Effects of Competing Vegetation and Post-Planting Weed Control on the Mortality, Growth and Vole Damages to *Betula pendula* Planted on Former Agricultural Land

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Effects of competing vegetation and weed control methods (fibre board mulch, cover crop of clover, various herbicides) on the survival and growth of and vole damage to silver birch (*Betula pendula* Roth) were analysed based on data from a field experiment established in southern Finland. The cover percentage of competing vegetation and its shading effect were assessed, and seedling size and vitality were recorded several times during the 11-year research period. Mean seedling height and height increment decreased linearly with increasing vegetation cover. Seedling mortality started to significantly increase once the vegetation cover had reached the level of 60–80%. Herbicides significantly retarded increase of weed cover on the initially weedless areas for two to three years, and a cover crop promoted increase in cover percentage. Successful weed control with herbicides significantly increased seedling growth and survival. After 11 years, the average stem volume on the herbicide-treated plots (28.9 m^3ha^{-1}) was 2.5-fold as compared to that of the control plots (11.6 m^3ha^{-1}). Furthermore, seedling mortality on the control plots (21%) was almost 3.5-fold as compared to the seedling mortality on herbicide-treated plots (6%). Having a cover crop proved to be an ineffective weed control method both in terms of seedling growth and survival. The application of mulch had only a slight effect on height increment (0.6 m in 11 years), but on the other hand, it considerably decreased seedling mortality (control: 21%, mulch treatment: 1.5%). These differences were not, however, statistically significant. Small seedling size, high shading class, and high vegetation coverage percentage increased the risk of voles damaging the seedlings.

Keywords vegetation control, herbicides, mulch, cover crop, vole damage, weed cover, *Betula pendula*
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1 Introduction

Since 1969, 240 000 ha of agricultural fields have been afforested in Finland (Finnish …. 2004). In the 1970s and 1980s, Norway spruce (*Picea abies* L.) and Scots pine (*Pinus sylvestris* L.) were the most common tree species planted on abandoned fields. The share of silver birch (*Betula pendula* Roth) started to increase in the 1980s, and in 1990–1998 it accounted for 45% of all field afforestation (Saksa et al. 2003). The growth of silver birch on mineral soil fields has reached, on average, the height index 26 (Oikarinen 1983), which corresponds to the growth expected on the Oxalis-Myrtillus site type as used in the Finnish site classification system (Cajander 1926, Kinnunen and Aro 1996, Saramäki and Hytönen 2004).

Field afforestation is considered to be far more difficult to succeed in than reforestation of clearcut forests, and many failures have been reported. Pests, especially voles and moose, and tree diseases can cause damage to birch seedlings, and particularly on field-afforestation sites (Rossi et al. 1993, Hytönen 1998, 1999, Saksa et al. 2003). One of the major problems is how to control ground vegetation – its development after soil preparation is faster and more vigorous than on forest soils. The higher nutrient contents of afforested field soils (Hytönen and Ekola 1993, Hytönen and Wall 1997, Wall and Hytönen 2005) are probably the foremost explanation for the accelerated development of this vegetation. The thick field vegetation layer competes with tree seedlings particularly for water and nutrients (Davies 1985, Ferm et al. 1994), as well as for light. In winter, tall grass vegetation pressed down by a thick snow layer can seriously damage tree seedlings. Furthermore, abundant weed vegetation can increase the risk of seedling damage by providing shelter and nourishment for fungi and pests, such as voles. When planting silver birch, careful site preparation is recommended in order to reduce the effect of competing vegetation (Hyvän…2001).

After soil preparation, the open field is colonized by annual species during the first growing season (Törmälä 1982, Jukola-Sulonen 1983). Both arable and abandoned fields contain large banks of germinable seeds, up to 50 000 per m^2, consisting mostly of seeds of pioneer weed species (Paatela and Erviö 1971, Kiirikki 1993). These seeds can remain viable for a long time, up to 20 years (Kiirikki 1993). Subsequently, annual weeds give way to perennial herbs and grasses. Grasses often dominate the vegetation for a long time after afforestation, and thus the vegetation cover does not resemble that of normal forests even after 16–17 years from afforestation (Rossi et al. 1993, Hynönen and Saksa 1997, Hytönen 1999). The biomass of weeds can be very high, especially below ground. The average weed oven-dry biomass values (above and below ground level) of 274 g m^{-2} and 1054 g m^{-2}, respectively, were reported in a study covering 51 fields that had not been cultivated for between one and six years (Hokkanen and Raatikainen 1977).

Field voles (*Microtus agrestis*) are one of the foremost agents of damage impacting on birch seedlings on field afforestation sites. The risk of vole damage on afforested fields can be several times greater than the same risk in regular plantations established on forestland (Henttonen et al. 1995). On afforested fields, contrary to forestland, voles can inflict considerable damage in summer as well. The peak in field vole populations correlates with the peak in field-layer vegetation biomass, particularly that of the most favoured plant species (Teivainen et al. 1986). Thus, efficient weed control could reduce the risk of vole damages. Weed control could also accelerate the development of the seedling height, diameter and bark thickness, and thereby reduce seedlings' susceptibility to vole attacks.

The use of herbicides in Finnish forestry has been drastically reduced during the past decades (Fig. 1), mainly due to environmental concerns. Consequently, also the number of commercially available herbicides has decreased considerably. The need for cost effective alternative vegetation control methods has become more important. Therefore, information on alternative weed control methods, such as mulches and cover crops, is needed. Low-lying cover plants could be an attractive option if they could repel taller grass vegetation (Hänninen 1998, Willoughby 1999). Clover (*Trifolium* spp.) as a cover crop could also improve the nitrogen status of the soil and thereby of the planted tree seedlings due to its ability to fix nitrogen.

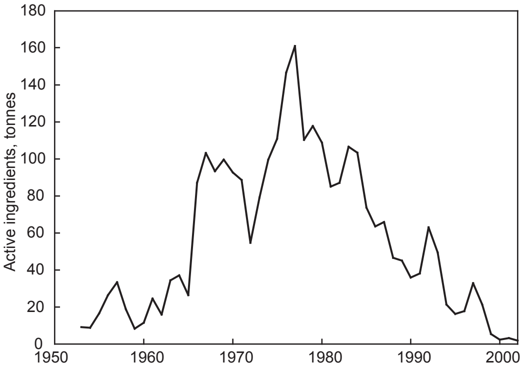

Fig. 1. Sales of forest herbicides in Finland 1953–2002 (Markkula et al. 1990, Finnish Plant Protection Inspection Centre 2003).

Tree species-specific vegetation management research is needed, since tree species differ considerably in their ecological characteristics and tolerance of herbicides. Research efforts have focused on conifers, and the effects of inter-specific competition and weed control on the growth and survival of birch are poorly known. Previous studies mainly report results from the first post-planting years only (Leikola 1976, Ferm et al. 1994, Siipilehto 2001, Karlsson 2002), or they are confined to nurseries (Rummukainen and Voipio 1983). They all demonstrate that successful weed control promotes birch seedlings' height increment at the initial stage (1–4 years). Also, growing site properties, seedling type, soil preparation treatments, etc., affect the intensity of competition and response to vegetation control.

The aim of this research was to investigate the effects of weed cover and various post-planting weed control methods applied in a plantation of silver birch (*Betula pendula*) in terms of seedling growth, mortality and vole damage during 6 or 11 post-planting growing seasons. The main results for the first two growing seasons have been presented earlier (Ferm et al. 1994).

2 Materials and Methods

The study site, a mineral-soil-based agricultural field with a good nutritional status (Ferm et al. 1994), is located in Vilppula, southern Finland (62º03'N, 24º27'E). It previously carried a crop of barley before being afforested. Complete soil preparation (ploughing and harrowing) was done in the spring of 1991. Containerized one- and two-year-old silver birch seedlings were planted in late May applying a spacing which resulted in 2200 seedlings per hectare. Thereafter, weed control was implemented using various herbicides, a cover crop of clover (*Trifolium repens* L.) and fibre board mulch (Table 1), and the study area was fenced off to prevent hare and moose damage. The application procedure is described in detail by Ferm et al. (1994).

The experiment was originally established as a randomised block design with three replications (plot size 100 m^2). Besides weed control methods, two types of seedlings (one- and two-years old containerised seedlings of equal size class) were compared, except on the glyphosate- and sethoxydim-treated plots. Furthermore, the chlorthiamid and dichlobenil treatments were repeated. The two seedling types were combined (Ferm et al. 1994), since there were no significant differences between their mean heights after any of the growing seasons. Thus, the number of replications per treatment was either three or six (Table 1).

All plots were inventoried after the 1st, 2nd, 3rd, 4th and 6th growing season. Furthermore, all control plots and the plots treated with mulch, cover crop, terbuthylazine and single chlorthiamid and dichlobenil were inventoried after the 11th growing season. The vitality and height (measured applying an accuracy of 1 cm) of the seedlings were recorded, and two main causal agents of damage were assessed on one circular 50 m^2 sample plot set up within each plot. Furthermore, the butt diameter ($d_{0.1}$) of each seedling was measured after the 2nd, 3rd and 4th season and the breast height diameter ($d_{1.3}$) after the 11th growing season. In the first three inventories, the shading class (SC) of weed vegetation on each seedling was assessed as follows: no shading (0), one quarter (1), half (2), or three quarters of the seedling in shade (3), and fully shaded (4). To

Table 1. Description of weed-control methods

Treatment	Brand name or species	Primary mode of absorption	Active ingredient	Application rate, product kg or 1 ha	Application date	Number of replications
Control (CONT)						6
Piece of particle board (MULCH)			50 cm × 50 cm		May 1991	6
Cover crop, clover (CLOV)	*Trifolium repens*				May 1991	6
Terbuthylazine (TERB)	Gardoprim	Soil active*	500 g l^{-1}	6 l ha^{-1}	13.–14.6. 1991	6
Chlorthiamid	Prefix	Soil active*	75 g kg^{-1}	60 kg ha^{-1}		3
(CHLO1)					30.5.1991	3
(CHLO2)					22.5.1992**	
Dichlobenil	Casoron G	Soil active*	67.5 g kg^{-1}	60 kg ha^{-1}		3
(DICH1)					30.5.1991	3
(DICH2)					22.5.1992**	
Glyphosate (GLYP)	Mon 14478	Foliar active	400 g l^{-1}	50%, ca. 0.5 l ha^{-1}***	31.7.1991	3
Sethoxydim (SETH)	Nabu	Foliar active*	186 g l^{-1}	5 l ha^{-1} + surfactant	31.7.1991	3
Pendimethalin (PEND)	Stomp	Soil active	400 g l^{-1}	5 l ha^{-1}	14.6.1991	6

* Secondary mode of absorption either foliar or soil activity (Mukula & Salonen 1990)
** Chlorthiamid and dichlobenil were respread for additional weed control
*** Average rate for this type of weed wiping application

ensure the consistency of this classification the same field team made the assessment throughout the whole follow-up period.

The vegetation was examined for species composition and cover percentage in mid-September 1991, late July 1992, and mid-July 1993. The species composition of the first two inventories has been reported earlier (Ferm at al. 1994). On fully treated plots, the cover percentage was visually estimated using three 1 m^2 sub-sample plots. On spot-treated plots (mulch and glyphosate), six 0.5 m^2 sample plots were placed around systematically selected seedlings. In addition, the dominant height of the weeds was estimated on these plots.

The stem volumes of the trees were computed applying the models presented by Laasasenaho (1982).

Analysis of variance was used to test the statistical significance of the weed control treatments on weed coverage, seedling mortality, seedling growth and vole damage. Before conducting the analysis, the homogeneity of variances was tested using Levene's test. Transformations were used to homogenize variances where necessary. Tukey's honestly significant difference test was used to separate the means of the treatments. The distributions were compared using the χ^2 test. When analysing the selectivity of the damage caused by voles (*Microtus agrestis*), the damaged and undamaged seedlings were divided into quartiles by their height. Since the voles could have damaged the seedlings both during the winter and summer time prior to the measurements made in the autumn, seedling height before the observation of vole attack was used in this analysis.

3 Results

3.1 Weed Coverage

Following complete soil preparation prior to planting, the experimental area was free of vegetation at the beginning of the experiment. The treatment continued to have a significant effect on weed coverage even in the third year ($F = 11.886$, $p < 0.001$), when the vegetation was inventoried for the last time (Fig. 2). Primarily soil-active herbicides terbuthylazine and repeated chlorthiamid and dichlobenil were found to be the most

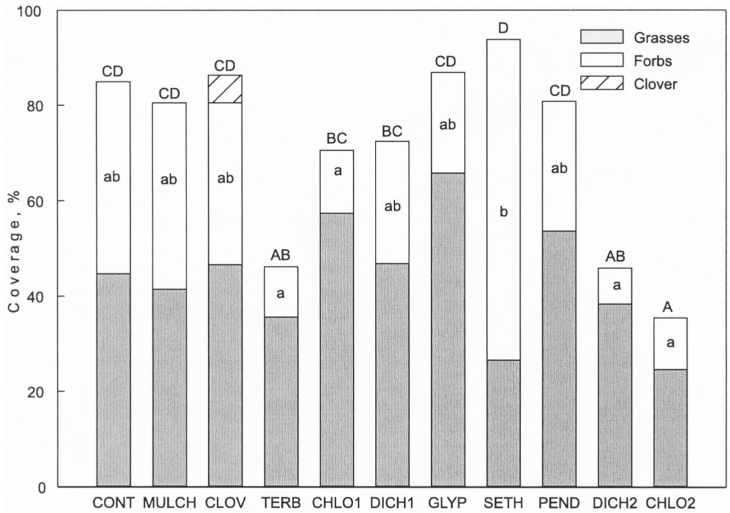

Fig. 2. Herbaceous cover in the third growing season. Means designated with the same letter did not differ from each other at 5% significance level. Upper-case letters indicate differences in total weed coverage, lower case letters in forb coverage (incl. clover on all plots). For notations of treatments see Table 1.

effective weed control treatments. The mean weed coverages of these treatments varied from 35% to 46%. On the control plots, the mean weed coverage had increased to 85% by the third year. However, the mean vegetation coverage on plots treated with mulch, pendimethalin, glyphosate, cover crop and sethoxydim did not significantly differ from that of the control plots. Repetition of chlorthiamid and dichlobenil treatments at the beginning of the second growing season slightly reduced weed coverage when compared to single applications. On the cover-crop plots, the coverage of clover, which had been as high as 91% and 47% during the first and second growing seasons, respectively, had diminished to just 6% by mid-July of the third growing season with other species having taken over.

Treatments also significantly affected the forb coverage ($F=3.145$, $p=0.006$), whereas grass coverage was independent of treatment ($F=1.348$, $p=0.244$). Terbuthylazine, chlorthiamid and dichlobenil decreased the coverage of forbs, and sethoxydim, on the other hand, increased the proportion of forbs higher than on control plots (Fig. 2).

3.2 Seedling Growth

As regards seedling height, two groups of treatments differentiated from the very beginning of the experiment (Fig. 3). The differences between the treatments remained approximately constant after the first six years, and the height increment between the 6th and 11th seasons was independent of the treatment applied ($F=1.04$, $p=0.420$). In all previous inventories, the differences in annual height increment were highly significant ($F=5.398-12.526$, $p<0.001$) except for the 4th year ($F=1.931$, $p=0.074$), while differential butt diameters were dependent on treatment both in the 3rd and 4th growing seasons ($F=6.159$, $p<0.001$; $F=2.558$, $p=0.019$).

Seedlings on the plots treated with chlorthiamid, dichlobenil and terbuthylazine were significantly taller than seedlings on control plots already after two growing season. The seedlings on these plots were tallest in every inventory, their mean height varying from 374 cm to 410 cm after four growing seasons, and from 705 cm to 778 cm after 11 growing seasons. At the same points in time, the shortest seedlings were found on the

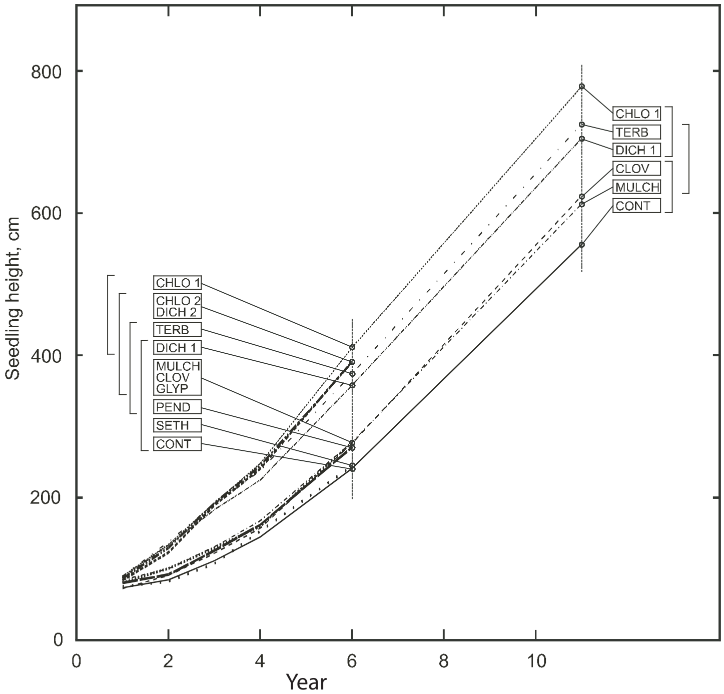

Fig. 3. Effect of weed control treatment on the seedling height. The square brackets indicate the significantly ($p<0.05$) homogenous groups of treatments according to Tukey's test at the end of the 6th ($F=7.643$, $p<0.001$) and 11th ($F=6.782$, $p=0.001$) growing seasons. For notations of the treatments see Table 1.

control plots, their mean height being 240 cm and 556 cm, respectively. Thus, the best treatment in terms of height increment was the chlorthiamid treatment, which gave the seedlings 71% and 40% height advantage over seedlings growing on the control plots after 6 and 11 growing seasons, respectively. After the 6th growing season, repetition of chlorthiamid and dichlobenil treatment did not significantly increase the mean height as compared to single applications. The butt diameters ($d_{0.1}$) of the seedlings were measured for the last time after the 4th season, when the dependence of butt diameter on treatment ($F=6.806$, $p<0.001$) was approximately as significant as in the case of seedling height (7.063, $p<0.001$). The thickest and tallest seedlings were found on plots treated with chlorthiamid, dichlobenil and terbuthylazine.

The mean stand volumes per hectare (total stem volume, m^3ha^{-1} over bark) were computed after the 11th growing season (Fig. 4). The effect of weed control treatment on mean stand volume was highly significant ($F=4.582$, $p=0.006$). The lowest mean volumes were recorded on the control (11.6 m^3ha^{-1}), cover crop (12.4 m^3ha^{-1}) and mulch plots (17.5 m^3ha^{-1}). The highest volumes of the six treatments under comparison, varying from 25.4 m^3ha^{-1} to 34 m^3ha^{-1}, were found on herbicide plots.

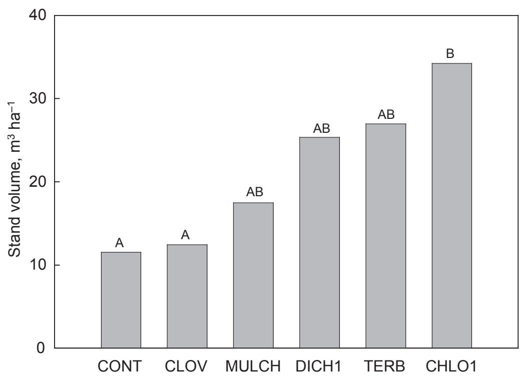

Fig. 4. Stand volume by treatment at the end of the 11th growing season. The means designated with the same letter did not differ from each other at 5% significance level. For notations of treatments, see Table 1.

The vegetation cover percentages measured during the 1st, 2nd and 3rd growing seasons correlated negatively and significantly with sub-

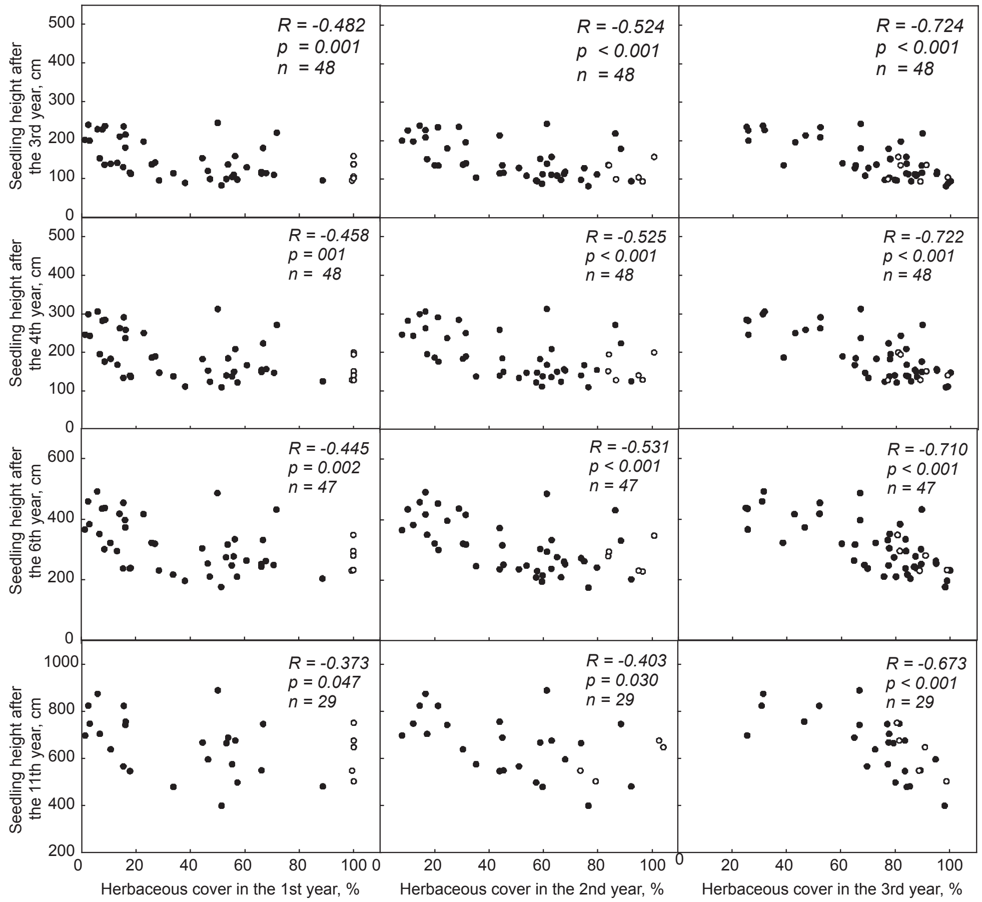

Fig. 5. Effect of herbaceous cover on average height of living seedlings (n=48). Open markers (°) indicate cover crop plots.

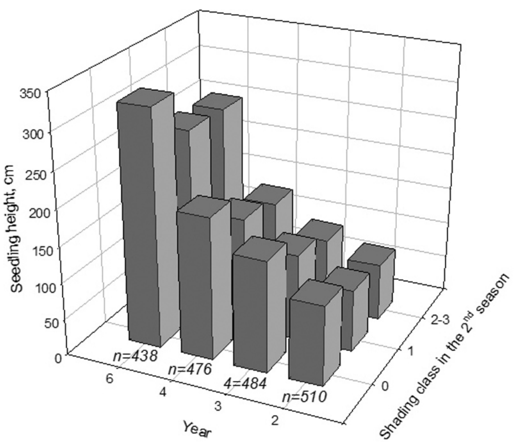

Fig. 6. Effect of shading on height of individual seedlings by shading class (2nd season). Dead seedlings excluded.

sequent plot-specific mean heights up to the 11th growing season (Fig. 5). The weed coverage of the 3rd growing season correlated significantly with all later height increments as well. Weed coverage of the 1st and 2nd season did not correlate significantly with height increment after six years.The shading class also appeared to indicate future growth at an early stage (Fig. 6). For example, seedlings classified by shading class in the 2nd growing season had significantly different mean heights even after the 2nd to 6th growing seasons ($F=6.542-10.813$, $p \leq 0.002$). The un-shaded seedlings of the 2nd season were 65 cm (25%) taller at the end of the 6th season than those, which had been only half-shaded.

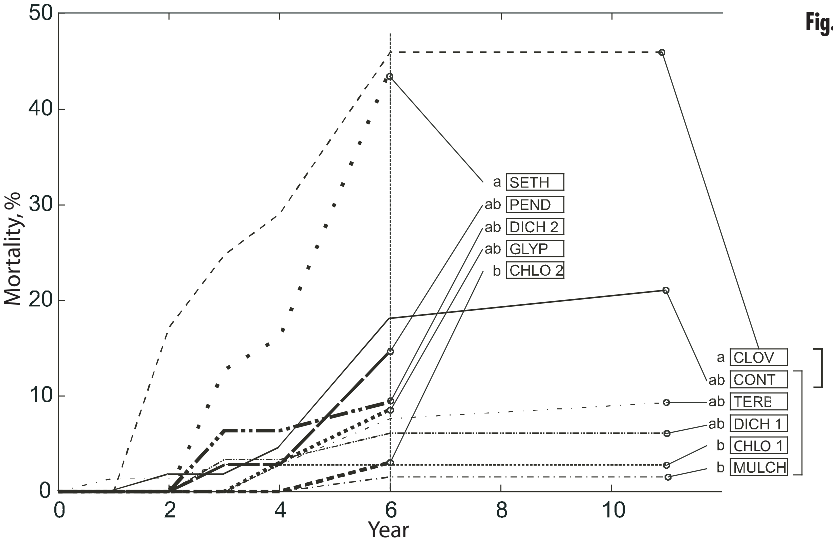

Fig. 7. Seedling mortality. Means with the same letter did not differ from each other at 5% significance level in the 6th year. In the 11th year, the brackets indicate the significantly (p<0.05) homogenous groups of treatments according to the Tukey's test. For notations of the treatments, see Table 1.

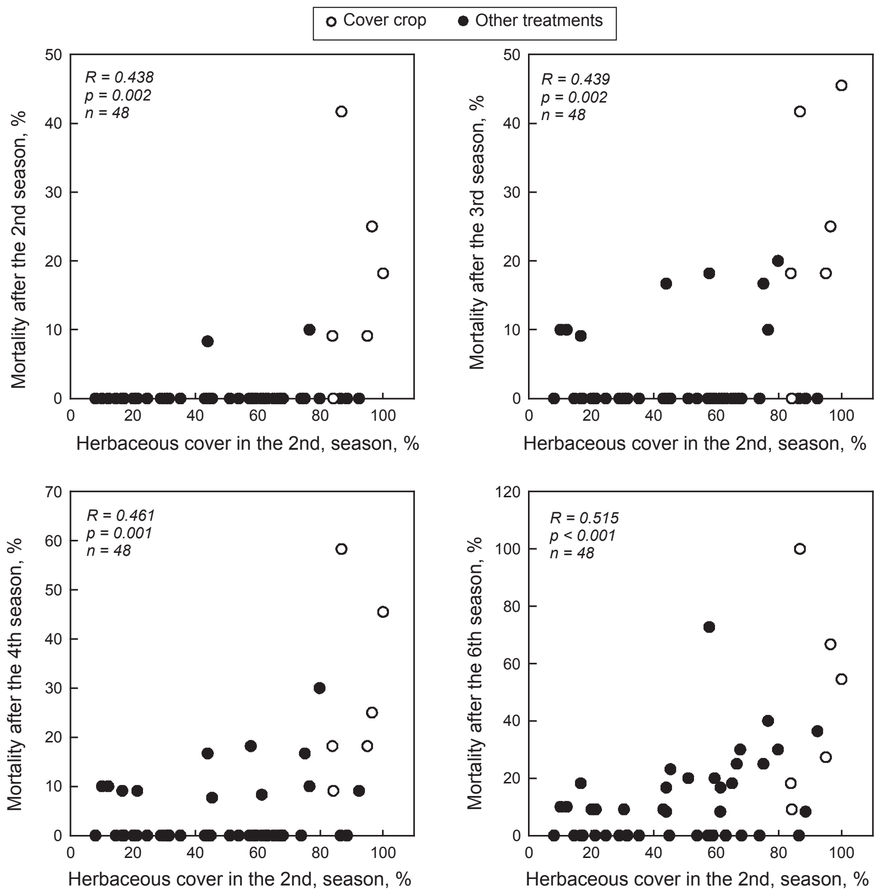

Fig. 8. Effect of herbaceous cover at the end of the 2nd growing season on cumulative seedling mortality.

Table 2. Correlation coefficients between weed coverage and mortality

Cumulative mortality, %	Weed coverage percentage		
	1st season	2nd season	3rd season
1st season (n=48)	–0.193		
2nd season (n=48)	0.505***	0.438**	
3rd season (n=48)	0.472**	0.439**	0.156
4th season (n=48)	0.523***	0.461**	0.189
6th season (n=48)	0.487***	0.515***	0.360*
11th season (n=30)	0.593**	0.599***	0.330

*p<0.05, **p<0.01, ***p<0.001

3.3 Mortality

Cumulative seedling mortality increased up to the 6th growing season, but thereafter only small increases in mortality were observed (Fig. 7). The effect of treatment on mortality was highly significant both after the 6th and the 11th growing seasons ($F=4.56$, $p<0.001$; $F=6.07$, $p=0.001$). Mortality on the control plots was 18% after the 6th and 21% after the 11th growing seasons. However, seedling mortality on the control plots did not differ significantly from the other treatments at either of these points of time. After the 6th growing season by far the highest mortalities were observed on the cover crop (46%) and sethoxydim-treated (44%) plots although these treatments differed significantly only from the two best treatments, chlorthiamid (3%) and mulch (2%).

Weed coverage measured in the 1st and the 2nd growing season correlated significantly with all subsequent cumulative seedling mortalities (Table 2).

Seedling mortality started to rapidly increase once the approximate coverage of 60% was exceeded (Fig. 8). Moreover, mortality increased along with increased shading of seedlings (Fig. 9). The SC-distributions of living and dead seedlings differed significantly from each other. In the case of SC distribution of the second growing season, χ^2 varied from 18.4 to 80.5 ($p<0.001$). At the end of the sixth growing season, the mortality of the un-shaded seedlings at the end of the 2nd growing season was 11%, whereas all seedlings with at least 3/4-shading were then dead (Fig. 9).

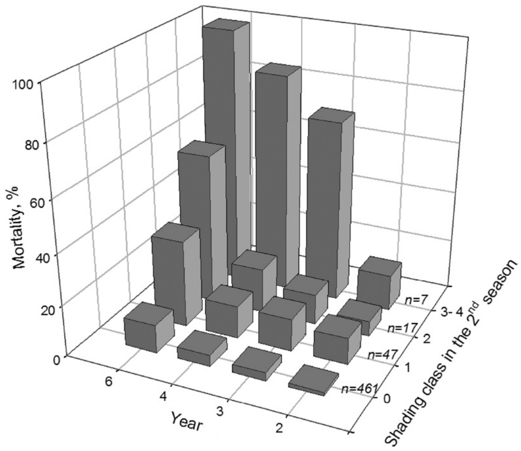

Fig. 9. Effect of shading class (2nd season) on cumulative seedling mortality.

3.4 Vole Damage

Annual vole damage was observed in connection with the measurements made at the end of the 4th and 6th growing seasons when voles had damaged 11% and 13% of all seedlings, mainly by nibbling stem bark to varying degrees. After the 4th season, 27% of the damaged stems were broken, and 11% after the 6th season.

After the 4th growing season, the lowest frequencies of vole attacks were found on the mulch, chlorthiamid and dichlobenil plots, and the highest on the sethoxydim plots (Fig. 10). The effect of treatment on the vole damage was not, however, statistically significant neither in the 4th nor in the 6th season. Instead, the voles proved to be selective by attacking mostly the smallest seedlings in both seasons. The effect of seedling size on the incidence of vole attacks was shown by testing the seedling height quartiles (2nd season: $\chi^2=29.482$, $p<0.001$; 4th season: $\chi^2=28.853$, $p<0.001$) (Fig. 12). Most seedlings had probably passed the critical size for being attacked by voles by the 6th year for the reason that the height distributions of the damaged and undamaged seedlings were equal ($\chi^2=2.168$, $p=0.538$).

Weed coverage was inventoried for the last time in the 3rd year, and correlations between the weed coverage of that year and subsequent occurrences of vole damage were not statistically significant. Figure 12 A indicates, however, that the risk of

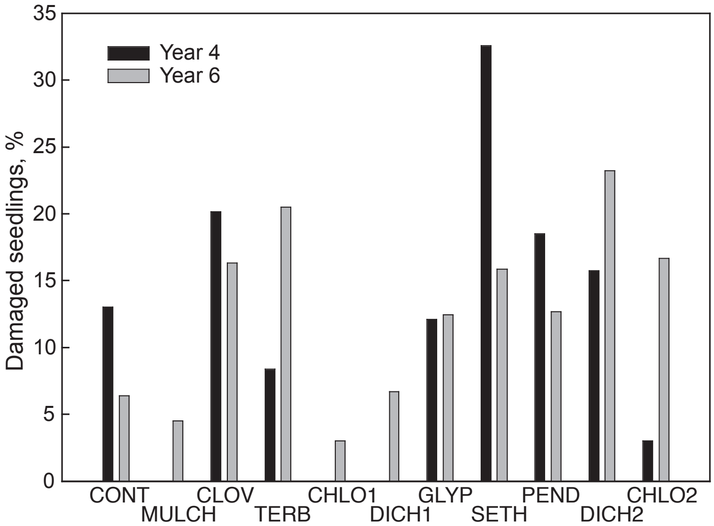

Fig. 10. Vole damage in the 4th and 6th growing seasons. For notations of treatments, see Table 1.

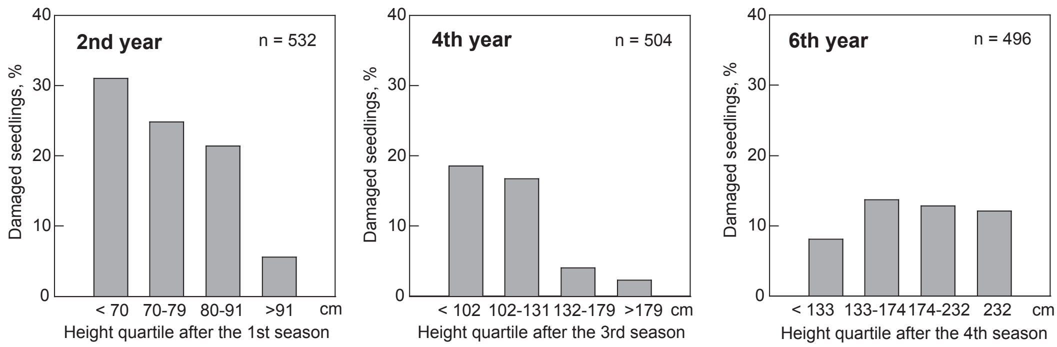

Fig. 11. Effect of seedling height on frequency of vole damage. Height measured one year prior assessment of vole damage.

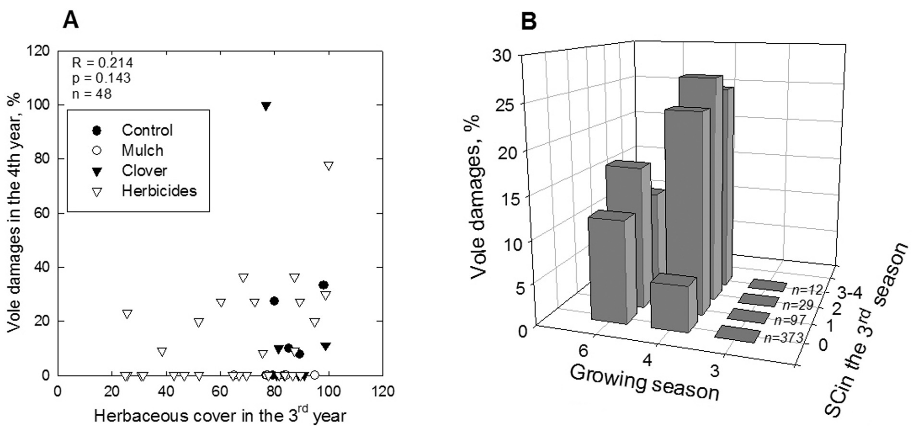

Fig. 12. Correlation between weed coverage and annual vole damage (A) and effect of shading on the risk of annual vole attack (B).

vole damage tends to increase along with increase in the coverage of competing vegetation. Also, higher SC indicated higher risk for vole damage after the fourth but not any more after the sixth growing season (Fig. 12 B).

4 Discussion

The competition from herbaceous vegetation had a significant detrimental effect on the development of silver birch seedlings planted on the studied former mineral soil agricultural field. Even complete soil preparation (ploughing and harrowing), leaving the area totally weedless before planting, was not adequate in ensuring the good development of the seedlings. Pioneer weed species germinating from the exposed seed bank of the field rapidly colonized the area (Ferm et al. 1994). During the subsequent years, especially the 3rd growing season, annual weeds gave way to perennial grasses and herbs.

The vegetation cover percentage measured during the 1st, 2nd and 3rd growing seasons correlated negatively with the seedling height growth and mean height of the same growing season. In this study, the vegetation cover percentage of the 1st growing season correlated with the height of the seedlings even after the 6th growing season. This finding clearly points to the importance of immediate post-planting vegetation control. Since the correlation between vegetation cover and height growth was linear, decreasing the weed cover would result in growth increment. Seedling mortality started to increase only when the vegetation coverage was very high, more than 60%. In the case of cover-crop plots with a high cover percentages, increase in mortality could partly be explained by the increase in vole damage. Consequently, keeping the vegetation cover percentage below this limit was a means of preventing high mortality. Even light-demanding birch seedlings are able to survive in dense vegetation for many years, even though their growth will be adversely affected.

The shading effect of competing vegetation depends on its density and height, as well as the height of the seedlings. Therefore, a simple assessment of the degree of shading can yield important information on the competition situation. A higher shading class (SC) indicated growth retardation and increase in mortality. Our shading class was quite prognostic as well, even though it was based on a subjective estimate. The SC of the 2nd growing season explained the growth and mortality of the seedlings in the following years fairly well. All living seedlings in the shading classes 3 and 4 (more than 75% of the seedling in shade) were dead after the 6th growing season. Our results show that the future growth rate of the seedlings could be predicted at an early stage on the basis of shading and weed cover percentage.

After the first two years of this experiment, it was concluded that herbaceous vegetation competes more for underground resources (nutrients and water) than for light (Ferm et al. 1994). On abandoned fields, the under-ground weed biomass may be several times greater than the above-ground biomass (Törmälä and Raatikainen 1976, Hokkanen and Raatikainen 1977). This shows the importance of below-ground competition. Seeing as the seedlings were much taller than competing vegetation, the competition for nutrients and water was probably much more important than competition for light.

Considerable numbers of birch seedlings damaged by the voles were found in the inventories following the 2nd, 4th and 6th growing seasons. Increase in vegetation coverage increased the risk of vole damage. Also, increase in the shading class increased the risk of vole damage, and short seedlings were more susceptible to vole damage than taller ones. The positive effect of weed control on the incidence of vole damage has been reported in the earlier studies, too (Leikola 1976, Teivainen et al. 1986). Our findings show that weed control averts vole damage in two ways: it reduces the amount of plant biomass suitable as food and accelerates seedling growth into such size classes that their stem bark is too hard and thick for the voles. In addition to vole damage, some slight bark necrosis caused by fungi and insects were observed. Fencing the experimental area completely prevented moose damage.

The use of short cover crops, especially leguminous clovers capable of biologically fixing nitrogen, as an alternative method in controlling harmful vegetation has aroused interest in recent years (Hänninen 1998, Hänninen et al. 1999, Willoughby 1999). However, perennial clovers have in many studies failed to increase the nitrogen status of birch (Ferm et al. 1994, Hänninen et al. 1999), or to improve the nutrient status of the soil (Hänninen et al. 1999). In this study, dense clover vegetation was established by seeding, and it covered almost 100% of the ground after the 1st growing season (Ferm et al. 1994), but was almost completely replaced by other forbs and grasses by the end of the 3rd growing season. The cover crop proved to be an unsuccessful method, since it considerably increased mortality as compared to the control treatment.

High seedling mortality on plots with cover crops was probably a consequence of the increased incidence of vole damage. Many cover-crop species have been found to compete with the tree crop (Willoughby 1999), but the clover used in this study did not compete with birch seedlings so intensively as to have suppressed seedling growth. However, the slight increase (68 cm in 11 years) gained by cover crop was not statistically significant. Similar results on the effects of clover (*Trifolium repens*) have been reported by Willoughby (1999) from two sites on arable land in the United Kingdom. As a result of higher seedling mortality on the clover plots, the stand volumes on clover plots and control plots did not significantly differ from each other. It is also probable that the below-ground competition for nutrients and water between the birch seedlings and clover was as severe as the competition between natural grass vegetation and tree seedlings on the uncontrolled plots. In agreement with our results, Willoughby (1999) did not get encouraging results from cover crops.

Mulch slightly, but not significantly, decreased the cover percentage during the first two growing seasons (Ferm et al. 1994). During the 3rd season, mulch plots no longer differed from the control plots. Mulch treatment slightly increased seedling height growth (57 cm in 11 years), but the increment was not statistically significant. Siipilehto (2001) reported after three growing seasons almost identical (19 cm vs. 20–21 cm) non-significant height increases associated with mulching. The main positive effect of mulching was that it greatly reduced seedling mortality. Mainly due to this reduced mortality, the use of mulch increased the stem volume of birch by 6 m^3ha^{-1} in 11 years, but the increment was not statistically significant.

The durability and superficial area of mulches are key factors affecting the survival and growth of tree seedlings. Newsprint, wood fibre, fibre slurry and wood chip mulches have proved to be inefficient in controlling weeds (Siipilehto and Lyly 1995, Siipilehto 2001). The duration-of-effect of fibre board mulches used in this experiment was sufficient since their effect lasted for at least three years. It is probable that the roots of weeds grew underneath the mulch and thus mulching did not decrease the competition for water and nutrients effectively enough to increase seedling growth. In earlier studies, the seedlings of deciduous trees grew the faster the further away the weeds were kept from the base of the seedlings (Davies 1988, Samyn and de Vos 2002). According to Davies (1988), mulches should be at least one metre in diameter in order to promote seedling growth. The effect of mulches can be increased by trampling the vegetation around the mulches to prevent tall vegetation from falling on top of the seedlings and thereby damaging them. Thus, mulches larger than the 0.25 m^2 ones as used in this study are needed when controlling dense and tall field vegetation to ensure an adequate weed-free zone around the seedlings and to increase seedling growth and decrease mortality. On the other hand, mulching can promote vole damage by providing shelter for their nesting; this has been reported after two growing seasons in this experiment (Ferm et al. 1994) and in other studies as well (Davies 1988, Siipilehto 2001, Samyn and de Vos 2002). However, since mulching did not increase vole damage after the 2nd growing season, the mulch did not provide attractive nesting shelters for voles any longer.

In the present study, most of the herbicides controlled weeds quite efficiently for one to at least three growing seasons. Their effect depended on the species composition of the weeds, the application rate and the weather conditions, as well as the organic matter and clay content of the soil (Bärring 1965, Junnila 1984, Mukula and Salonen 1990, Siipilehto 1995). Sethoxydim, known for its poor impact on broadleaved herbs (Tu et al. 2001), was one of the most ineffective herbicides. It controlled grasses fairly efficiently, but allowed forbs to germinate and grow. Neither seedling growth nor mortality on the sethoxydim plots differed from those of the control plots. This was probably due to increased occurrence of vole damage on these plots, resulting from the increased amount of vegetation. Especially forb species are among the favourite food plants of voles (Teivainen et al. 1986).

Glyphosate and pendimethalin significantly decreased the vegetation cover percentage on the first growing season only (Ferm et al. 1994). Being a foliar active herbicide, glyphosate can damage birch seedlings. This damage can be prevented by careful spraying with a backpack sprayer (Siipilehto 2001) or (as in this study) by using a weed-wiping applicator. Since glyphosate does not inhibit germination of seeds of the seed banks (e.g, Morash and Freedman 1989), it allowed a rapid invasion of annual weeds in the second growing season. In order to achieve a good effect on afforested fields with large seed banks, its application should be repeated in the 2nd summer. In the study by Siipilehto (2001), glyphosate treatment gave good initial control as well, but after three growing seasons the sample plots were almost totally colonized by weeds. In our study, glyphosate gave the birch seedlings non-significant height advantages of 18 cm and 37 cm within three and six years as compared with untreated seedlings, respectively. Siipilehto (2001) found that the birch seedlings got a significant height advantage of 12 cm over the control seedlings in three years. Thus, a weed-control effect of one year seems to be too short a period for increasing seedling growth or reducing their mortality.

Pendimethalin is one of the dinitroanalines, which are supposed to be very effective pre-emergence herbicides. They affect even the underground buds and stolons of perennial weeds (Database on Pesticides…). In this study, pendimethalin was, however, one of the most ineffective herbicides. This was probably due to losses resulting from photo-decomposition and volatilisation, which probably could have been avoided by incorporating the herbicide in the soil (Database on Pesticides…).

The best results were achieved with terbuthylazine, chlorthiamid and dichlobenil, of which only dichlobenil is at present registered for forestry use (Torjunta-aineet 2003). Terbuthylazine significantly decreased vegetation cover for three growing seasons. Terbuthylazine is a soil active herbicide, but (unlike most chlorine triazines) it can also be absorbed through the leaves (Mukula and Salonen 1990). Germination and emergence of weeds are not effected, but as soon as green leaves are formed, the activity causes severe inhibition of photosynthesis and chlorosis (Database on Pesticides…).

Chlorthiamid and dichlobenil were the most versatile herbicides observed in this study. They show a broad spectrum of activity, and act by various processes of inhibition of growth and tissue disruption. Their chemical structures are alike, and chlorthiamid metabolises into dichlobenil in the soil. They are primarily soil herbicides, but they are foliar-active to some extent as well (Mukula and Salonen 1990). Single applications of dichlobenil and chlortiamid have significantly decreased vegetation cover percentage for two growing seasons (Ferm et al. 1994) and double treatments (in the 1st and 2nd growing season) for at least three growing seasons. It was probably due to their capability for inhibiting root and root system buds sprouting as well as inhibiting seed germination (Mukula and Salonen 1990). Mere seed germination inhibitors are ineffective against stoloniferous weed plants. Chlorthiamid and dichlobenil are very effective against *Elymys repens* which is harmful root-propagated weed on afforested fields. In terms of seedling growth and mortality, repeated applications of dichlobenil and chlorthiamid did not provide any advantage over single applications. Consequently, repetition of these treatments only increased costs without having any effect on growth or mortality. After 11 years, tree seedlings on terbuthylazine and single chlorthiamid and dichlobenil plots were 149–222 cm taller than the control seedlings. These treatments also reduced seedling mortality, but not statistically significantly. Their application increased birch volume by 13–22 m^3ha^{-1} in 11 years (control 11.6 m^3ha^{-1}, herbicide plots 25–34 m^3ha^{-1}). Thus, the herbicides significantly affected the development of the plantation by even trebling stand volume as compared to the control plots.

5 Conclusions

The results of this study affirm that competition from ground vegetation significantly affects the height growth, mortality and incidence of vole damage on birch plantations established on former agricultural land. Weed control methods with effects spanning more than two growing seasons proved to considerably increase seedling growth and decrease mortality. Our findings are in agreement with the earlier results of Leikola (1976), who stated that intensive soil preparation and weed control are necessary for successful cultivation of silver birch on abandoned fields. Our results also show that seedling growth starts to retard when the vegetation cover is relatively low, whereas mortality starts to increase only when the vegetation coverage is very high. A simple shading class based on visual estimates proved to be a useful tool in predicting the future growth rate and probability for mortality, as well as incidence of vole attacks.

The use of chemicals in forestry in Finland and elsewhere in Europe has become increasingly controversial issue due to strong public criticism (Siipilehto 2001). Consequently, the use of herbicides in forestry has dramatically decreased during the past ten years. As a result, of the herbicides used in this study, only glyphosate and dichlobenil are at the present approved for forestry use (Torjunta-aineet 2003). Therefore, research on the competition dynamics of afforestation and reforestation areas, as well as developing and testing alternative weed control methods, are urgently needed.

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