs (a) and (b) for clarity. Biodegradable starch membrane not shown as the probe had been damaged by rodents.

Growth
There were significant differences in height and stem diameter growth among treatments at each assessment (height: p = 0.003; <0.001; <0.001; stem diameter: p = 0.016; <0.001 and <0.001 for the first, second and third growing seasons respectively). By the end of the third growing season the ranking of materials based on the performance of height growth and on stem diameter growth was the same (Figures 4 and 5).

Biodegradable starch membrane, compressed wood fibre boards and hemp mats did not significantly improve height or diameter growth compared to the control; there were no significant differences among these treatments. Black polythene mats (1.0m and 1.2m), hardboard, rubber mats and coir + membrane mats did significantly improve height and diameter growth compared to the control. Again, there were no significant differences among these treatments. The chemical herbicide treatment resulted in significantly larger height and stem diameter growth than all other treatments by the end of the second growing season, and this was maintained to the end of the third growing season.

Discussion
The heavy weed growth on the site did not cause high mortality, although ash is known to be particularly susceptible to weed competition. However, there was a strong limiting effect on growth. Trees in many of the treatments achieved 2-3 times the height and diameter of those in the unweeded control by year three. Chemical weed control was the cheapest and most effective treatment tested, and remains the best choice where herbicides are acceptable and high growth rates are a priority. The complete removal of weed vegetation from the herbicide treated plots resulted in high soil moisture content,

indicating that competition for water may be the limiting factor on the experiment site (although further sampling would be needed to confirm this). Weed vegetation rooted outside the treatment area was recorded flopping over the trees in all treatments, including the chemical herbicide treatment. Although this vegetation may have competed with the trees for light, it did not prevent large growth responses where weed growth rooted within the plot was controlled effectively.

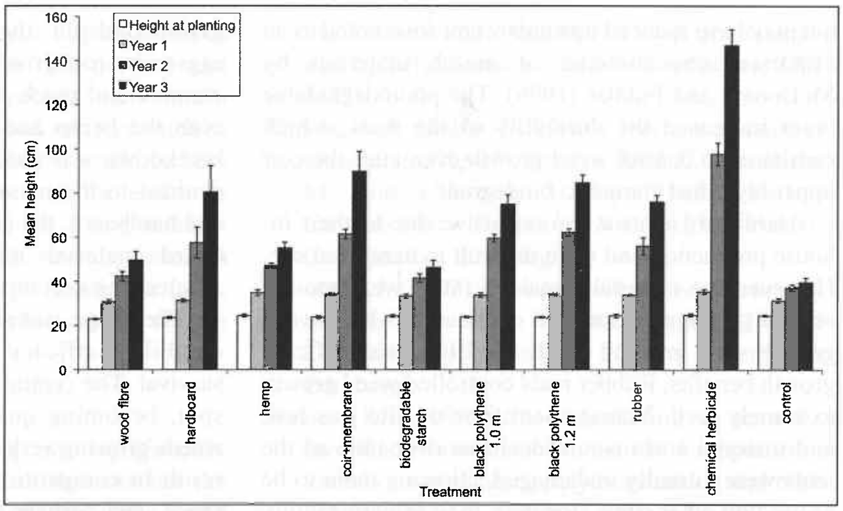


Figure 4. Mean height (cm) of trees in the different weed control treatments immediately after planting and at the end of the first, second and third growing seasons. Error bars are ±1 standard error of the mean. Treatments ranked in order of performance in year 3.

None of the materials tested provided good weed control at a cost comparable with chemical herbicide application. However, polythene mats, coir + membrane mats, hardboard and rubber mats are likely to provide the most practical alternatives on some sites where herbicides are not appropriate. The relative benefits and drawbacks of these treatments are discussed below.

Polythene mats are a relatively inexpensive, practical and effective alternative where visual impact is not important, but site clean-up costs must be allowed for. The mats used in this experiment were resilient and persisted well into the second growing season, with some remaining fully intact for three growing seasons. However, the impermeability of the material to water could cause problems for drought susceptible species on some site types; soil moisture deficits have been recorded underneath a range of plastic and polyethylene mulch mats (McCarthy et al., 2007). In contrast, Parfitt and Stott (1984) observed higher soil moisture content beneath polythene mulch material than on herbicide treated bare ground due to a reduction in evaporation of soil water.

On sensitive landscapes, or where removal of polythene residue is not practical, coir + membrane mats were highly effective and visually attractive. This was the cheapest commercially available degradable material tested that resulted in a good growth response. Despite the photodegradable membrane backing, the mats allowed the infiltration of rainwater, presumably through the stitching holes,

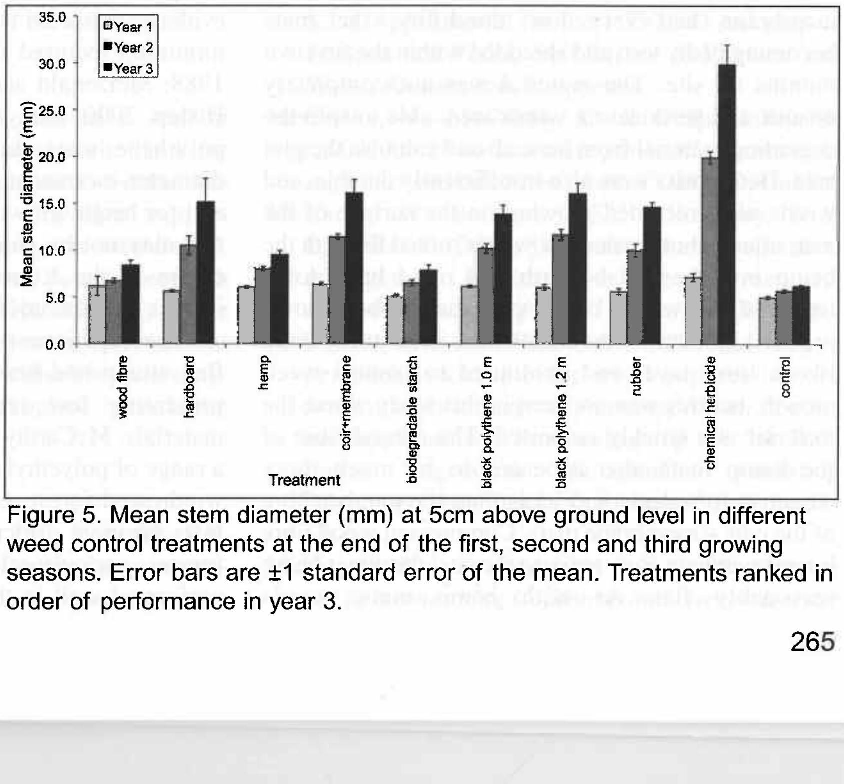


Figure 5. Mean stem diameter (mm) at 5cm above ground level in different weed control treatments at the end of the first, second and third growing seasons. Error bars are ±1 standard error of the mean. Treatments ranked in order of performance in year 3.

but may have reduced upwards water loss, noted as an important characteristic of mulch materials by McDonald and Fiddler (1996). The photodegradable layer increased the durability of the mats, which continued to control weed growth even after the coir upper layer had started to biodegrade.

Hardboard mats were expensive due to their in-house production and were difficult to handle on site. However, the material remained intact well into the second growing season and continued to limit weed growth well into the third, resulting in significant growth benefits. Rubber mats controlled weed growth extremely well. Management time on-site was low, and material costs would decrease over time as the mats were virtually undamaged, allowing them to be re-used on other sites. However, their impermeability to water may have reduced survival, particularly in year 1, and rubber mats may be unsuitable for drought susceptible species on some sites. These treatments offer a range of options for managers wanting to reduce herbicide use while still ensuring good establishment.

The remaining materials (biodegradable starch membrane, hemp mats and compressed wood fibre boards) were not effective at controlling weed growth on this site and did not increase tree growth. Although these materials are attractive due to their complete biodegradability and (in the case of hemp and compressed fibre boards) natural appearance, there was no benefit to the trees. Biodegradable starch membrane had very low durability, the mats becoming badly torn and shredded within the first two months on site. The material was not completely opaque and germinating weeds were able to split the degrading material from beneath and colonise the plot area. Hemp mats were also insufficiently durable, and weeds were recorded growing on the surface of the mat; after a short period the weeds rooted through the hemp into the soil beneath and rapid breakdown followed. Haywood (1999) noted that the breakdown products of natural fibre mulch mats in his study acted like a litter layer and continued to control weed growth, but this was not seen in this study where the material was quickly colonised. The natural fibre of the hemp mats also appeared to be much more attractive to rodents and birds than the tougher fibre of the coir + membrane mats. Compressed wood fibre boards were not easy to fix to the site, despite it being reasonably flat. As with hemp mats, weeds germinated on the surface of the boards and aggressive root growth quickly caused the material to crumble and crack. Observations also indicated that both the hemp and compressed wood fibre board breakdown was particularly rapid during winter. In contrast to the reasonably water-repellent coir fibre and hardboard, the hemp and compressed wood fibre board material may have absorbed rainwater, accelerating decomposition rates.

The shape and size of the mats influenced their durability, efficacy and the effect on growth and survival. The central hole of mats was clearly a weak spot, becoming quickly colonised by competitive weeds growing very close to the tree. This is likely to result in competition for water, nutrients and root-space, and perhaps for light on rich sites with tall, heavy weed growth. Willoughby et al. (2006) have shown that even relatively low densities of weed growth can be competitive, and therefore the central hole should be as small as possible without causing damage to the tree. Five treatments had a slit to the centre, which also proved to be a weak point allowing weed ingress. The 1.0m polythene mats had a 5cm overlap at the slit, which resulted in much slower colonisation of weeds at the slit; this may also have increased soil moisture beneath the mat compared to the 1.2m polythene mats which were not slit and were impermeable to water.

Size of mats in this study was 1.0-1.2m, although many smaller mulch mats are marketed despite clear evidence that a 1m wide weed-free spot or band is the minimum required for good establishment (Davies, 1988; McDonald and Helgerson, 1990; Beaton and Hislop, 2000; Samyn and De Vos, 2002). The 1.2m polythene mats did result in larger height and diameter increment than the 1.0m polythene mats, and for height growth this was significant. However, this may not be entirely due to size: the slit to the centre of the 1.0m mats resulted in higher weed ingress than the un-slit 1.2m mats.

The experiment was carried out on a relatively flat, stump and brash free, lowland ex-arable site, presenting few serious obstacles to the mulch materials. McCarthy et al. (2007) carried out trials of a range of polyethylene mulch mats on mounded and windrowed forest restock sites and found laying of mats far more difficult and time consuming than on former agricultural land. Of the materials that performed well in this study, hardboard and rubber mats may be impractical on rougher, upland restock sites due to the difficulties in transporting and handling. In addition, while rubber mats might conform well to cover rough ground surfaces, such as brash or excavated mounds, hardboard would be very difficult to fix. Polythene mats may be easier to transport under such conditions, but fixing remains difficult and their use on exposed sites may result in tearing and disintegration. Coir + membrane mats, although expensive, may be the most suitable for use on difficult sites.

Conclusions

Uncontrolled weed growth did not significantly reduce survival of young trees on this site but the large impact on growth demonstrates strong weed competition. Results from this study demonstrate that even on rich sites, alternatives to chemical herbicides can be used to control weed competition and achieve good establishment growth rates. All materials initially controlled weed growth, but only coir + membrane, hardboard, rubber and black polythene mats had sufficient durability to aid tree establishment. However, hardboard proved difficult to handle on site, rubber mats were costly and may have reduced survival, and polythene residues require collection and can be unsightly. Although costly, 1.2 x 1.2m coir + membrane mats were easy to handle, fully degradable and the growth rates achieved indicate that they are an effective, albeit more expensive, alternative to chemical herbicides.

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