Effect of Weed Control with Fibre Mulches and Herbicides on the Initial Development of Spruce, Birch and Aspen Seedlings on Abandoned Farmland

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Post-planting weed control methods on abandoned farmland were studied in three field trials in southern Finland using a completely randomized design with four treatments and 30 to 40 replications. Mulches of 60 × 60 cm [sheet mulch – strips of plane waste and plastic fibre, newspaper – waste paper slurry, wood chips, pure wood fibre slurry], herbicides [i.e. glyphosate or terbuthylazine alone or mixed and dichlobenile applied to 1 m^2 spots] and hoeing treatments were compared to an untreated control plot. The study material consisted of two-year-old containerized aspen (*Populus tremula* L.), silver birch (*Betula pendula* (L.) Roth) and Norway spruce (*Picea abies* (L.) Karst.) seedlings planted in spring 1996. The ground vegetation was dominated by *Elymys repens*, *Deschampsia cespitosa*, *Cirsium arvense* and *Epilobium angustifolium*. Monitoring of the trials over a 3-year period showed a moderate effect of weed control, which varied according to the method used and by the crop species. Significant growth responses were found with herbicide in spruce, wood chips in spruce and birch and with sheet mulch in aspen seedlings. Sheet mulch also encouraged vole nesting thus increasing damages. Generally, slurry mulches proved to be insufficiently durable. Mulching had a clear insulating effect, which may increase the risk of winter drought.

Keywords *Betula pendula*, dichlobenile, glyphosate, herbicide, *Picea abies*, *Populus tremula*, mulching, terbuthylazine, weed control
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1 Introduction

Traditionally, vegetation has been controlled in Finnish forest plantations either mechanically, by cutting or trampling, or chemically with herbicides. The rate of field afforestation decreased from 10 000 ha/year in the early 1970's to only 2500 ha/year at the mid 1980's. A new peak was reached in 1992–1993 with over 17 000 ha in both years, thereafter it decreased rapidly to 4000 ha in 1995 (Metsätilastollinen ... 1998). In the last few years, the area of afforested abandoned agricultural land has been increasing. With support from EU funding, about 70 000 ha were assumed to be afforested in the previous 4–5 years (Uusiutuvien ... 1995). This assumption seems to be unreasonably high, from 1996 to 1998 only 7.3–9.3 thousand hectares were afforested. According to the latest study by Niskanen (1999), field afforestation was financially profitable for farmers regardless of species used in planting. However, undesired changes in the landscape have been a key reason among farmers for resisting afforestation (Selby and Petäjistö 1995).

On agricultural land, competition for light and especially for water and nutrients are more severe than on forest land. The root biomass on agricultural land may greatly exceed the above ground vegetation biomass, while the total vegetation dry mass can be even 10 000–20 000 kg ha^{-1} (Hokkanen and Raatikainen 1977, Hynönen and Hytönen 1998). The recommended method of afforestation is site preparation followed by whole area treatment with both soil-acting and foliar herbicides before planting (Hytönen 1995, Hynönen and Hytönen 1998). In addition, mechanical protection (tubes) is increasingly used because of the effective protection they provide against vole damages (Henttonen et al. 1995).

The use of chemicals in forestry is an increasingly controversial issue due to strong public criticism. Consequently, information on alternative vegetation management methods is needed. Crop cover mulching with *Trifolium repens* (Ferm et al. 1994) and other species (Willoghby 1999) has not been successful to date. Despite encouraging results with a biological weed control agent (*Chondrostereum purpureum*), it is not a practical solution in the near future (see Shamoun and Hintz 1998, Pitt et al. 1999, Harper et al. 1998, Becker et al. 1999). In a previous study by Siipilehto and Lyly (1995), mulching with waste paper slurry did not improve the initial development of pine seedlings on forest land, even if the mulch provided good control of weeds for several years. This was because scarification reduced the competitiveness of all seedlings. Thus, the growth of the seedlings was quite similar no matter which weed control method was used.

The objective of this study is to examine different materials and methods for mulching and to compare the effects of mulching and herbicide treatments in terms of seedling survival, growth and vigour with the untreated control.

2 Material and Methods

2.1 Luumäki Experiments

The study area was in Luumäki, in southeastern Finland, about 200 km northeast of Helsinki (61°02'N, 27°24'E, 80 asl.). The site chosen was abandoned agricultural land that was ploughed and sprayed with glyphosate and terbuthylazine (Folar®) in 1995, one year before planting. Possibly due to its application in late autumn, the herbicide treatment did not work well and further weed control was needed. The field was planted with 2-year-old containerized Norway spruce (*Picea abies* (L.) Karst.) and silver birch (*Betula pendula* (L.) Roth) seedlings at the end of May 1996.

The soil was very fine sand (loam) in the spruce plantation and fine sand (sandy loam) in the birch plantation area. The ground vegetation was dominated by *Elymys repens* (L.) Gould and *Ranunculus repens* L. in the area of spruce plantation and by *E. repens*, *Deschampsia cespitosa* (L.) Beauv., *Cirsium arvense* (L.) Scop., *Epilobium angustifolium* (L.) Scop, *Rubus idaeus* L. and *Urtica dioica* L. in the area of birch plantation. The average height of the vegetation was about 60 cm and 100 cm, respectively.

The layout of the experiment was a complete random design with 30 replicates. The five treatments were: Control – no mulch or herbicide; Newspaper – weed control with newspaper (waste paper slurry) mulch; Wood chips – weed control with wood chip mulch; Herbicide – glyphosate together with terbuthylazine (Folar®) for spruce seedlings, glyphosate (Roundup®) for birch seedlings; Wood fibre – weed control with pure wood fibre (mechanical pulp slurry) mulch.

The mulches were applied approximately in a 2 cm thick layer to an area of 60 × 60 cm square around the seedling at the beginning of June. Newspaper and wood fibre mulches were applied by mixing them with water. A bucketful of mulch per seedling was applied manually. The herbicide, glyphosate (1.2 kg ha^{-1} a.i.) with terbuthylazine (3.4 kg ha^{-1} a.i.) for spruce and glyphosate for birch (2.2 kg ha^{-1} a.i.) was sprayed on a 1 m^2 spot around the seedling, using a backpack sprayer, in a solution of water (400 l ha^{-1}). The herbicide application was made on August 10th in favourable (24 Cº, sunny and windless) weather. During herbicide treatments seedlings were protected by a plastic cover. Vegetation around all the seedlings, including the control plot, was trampled before the arrival of snow in order to avoid mechanical damage over the winter.

2.2 Lapinjärvi Experiment

In Lapinjärvi (100 km east of Helsinki, 60°37'N, 26°10'E, 30 asl.), a fenced, abandoned field was afforested with several broad-leaved species. The weed control trial was established in spring of 1996 with aspen (*Populus tremula* L.). The field of fine texture (clay) soil was ploughed and harrowed before planting in spring 1996.

Four dominating weed species existed in the experiment area. They were *Elymys repens*, *Ranunculus repens* together with *Tripleurospermum inodorum* Schultz Bip., and *Cirsium arvense* forming patchy vegetation cover.

The layout of the experiment was a complete random design with 40 replicates. Treatments were: Control – untreated; Newspaper – waste paper slurry; Sheet mulch – woody sheet mulch consisted of strips of plane waste and plastic fibre being somewhat translucent and permitting rain infiltration; Herbicide – granulated dichlobenil (Gasoron G®); Hoeing – manual hoeing of weeds once per year, at the end of growing season.

Mulching and herbicide applications were made on June 5th,1996. Newspaper mulch was applied as in the Luumäki experiment. Sheet mulch was anchored with five nails per sheet. The herbicide (2.7 kg ha^{-1} a.i.) application and hoeing were made to an area of 1 m^2 around the seedlings. Before applying the herbicide, the ground surface was moistened to make the dichlobenil granules visible and to improve their efficiency. The soil surface dried quickly during the application due to windy conditions, but heavy rain helped to wet the soil 3 hours after application.

2.3 Measurements and Assesments

Vegetation was assessed in an area of 1 m^2 around the seedlings in the beginning of August. The total percentage cover and the main weed species were assessed visually. The average height of the dominating weeds was also recorded. Weed intensity was calculated as follows (Christensen 1998):

$$\text{Weed intensity} = \text{Weed cover (\%)} \times \text{Mean vegetation height (cm)}$$

Mulch durability was determined by the % cover of weeds growing through the mulch and overlapping the mulched (60 × 60 cm) area. The total height and ground base diameter of the seedlings were measured (except diameter for spruce immediately following establishment). Seedling vigour was scored visually on a 5-point scale; no damage, slightly damaged, damaged, seriously damaged and dead. The two main causal agents for damage were assessed and recorded.

2.4 Weather Conditions and Frost Thaw

Weather conditions in 1996 varied from cool and rainy in early summer to dry and warm during autumn. At the end of June, the temperature sum was only 86% but precipitation was as high as 230% compared with the long-term averages. From August till the end of October, the weather was exeptionally warm and dry. Consequently, the final temperature sum (1280 d.d. C°) was normal due to the late autumn, but precipitation (402 mm) was still above long-term average (360 mm) in Lapinjärvi. In 1997, the temperature sum was 1360 d.d. C° and precipitation only 200 mm. Precipitation in 1998 was again above normal (400 mm) but temperature was normal (1270 dd). In Luumäki, the weather conditions were similar to the long-term averages (1360 d.d. C° and 305 mm) except for precipitation in 1997 (126 mm), which was only 40% of the long-term average, and in 1998 (381 mm) 25% above long-term average.

The risks with mulch treatments are closely related to drying injuries in springtime and freeze injuries in the autumn. Drying injury (drought) occur if seedlings transpirate while the roots are in frozen soil. Because of this risk, the frost thaw on soil surface was monitored. The frost thaw was recorded weekly in March and April 1997 in Lapinjärvi. Additional aspen seedlings were treated with wood fibre and wood chip (coarse saw dust) mulch to enable a more intense monitoring of frost thaw in Lapinjärvi. Five seedlings per treatment were randomly chosen for this study.

2.5 Statistical Analysis

The data were analysed using SAS software (SAS...1989). Treatments were compared by a general linear model (GLM). Paired comparisons were made by Dunnett's t test at $\alpha = 0.05$ level against the control. Dead seedlings and those with a missing shoot (e.g. damaged by voles and hares) were excluded from height and diameter comparisons. All the observations were present in the GLM model in 1996, 80% later on in Luumäki experiment. In Lapinjärvi, observations fell to 62% in 1997 and to only 40% in 1998 due to severe vole damages. The weed cover % was tested by ANOVA following arc sine transformations. The chi-square test was applied for testing the independence of the classified variables (seedling vigour, damage incidence and severity) from the treatments. To obtain reliable chi-square tests, some neighbouring health status classes were aggregated.

3 Results

3.1 Percentage Weed Cover

All the mulches used in these experiments were based on wood fibre. Comparing mulches two and three years after application, the sheet mulch was found to be the most durable (Table 1). The weeds that had grown through the sheet mulch covered 5.7% and 23.2% of the mulched area in 1997 and 1998, respectively. The greatest single weed cover, when voles had damaged the sheet, was 30% and 80% respectively. In the Luumäki experiment, the newspaper slurry was significantly more durable than wood fibre slurry or wood chip mulch, both of which required a repeated application after the second growing season.

In the Luumäki experiment, the herbicide treatments controlled the weeds most effectively. One month after application live weeds covered only 1–5% of the treated area. On the spruce plantation, the percentage weed cover (mostly grasses) was considerably high one year after treatment (84%). With the mean height of the weeds being the lowest, the weed intensity of the herbicide treatment was only half of the weed intensity

Table 1. Weed penetration and overlap of mulch, % of mulch area.

	Spruce 1996	Spruce 1997	Spruce 1998	Birch 1996	Birch 1997	Birch 1998	Aspen 1996	Aspen 1997	Aspen 1998
Sheet mulch							a 2.9	a 5.7	a 23.2
Newspaper	a 16.7	a 42.4	a 86.9	a 11.5	a 27.3	a 54.0	b 35.8	b 43.6	b 89.1
Wood chips	b 48.5	b 63.7	*b 40.5	b 39.2	b 57.0	*b 84.3			
Wood fibre	b 39.5	b 57.0	*b 35.0	b 28.5	b 46.5	*b 83.7			
F	41.9	11.2	40.8	22.8	14.8	13.0	7.9	56.7	125.4

Means with the same letter are not significantly ($p < 0.05$) different (pairwise t tests).
* NB. Wood chip and wood fibre mulch application has been repeated after the second growing season

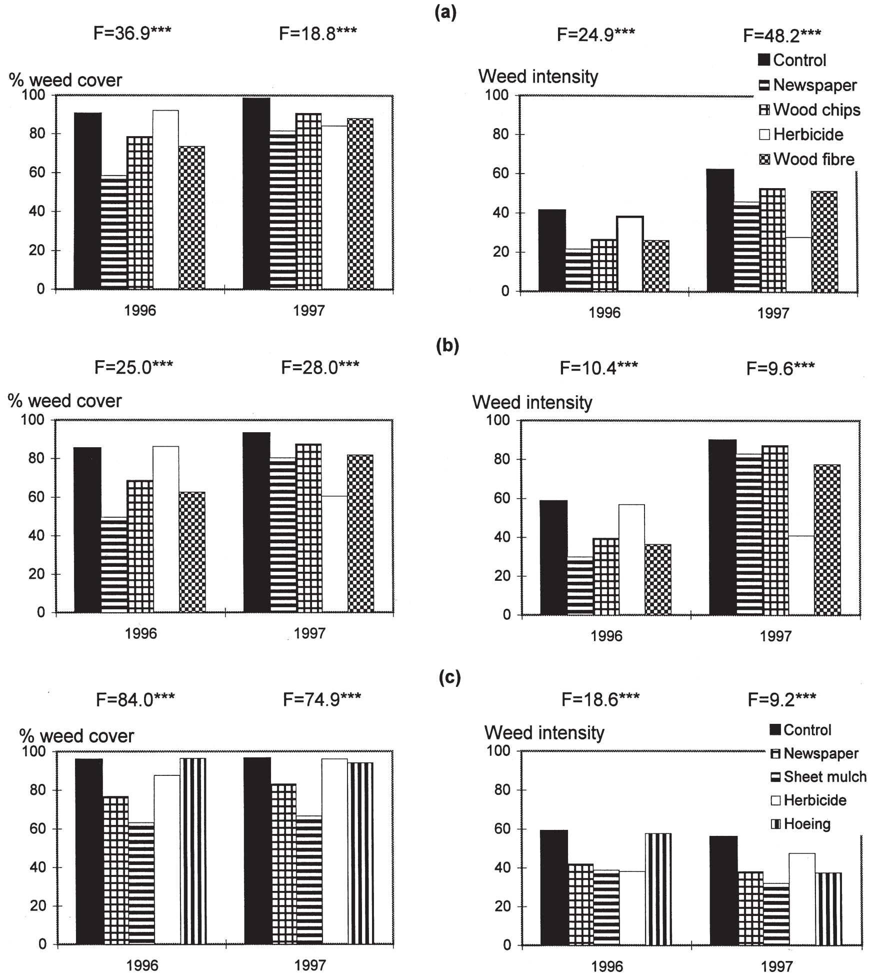

Figure 1. Percentage of weed cover (left) and weed intensity (right) at the end of the growing season in 1996 and 1997 for spruce (a), birch (b), and aspen (c) plantation areas. Notice that the timing of weed observation is just before the herbicide application in 1996 (Fig. a and b) and just before mechanical hoeing (Fig. c).

of the control plot (Fig 1a). In 1997, all treatments significantly reduced weed cover and weed intensity compared to the control plot. In 1998, the two lowest weed cover averages, 67% in wood fibre and 73% in the wood chip treatments differed significantly from the control (100%). Due to the repeated application of these treatments in 1997, weed intensity and the average height of weeds, 35 cm and 38 cm respectively, differed significantly from the control (54 cm).

The weed cover results for the birch plantation were similar to the spruce plantation. In 1997, all the weed control treatments significantly reduced weed cover compared to the untreated control plot (Fig 1b). However, only the herbicide treatment significantly reduced weed intensity after two growing seasons. Glyphosate was effective against forbs, except *Rubus idaes* and *Urtica dioica*. After three growing seasons, all the treated plots were almost totally colonized; the lowest two average weed cover percentages, 85% in the newspaper and 93% in wood fibre (NB: repeated application in 1997) treatments differed significantly from the control (99.7%). The greatest average height of weeds in glyphosate application (105 cm) differed significantly compared to the control (79 cm).

In the Lapinjärvi experiment, the amount of weeds differed significantly between treatments in each year. After the first growing season, relatively low weed intensity was found in the herbicide treatment despite of high percentage weed cover (Fig 1c). After two growing seasons, the weed intensity was considerable lower in the case of the sheet mulch treatment (Fig. 1c). The herbicide (dichlobenile) treatment was ineffective especially against *Ranunculus repens*, which colonized the herbicide treated spots at first, and *Elymys repens*, which covered some of these spots totally after the second growing season. Despite of the high percentage of weed cover in 1996, the weed intensity was the lowest due to the lowest vegetation height of the herbicide treatment (Fig. 1c). In 1998, the average percentage weed cover was 100% in each treatment, except the sheet mulch (80%). The average weed height was 61 cm, with no significant differences between treatments.

3.2 Survival and Damage

The majority of spruce seedlings survived, even though they suffered from drought in spring 1997. The health status at the end of growing season was dependent on treatments (Table 2). In 1997, lammas shoots were found with 10% of spruce seedlings. It was most frequent in the herbicide treatment (15%), average in the different mulching treatments and most infrequent in the untreated control (3%). The proportion of healthy spruce seedlings in 1998 was the greatest in the herbicide treatment, while the lowest proportions were found with newspaper mulched and untreated seedlings. Dependence on treatment was significant (p = 0.008).

Birch seedlings were damaged less than spruce seedlings. About half of birch seedlings were considered to be healthy even in the untreated control plot, and varied from 57% to 67% in the remaining treatments in 1998 (Table 2). In 1997, the proportion of seriously damaged seedlings was 19% on average, while in the wood fibre treatment and in the control it was 30% and 27%, respectively. Vigorous seedlings were the most frequent in the herbicide treatment.

Table 2. Health status of seedlings by treatments and tree species in 1997 and 1998.

	1997			1998		
	Vigorous	Damaged	Stunted	Vigorous	Damaged	Stunted
Spruce	χ^2 = 23.0	(p = 0.003)		χ^2 = 20.7	(p = 0.008)	
Control	13.3	20.0	66.7	30.0	33.3	36.7
Newspaper	30.0	23.3	46.7	26.7	50.0	23.3
Wood chips	53.3	10.0	36.7	40.0	36.7	23.3
Herbicide	53.3	13.3	33.3	73.3	16.5	10.0
Wood fibre	20.0	36.7	43.3	33.3	33.3	33.3
Birch	χ^2 = 17.9	(p = 0.022)		χ^2 = 5.3	(p = 0.725)	
Control	36.7	36.7	26.7	53.3	26.7	20.0
Newspaper	66.7	23.3	10.0	56.7	26.7	16.7
Wood chips	66.7	20.0	13.3	66.7	23.3	10.0
Herbicide	76.7	6.7	16.7	63.3	13.3	23.3
Wood fibre	40.0	30.0	30.0	63.3	13.3	23.3
Aspen	χ^2 = 30.1	(p = 0.001)	*	χ^2 = 21.1	(p = 0.007)	*
Control	17.5	45.0	37.5	30.0	15.0	55.0
Newspaper	30.0	67.5	2.5	40.0	40.0	20.0
Sheet mulch	10.0	77.5	12.5	22.5	32.5	45.0
Herbicide	20.0	67.5	12.5	35.0	25.0	40.0
Hoeing	37.5	45.0	17.5	52.5	12.5	35.0

* Stunted class consists of dead aspen seedlings, while seriously damaged living aspen seedlings are aggregated to the damaged class.

Only 23% to 36% of the aspen seedlings were considered to be healthy and 17% to 39% were dead in 1997 and 1998, respectively (Table 2). The greatest proportions of vigorous seedlings were found in the newspaper mulch and hoeing treatments. The health status was significantly dependent on treatment (p = 0.007).

Aspen suffered greatly from vole damages. About 70% of seedlings had some kind of vole damage after three growing seasons (Table 3). Vole damage severity was dependent on treatments in 1998 (p = 0.001). In 1996, only 15% of seedlings had meaningful damages and these were distributed evenly between treatments. Less meaningful damages, such as leaf necrosis caused by fungi or insects, were found generally. Vole damages mainly occurred in spring and early summer in 1997, prior to the appearance of fresh ground vegetation.

Table 3. Severity of vole damage to aspen seedlings by treatments in 1998.

Treatment	Control	News-paper	Sheet mulch	Herbi-cide	Hoeing
No damage	22.5	40.0	10.0	40.0	47.5
Damaged	22.5	40.0	45.0	22.5	17.5
Dead	55.0	20.0	45.0	37.5	35.0

$\chi^2 = 26.8$ (p = 0.001)

3.3 Seedling Growth

Mulches of newspaper and wood chip slightly improved the growth of spruce seedlings, while wood fibre mulch had no effect (Table 4). The herbicide treatment had significantly the greatest effect on total height growth (28.2 cm) and diameter growth (2.7 mm) of spruce seedlings, even though it was applied one growing season later. Wood chip mulch was the next best, improving significantly height growth (20.0 cm) compared with the control (13.5 cm).

Wood chip and newspaper mulches increased birch seedlings growth, but the wood fibre mulch gave slightly worse growth results than the untreated control (Table 4). In 1997, significant differences were found between diameter and diameter growth in the case of the wood chip treatment compared with the control. Weed control treatments, except wood fibre mulch, slightly improved the height growth. The wood chip treat-

Table 4. The average dimensions of seedlings by treatments and tree species in 1997 and 1998.

Year	1996		1997		1998	
	Diameter	Height	Diameter	Height	Diemeter	Height
Spruce		2.49 (0.046)	12.7 (0.000)	3.95 (0.005)	13.8 (0.000)	9.7 (0.000)
Control		27.8	3.9	33.5	5.5	41.3
Newspaper		30.3	4.4	35.7	6.0	45.5
Wood chips		26.9	* 4.6	35.3	* 6.8	45.2
Herbicide		29.2	* 5.5	* 40.3	* 8.1	* 57.4
Wood fibre		30.0	4.2	34.1	5.8	42.1
Birch	1.78 (0.14)	0.62 (0.65)	3.66 (0.007)	3.03 (0.02)	1.90 (0.11)	1.60 (0.18)
Control	5.9	79.4	7.2	112.6	11.9	166.9
Newspaper	5.6	79.7	7.9	121.5	14.0	184.4
Wood chips	5.5	80.3	* 8.5	127.1	14.0	187.5
Herbicide	5.7	78.7	8.0	114.5	13.5	175.4
Wood fibre	5.6	75.7	7.1	103.1	11.4	155.5
Aspen	0.89 (0.47)	0.57 (0.68)	3.57 (0.009)	2.41 (0.053)	13.6 (0.000)	8.69 (0.000)
Control	6.1	81.9	6.5	87.5	8.5	103.8
Newspaper	6.3	82.8	6.6	86.6	9.0	106.0
Sheet mulch	6.4	85.8	* 7.4	95.9	* 13.3	* 145.1
Herbicide	6.4	80.7	6.6	82.7	9.4	112.9
Hoeing	6.2	81.0	6.4	83.2	8.5	103.1

The F value (and significance probability value) of GLM is given in the first row of each species.
An asterisk * indicates a significant difference ($p < 0.5$) compared with the control (Dunnett's t-test).

ment resulted in 21.0 cm, newspaper mulch 19.5 cm and herbicide 11.7 cm greater total height growth compared with the control plot. However, differences were not statistically significant.

Sheet mulch improved the diameter and height growth of aspen seedlings (Table 4). Differences in diameter growth in 1997, and both diameter and height growth in 1998 were significant compared to the control. No other weed control method significantly affected growth.

3.4 Frost Thaw

Mean temperature and precipitation explained the trends in frost thaw (Fig. 2). The insulating effect of vegetation (control) or various mulches was considerable. The soil in the herbicide treated and mechanically weeded plots thawed faster than the soil beneath the mulches (Fig. 2). Differences between the various mulch materials were also evident, the most insulating materials being wood fibre and wood chips (coarse saw dust). Frost thaw was progressing in unmulched treatments but turned to frost formation under all types of mulches during the cool period in early April. The thawed layer reached about 15 cm at the beginning of April in the case of the hoeing, herbicide, newspaper and sheet mulch treatments, but two weeks later in the case of the wood fibre and wood chip treatments.

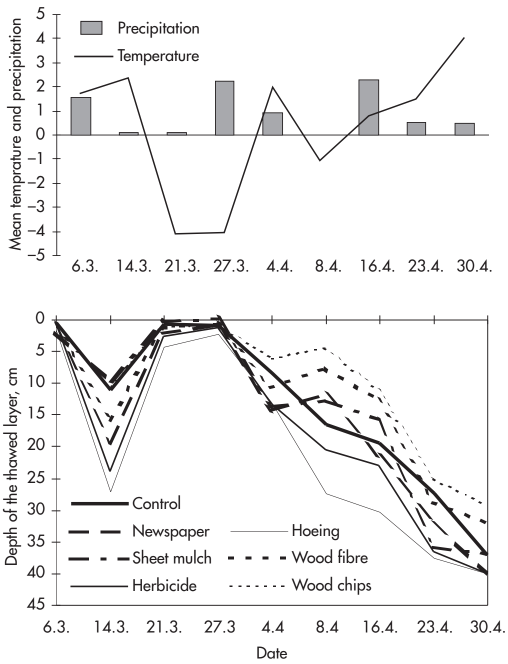

Fig 2. Mean periodic temperature (C°) and precipitation (mm) (above) and frost thaw by treatments indicated as mean depth (cm) of the thawed layer on top of the soil (below) during March and April.

4 Discussion

None of the weed control treatments used was effective in controlling weeds for more than a year or two. The most durable effect was provided by sheet mulch and even then, the average weed cover was 80% three years after the application. With other mulches or herbicides, 80% weed cover was exceeded during the second year. However, the herbicide (glyphosate + terbuthylazine) treatment achieved the greatest growth response in spruce seedlings. Its effectiveness could partly be due to reduced root competition, partly due to the nitrification (decomposition) of dead weeds including roots, and thus improving the aeration and nitrogen content of the soil (Lund-Høie and Grøvold 1987). There were no such growth responses in birch seedlings, despite a visibly successful weed control with foliar (glyphosate) herbicide. The growth responses in birch have varied greatly in other studies. Both the greatest and the weakest responses to effective weed control are found with birch (Leikola 1976, Hytönen and Lilja 1995), on the other hand, no response is found (Hytönen and Lilja 1995). Soil-acting herbicides seems to improve birch growth more than foliar herbicides (Ferm et al. 1994).

Glyphosate benefited *Cirsium* and *Epilobium* weed species resulting in significantly greater weed height and weed intensity compared to the control site two years after application. Similar results have been reported earlier by Lund-Høie and Grøvold (1987) and Siipilehto and Lyly (1995). In addition, there was considerable invasion of *Deschampsia cespitosa* on the bare soil. Thus, following the glyphosate treatment and ploughing, a decreasing cover of *Elymys repens* in the birch plantation was replaced with an increasing cover of *Deschampsia cespitosa*. Adding soil acting herbicides (terbuthylazine or dichlobenil) achieved vegetative recolonization of *Elymys repens* and to some extent *Ranunculus repens*.

In the Lapinjärvi experiment, the herbicide treatment was ineffective, probably because it was applied too late in the growing season. For the effective use of granulated dichlobenil, the ground surface should be wet and weeds hardly visible, but at the time of application, the ground surface was already dry and the weeds were about 1–5 cm high. The ground surface was irrigated before application but possibly not enough. The experiment area was also exposed to drying winds. According to Ferm et al. (1994), dichlobenil controlled *Tripleurospermum inodorum* well at 4.7 kg ha^{-1} a.i. application rate. In this study, a lower application rate was used because of the low tolerance of aspen seedlings and the treatment showed little effect.

Even if the mulches used could not control weeds effectively, they had both adverse and beneficial effects on seedling growth. This contradictory situation could be due to changes in soil properties. According to frost thawing results, all the mulches used in this study had an insulating effect compared with herbicide and hoeing (bare soil) treatments. Not only faster thaw, but also frost thaw progress in unmulched treatments was noticed while frost formation was recorded under mulches during the cool period in April. This was probably due to the greater amount of water which had penetrated the soil without mulch cover. None of the treatments could prevent drought injury in spring 1997. Lammas shoots were found more frequently in mulch and herbicide treated spruce seedlings than in the control.

Generally, organic or light-coloured materials (e.g. hay, sawdust, bark, paper, aluminium) decrease soil temperature, while dark mulches (e.g. tarpaper, black plastic) increase soil temperature (e.g. Waggoner et el. 1960, Ballik 1970, Litzow and Pellet 1983, Davies 1988a, Siipilehto 1995). The soil under mulch may remain cool due to the insulating air layer beneath the mulch (Waggoner et al. 1960). In this experiment, such an air layer was not formed, except in the case of the sheet mulch.

The mulch materials with the greatest insulating effect were wood chips (coarse saw dust) and wood fibre. The slightly adverse effect on birch growth in 1996 and 1998 may have been caused by the cool and rainy summers, the effect being aggravated by the wood fibre mulch. The better results with wood chip mulch may be due to relatively good permeability. In fact, the texture of wood chips in Lapinjärvi were less coarse and thus more insulating than the coarse wood chips used in Luumäki (Litzow and Pellet 1983). Some adverse effects of mulches including winter injury (Creech and Hawley 1960, Whitcomb 1980), lethal temperatures under the mulch (Salisbury and Long 1959, Davies 1988), and lethal temperature above mulches (Kokkonen 1963, Richards 1970) have been reported.

The growth results are also explained by soil moisture, which has been reported to be greater under mulches than on soil covered by weeds (e.g. Ballik 1970, Litzow and Pellet 1983, Davies 1985). Wood chips are more permeable than newspaper or wood fibre mulch. The pure wood fibre used was not only insulating but also the most absorbent material (rawmaterial for napkins). These properties may have caused the poor growth of the birch seedlings. Also, the poor health status of the birch seedlings was associated with fibre mulch in the dry season of 1997. None of the mulches used in Luumäki significantly benefited either the growth or health status of birch seedlings in the rainy summer of 1998.

The great majority of the best growing aspen seedlings were treated with sheet mulch. In the hot and dry weather in 1997, clay soil became very hard. The soil was softer under the sheet mulch and the ground surface had a granular structure. It is possible that the good growth result with the sheet mulch was due to improved aeration conditions of the soil beneath the mulch (Ballik 1970). Perhaps only these best-grown seedlings established a good root system in the first growing season. In the cool and rainy summers of 1996 and 1998 it was especially important that sheet mulch did not prevent gas exchange. In extreme cases, impermeable (plastic) mulch could cause anaerobic conditions in the soil (Davies 1985). Root growth can be dramatically decreased if the soil oxygen content is too low (Leyton & Rousseau 1958). Even so, Davies (1988a) recommended impermeable mulch materials because of their ability to retain moisture transpired by weeds beneath them. Increasing the size of plastic mulch has proved to be more effective against weeds and also more beneficial for the crop tree (Davies 1988b, Harper et al. 1998, Thomas and Comeau 1998).

Vole damage typically increases with increasing weed volume (Ferm et al. 1994). Also, nests under the sheet mulch increase the risk of damage (e.g. Davies 1988a, Ferm et al. 1994). This may be prevented by covering the sheets with a thin layer of soil (Davies 1988a). The newspaper slurry mulch adhered tightly to the ground and no nests were found beneath them. Consequently, vole damage was the least frequent with this treatment. In addition, the light-coloured surface of the newspaper mulch provided a less desirable shelter for voles. Some nests were found in wood fibre mulch.

The size and durability of mulch and its parent material are important aspects governing its use. More research is needed on the ecological effects of mulching, the effect of the material and size of the mulch, and the final cost-effectiveness of their use. Approximately 2 cm deep newspaper, wood fibre, and wood chip mulches proved to control weeds insufficiently. Too thick a layer of wood chips is also found to be harmful due to decline in soil temperature and soil oxygen content (Greenly and Rakow 1995). Cost-effectiveness is typically greater with herbicides (Christensen 1998). In this study, the effect of herbicides was temporary. First, vegetation showed a rapid recovery, which has been noticed elsewhere (Lund-Høie and Grøvold 1987, Ferm et al. 1994, Siipilehto and Lyly 1995, Wagner et al. 1999). Secondly, the greatest growth response, found in spruce, corresponded to one year's growth. Similar, or less impressive results are reported for spruce (Nilsson and Örlander 1995, Nilsson and Örlander 1999) and for *Pinus radiata* (Mason 1999). If herbicides are used, more than one application is profitable in the long term. Wagner et al. (1999) reported a greater growth response to weed control with shade tolerant than intolerant conifer species. Because of the rapid recovery of weeds after application of glyphosate, conifers benefited greatly from annual applications for three to five years after planting (Wagner et al. 1999).

In this study, sheet mulch was able to control weeds for many years, but with an increase in the risk of vole damage. Slurry mulches, wood chips or herbicides had no lasting weed control effects. Repeated applications are necessary for effective weed control, thus, decreasing the cost-effectiveness of these treatments. Organic mulches had a definite insulating effect, which may increase the risk of winter drought.

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