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Long-term Effect of Weed Control on Survival and Growth of Silver Birch Planted on Arable Land

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Hytönen, J. and Jylhä, P. 2013. Long-term Effect of Weed Control on Survival and Growth of Silver Birch Planted on Arable Land. *Baltic Forestry* 19(2): 170–178.

Abstract

The effects of competing vegetation and weed control methods (fibreboard mulch, herbicide) on the survival and growth of silver birch (*Betula pendula* Roth) were analysed based on 20-year data from a field experiment established in Central Finland. The growth of birches was equivalent to that on the most fertile forest sites in Finland. Herbicide treatment did not reduce the total vegetation cover but it decreased the coverage of grasses and increased that of forbs. After 20 years, the average stem volume on the herbicide-treated plots was 38% higher than on the control plots (148 m^3ha^{-1} vs. 107 m^3ha^{-1}). The increase in volume was mainly due to reduced seedling mortality (24% vs. 43%). Weed control increased seedling height during the first seven years, but did not significantly affect seedlings' final height or diameter. The mean stand volume (123 m^3 ha^{-1}) and mortality (31%) on mulched plots did not differ from the other treatments. Weed control did not affect seedlings' biotic or abiotic damage and most foliar nutrient concentrations.

Key words: vegetation control, herbicide, chlorthiamid, mulch, weed cover, *Betula pendula*

Introduction

Afforestation of agricultural land in the EU countries has been promoted as part of the Common European Agricultural Policy (CAP). Afforestation is also considered as a means to protect groundwater reserves, to increase carbon (C) sequestration in wood biomass and soil, and to promote restoration of biodiversity. Before joining the EU, large areas of agricultural land were abandoned and left uncultivated in many countries due to socio-economic reasons. In Estonia and Latvia, for example, about 400,000 ha and 340,000 ha of agricultural land was abandoned, respectively (Jõgiste et al. 2005, Liepins 2007). Since the 1960s, more than 530,000 ha and 260,000 ha of agricultural land has been afforested in Sweden and Finland, respectively (Juntunen and Herrala-Ylinen 2012, Johansson 1995). In addition to that, large areas of abandoned fields are being naturally afforested.

Agricultural cultivation practices such as soil tillage, fertilisation and liming have changed the physical, chemical and biological properties of former forest soils (Hytönen and Wall 1997, Wall and Hytönen 2005). The changes in soil properties are usually beneficial for tree growth and this effect can last for several decades or even centuries (Koerner et al. 1997, Wall and Hytönen 2005). Afforested arable soils tend to be more fertile than forests soils. High fertility, however, can promote seedling mortality and damage, and impair the technical quality of timber (Hytönen 1998, 1999, Rossi et al. 1993, Saksa et al. 2003, Hynönen and Saksa 1997a,b). The potential for producing high-quality Scots pine (*Pinus sylvestris* L.) saw logs on former agricultural fields rich in nutrients is considered to be particularly poor. Scots pine was the most common tree species planted on abandoned fields in the 1970s and 1980s, but its use started to decline when many failures in afforestation were reported (Hynönen and Hytönen 1997). Birches (*Betula* sp.) and Norway spruce (*Picea abies*) are better adapted to the increased nutrient concentrations prevailing in agricultural soils than Scots pine.

The use of silver birch (*Betula pendula* Roth) in the afforestation of agricultural land started to increase in the 1980s, and in 1990-1998, it accounted for 45% of all field afforestation in Finland (Saksa et al. 2003). Silver birch (*B. pendula* Roth) is found mostly on moist and fertile mineral soils. Its growth on mineral soil fields has reached an average height index of 26 m (Oikarinen 1983), which equals the growth rate expected in the most fertile forest soils in Finland (*Oxalis-Myrtillus* site type) (Cajander 1926, Kinnunen and Aro 1996, Saramäki and Hytönen 2004). In Estonia, the silver birch is also considered the most suitable species for afforestation of arable land due to its high growth rate and survival in various soil types (Vares et al. 2001, 2003).

Controlling ground vegetation is one of the major problems with the afforestation of arable land – its development after soil preparation is faster and more vigorous than on forest soils. Abandoned agricultural soils 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), and soil preparation launches the invasion of weed vegetation. An open field is first colonised by annual species (Törmälä 1982, Jukola-Sulonen 1983). After a couple of years, they give way to perennial herbs and grasses. Grasses often dominate the field layer for a long time, and vegetation does not resemble forest flora even 16–17 years after afforestation (Rossi et al. 1993, Hynönen and Saksa 1997a,b, Hytönen 1999). Weed biomass can be abundant, especially below ground. The average oven-dry weed biomass per square metre was 1,328 g in the study by Hokkanen and Raatikainen (1977), derived from 51 agricultural fields which had not been cultivated for 1–6 years. About 80% of that biomass was found below ground.

Dense ground vegetation competes with tree seedlings, particularly for water and nutrients, as well as for light. In winter, tall vegetation pressed down by a thick snow layer can seriously damage small tree seedlings. Furthermore, abundant weed vegetation can increase the risk of seedling damage by providing favourable conditions for fungi and pests, such as voles. Attack by field voles (*Microtus agrestis*) is one of the main risks to field afforestation with birch (Hytönen 1998, Saksa et al. 2003). The risk is much higher than in regular plantations established on forest land (Henttonen et al. 1995). The size of the field vole population tends to correlate with the biomass of ground vegetation, in particular with that of the most favoured plant species (Teivainen et al. 1986). Weed control can reduce the incidence of vole damage (Leikola 1976, Teivainen et al. 1986, Hytönen and Jylhä 2005). Weed control also reduces seedlings' susceptibility to vole attack by accelerating seedlings' height growth and the increase in bark thickness. However, mulching can promote vole damage by providing shelter for their nesting in the first few years after planting (Ferm et al. 1994, Davies 1987, 1988, Siipilehto 2001, Vares et al. 2001, Samyn and de Vos 2002).

There is a great deal of variation in ecological characteristics and tolerance of herbicides among tree species. Therefore, species-specific vegetation management is of great importance. Research into forest vegetation management in the Nordic countries is focused on conifers, and the effects of inter-specific competition and weed control on the growth and survival of birch are little known. Successful weed control, either with herbicides or mulches, promotes seedlings' height growth at the initial stage (1–4 years) (Ferm et al. 1994, Karlsson 2002, Leikola 1976, Siipilehto 2001, Vares et al. 2001, 2003). The response of silver birch to weed management with herbicides or mulches in field afforestation experiments has been reported to last for at least 8–11 years (Hytönen and Jylhä 2005, Kund et al. 2010). The lack of long-term data on the sustainability of the initial effects of weed management, required for economic analysis, is one of the shortcomings in the research into vegetation management (Thompson and Pitt 2003).

In the present study, based on a 20-year follow-up, we investigated the effects of competing vegetation and two post-planting weed control methods on the growth and mortality of silver birch planted on former agricultural land.

Material and Methods

The experiment was established in the spring of 1990 in Toholampi, Central Finland (63°45'N, 24°18'E) on former arable land composed of silt with pH of 5.1–5.4 and organic matter content of 10–13%. Complete soil preparation was performed by rotavating and harrowing prior to planting in spring 1990. Containerised one-year-old silver birch seedlings were planted at a density of 3,000 seedlings per hectare in June. The field was completely free of vegetation when starting the experiment, due to complete soil preparation. Therefore, weed control did not take place until the second growing season, in spring 1991. The treatments included in the experiment were a) control (untreated), b) weed control with herbicide (Prefix 60 kg/ha), and c) weed control with fibreboard mulch (50 cm x 50 cm). The active ingredient of the herbicide was soil active chlorthiamid (75 g kg^{-1}). The product was applied in granulated form and spread throughout, avoiding its application at seedling bases with a radius of 5 cm. Weed control was done only once in spring 1991 and was not repeated during the following years. The experiment was originally carried out as a randomised block design with twelve replications on plots sized 100 m^2. Four of the blocks located on the river shore were repeatedly inundated by flooding water and therefore discarded. During the first seven years, measurements were confined to two blocks and in the final measurement all eight blocks were measured. The total number of sample plots on each block was three, i.e. ca. 720 Silver birch seedlings (240 per treatment) were planted on these eight blocks covering 0.24 ha. The area was surrounded by Scots pine and Norway spruce plantations of the same age thus reducing the edge effect.

Seedling height (h) was measured to an accuracy of 1 cm along with determining their vitality (alive or dead). The two main causal agents of damage were assessed within a circular 50 m^2 sample plot set up in the middle of each plot after the 2nd, 3rd, 4th, 5th, 7th and 20th growing seasons. Breast height diameter ($d_{1.3}$, mm) was recorded after the 20th growing season.

The vegetation was examined for species composition and cover percentage on the control and herbicide-treated plots in the autumns, two, three and four growing seasons (August 1991, July 1992, and July 1993) following planting, i.e. from one to three growing seasons from the herbicide treatment. The vegetation coverage percentage was estimated on 3–5 circular sub-sample plots of 1 m^2, and the dominant height of the weeds was recorded on these plots with an accuracy of 10 cm. In the first four inventories, the shading index (SI) of each seedling was estimated based on visually assessed density of the weed vegetation and the height relation between the seedling and surrounding vegetation. The shading indices were as follows: no shading by weeds (0), one-quarter (1), one-half (2), or three-quarters of the seedling in shade (3), and fully shaded (4).

Composite leaf samples were collected from each plot in mid-August 1992. The samples were analysed for ash, N (Kjeldahl method), P, K, Ca, Mg, Fe, Mn, Zn, Cu, and B concentrations (Halonen et al. 1983). P was analysed with a spectrophotometer and base cations with an atomic absorption spectrometer (AAS).

The mean annual temperature sum (the threshold temperature +5°C) in the experimental field during the follow-up period was 1,111 dd °C. In the summer months (June-August), the mean temperature was 14.2°C. The mean precipitation of these months was 193 mm, which is 35% of the mean annual precipitation (Figure 1).

The stem volumes of the trees 20 years after planting were computed by applying the models of Laasasenaho (1982). Analysis of variance was used to test the statistical significance of the weed control treatments on mean weed coverage, basal diameter and volume. Repeated measures analysis of variance (time as within-subject factor; treatment and block as between-subject factors) was used when testing the effects of treatments on vegetation coverage, and mortality and height of the seedlings. The arcsin transformation was applied to weed coverage and mortality, which were presented in percentages. Prior to analyses, the homogeneity of variances was tested using the Levene's test. The Tukey's honestly significant difference test was used to test differences among treatments at the 0.05 level of significance. The effect of weed control intensity on the vegetation cover percentage was tested only for herbicide application and control. All statistical analyses were conducted using the IBM SPSS software (version 20).

Results

Coverage, species composition and height of the weeds

Herbicide application was done at the beginning of the second growing season. The first inventory took place at the end of that growing season when

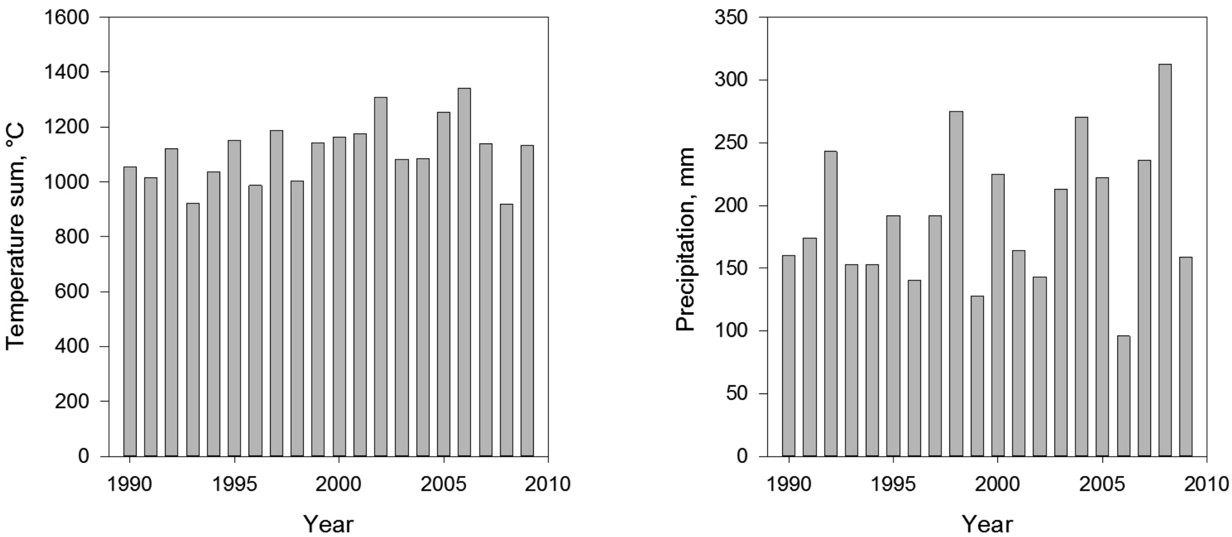

Figure 1. The effective annual temperature sum (A, threshold value +5°C) and precipitation during growing seasons (June-August) on the experimental site

the weed vegetation on control plots had developed for two growing seasons. The effect of herbicide application on grass and forb coverage was significant, but the total vegetation coverage was independent of treatment. Herbicide treatment decreased the coverage of grasses and increased that of forbs. The decreases in grass coverages were 44, 42 and 6 percentage points in the first, second and third growing seasons following application, respectively (Figure 2).

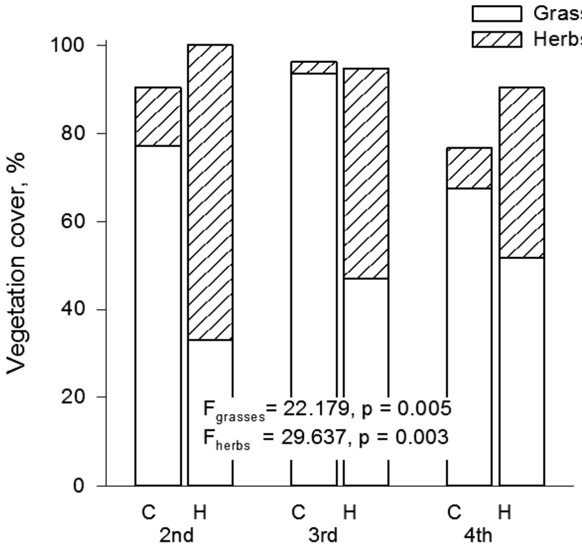

Figure 2. Effect of vegetation control with herbicide on the vegetation cover of grasses and herbs at the end of the 2nd, 3rd and 4th growing seasons. Weed control was done in the beginning of the 2nd growing season. H = herbicide treatment, C = control

Herbicide treatment increased the coverage of creeping buttercup (*Ranunculus repens* L.) (Figure 3). On the control plots, its coverage was almost zero while on herbicide-treated plots it covered 15–23% of the inventory plots. Herbicide application seemed to decrease the coverage of some grass species (*Alopecurus* sp., *Agrostis* sp.), but this was not statistically significant.

The mean height of weed vegetation was 25 cm, 14 cm and 16 cm lower on herbicide treated plots than

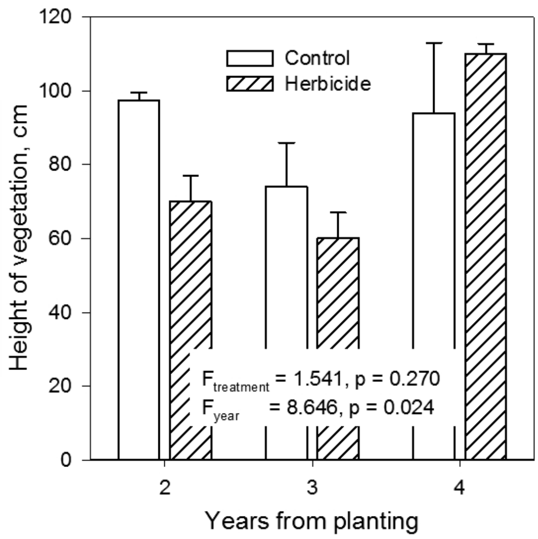

Figure 4. The mean height of vegetation at the end of 2nd, 3rd and 4th growing seasons following planting. Weed control was done in the beginning of second growing season

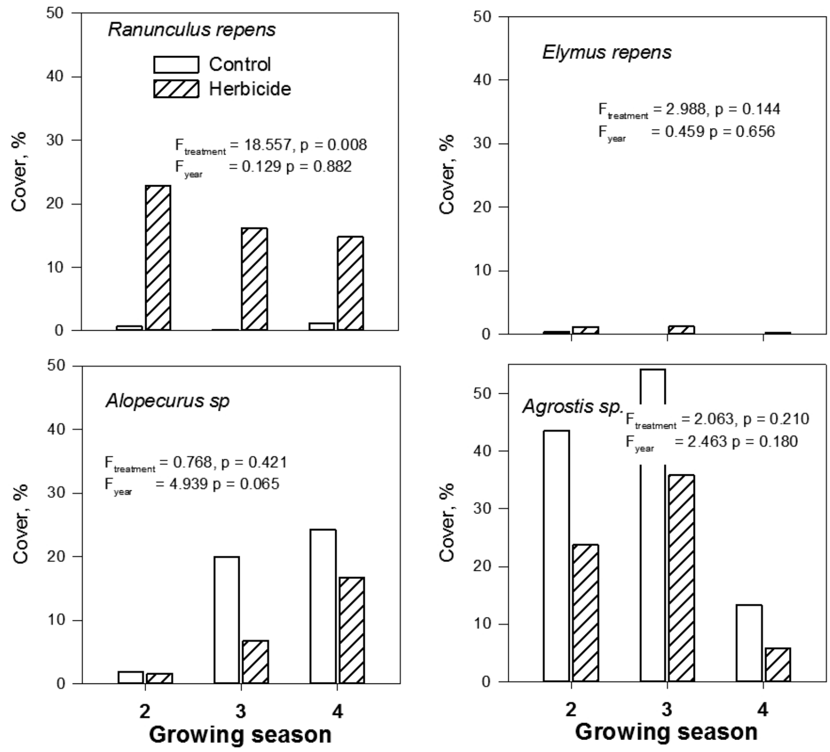

Figure 3. The effect of vegetation control on the coverage of some herb and grass species at the end of the 2nd, 3rd and 4th growing seasons. Weed control was done in the beginning of the 2nd growing season

on the control plots in the first, second and third post-treatment growing season, respectively, but these differences were not statistically significant (Figure 4). At their tallest, weed vegetation was higher than one metre.

Seedlings' shading by competing vegetation was negligible (Figure 5). Herbicide treatment completely eliminated shading in the second growing season, while mulching had no effect on it. In the following inventories the seedlings were taller and shading was only negligible.

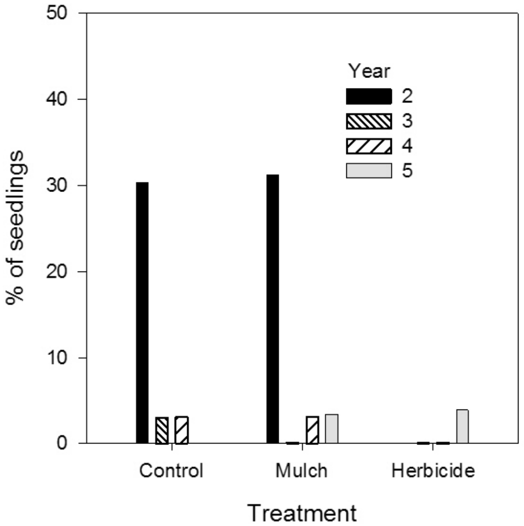

Figure 5. Proportion of birch seedlings with 25% or more of the crown shaded by competing vegetation during the 2nd, 3rd, 4th and 5th growing seasons. Weed control was done in the beginning of second growing season

Mortality, growth, damage and nutrition of the birches

The highest seedling mortality was recorded on control plots, while the lowest mortality was found on herbicide treated plots. In repeated measures analysis of variance, the effect of treatment was almost significant (F= 4.397, p= 0.052) and that of year was highly significant (F=45.938, p=0.000). Most mortality occurred during the first five years. After that, only a few seedlings died (Figure 6). The final mortalities were 43%, 31% and 24% on the control, mulch and herbicide treated plots.

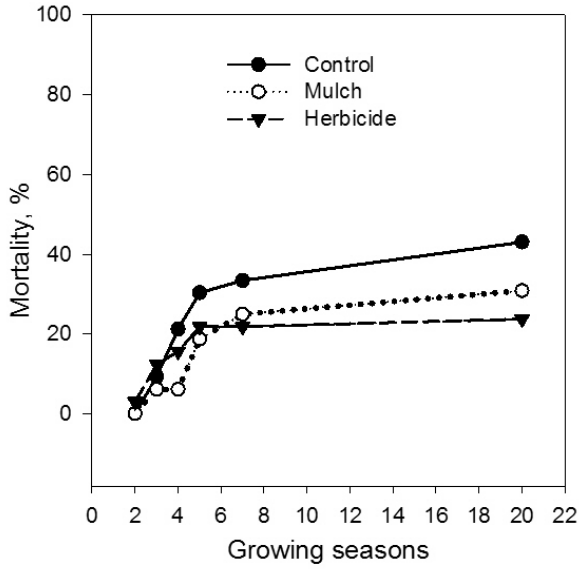

Figure 6. Seedling mortality by treatment

After the first seven growing seasons, the mean height of seedlings on the control plots was 2.5 m. On the other plots, the seedlings were 70–80 cm taller (F=4.381, p=0.026). In the final measurement at the age 20 years, however, the mean height and diameter were independent of weed control treatment. The birches were then 13.5–13.8 metres high (Figure 7), and their mean diameter at breast height was 10.5–10.8 cm (F=1.0333, p=0.383). The dominant height of the birches was 15.4 – 15.5 m.

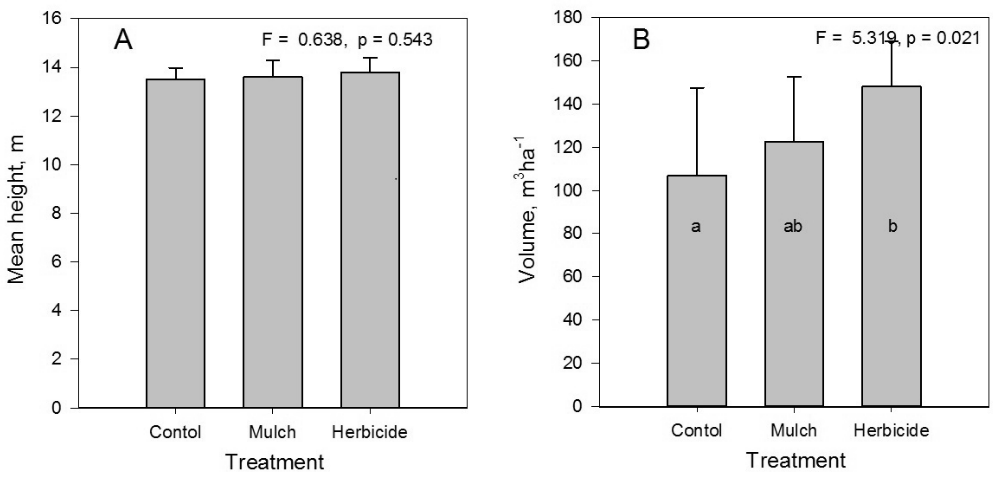

Figure 7. Mean height of seedlings (A) and stand volume after 20 growing seasons (B). Lines indicate standard deviation. Means with the same letter did not differ from each other (p<0.005)

During the follow-up period covering 20 growing seasons, herbicide treatment increased the stem volume of the birches by 41 $m^3 ha^{-1}$ (2.1 $m^3 ha^{-1}a^{-1}$) when compared to untreated plots (Figure 7). The final stand volume and mean annual increment on the herbicide-treated plots were 148 $m^3 ha^{-1}$ and 7.4 $m^3 ha^{-1}a^{-1}$, respectively. Stand volume on mulched plots (123 $m^3 ha^{-1}$) did not differ significantly from the other treatments.

Voles damaged seedlings only on the control plots, but the number of damaged seedlings was very low. In all, less than 4% of the seedlings have been browsed by voles at least once by the end of the fourth growing season.

The foliar samples were taken one growing season after the treatments. The weed control methods only affected foliar Fe (F=50.538, p=0.019) and Zn (F=14.154, p=0.066) concentrations. Fe concentration on the control plots was lower than on the plots subjected to herbicide treatment (68 mg kg^{-1} vs. 81 mg kg^{-1}), while higher Zn concentration was found on the control plots (176 mg kg^{-1} vs. 132 mg kg^{-1}). The concentrations of the other foliar nutrients were as follows:

N	P	K	Ca
34.1 mg g^{-1}	3.9 mg g^{-1}	10.6 mg g^{-1}	4.2 mg g^{-1}
Mg	**Mn**	**Cu**	**B**
2.8 mg g^{-1}	485 mg kg^{-1}	9 mg kg^{-1}	29 mg kg^{-1}

Discussion

Herbicide treatment by chlorthiamid increased the volume of silver birch by 41 m^3ha^{-1} in 20 years. The mean annual growth increment attained with herbicide treatment (2.1 $m^3 ha^{-1} a^{-1}$) is at the same level with the results achieved using the most effective herbicides in the field afforestation study of Hytönen and Jylhä (2005), based on a follow-up of 11 growing seasons. In the present study, volume increment was mainly due to reduced mortality. The diameter growth and the final height were independent of treatment. However, herbicides can also increase the height growth of silver birch planted on the former agricultural land (Ferm et al. 1994, Hytönen and Jylhä 2005).

The mean annual volume increment on herbicide-treated plots was 7.4 $m^3ha^{-1}a^{-1}$. In terms of site index (h50=28, cf. Oikarinen 1983), the growth corresponds to that expected in the most fertile sites in Finland, the *Oxalis-Majanthemum* site type (Cajander 1926). These sites have been cleared for cultivation to a great extent and nowadays they cover only 2% of total forest land area available for wood production in Finland (Peltola and Ihalainen 2012). Also earlier Finnish studies have shown high growth rates of birch (h50= 26) on afforested fields, both mineral and organic soils (Kinnunen and Aro 1996, Saramäki and Hytönen 2004). Therefore, afforestation can also be seen as a means of restoring fertile site types and increasing biodiversity (Wall 1998).

The shading effect of competing vegetation depends on its density and height, as well as the height of the seedlings. In addition to the cover percentage of weed vegetation and leaf area index, other simply assessed competition indices have been used successfully. The shading index applied in the present study can provide valuable information on the severity of the competition for light, water and nutrients (Hytönen and Jylhä 2005). On untreated plots, weed vegetation reached a height of almost one metre within two growing seasons, which means that the seedlings 1.0–1.2 m in height were almost fully shaded. As a pioneer tree species, however, birches soon caught up with competing vegetation. By the end of the fourth growing season, the seedlings were 50–80 cm taller than weed vegetation and there was no longer any scarcity of light. This was seen in lowered shading indices in all treatments. However, it is likely that below-ground competition continued and caused seedling death until the age of 5–7 years, when they were competitive enough. This is in accordance with the study of Kund et al. (2010), in which seedling mortality increased steeply up to the age of five years. Ferm et al. (1994) also concluded that competition caused by herbaceous vegetation is more severe for underground resources (nutrients and water) than for light. On abandoned agricultural land in particular, underground weed biomass may be several times greater than the above-ground biomass (Törmälä and Raatikainen 1976, Hokkanen and Raatikainen 1977).

Hytönen and Jylhä (2005) concluded that weed coverage of 60–80% is critical in terms of survival for silver birch planted on former agricultural land. In the present study, however, the total weed coverage exceeded that threshold coverage even on herbicide treated plots without a drastic increase in mortality. This was probably due to a more favourable species composition than in Hytönen and Jylhä (2005), in which the proportion of more competitive grasses was higher than in the present study. Differences in vegetation dynamics can be explained by the diverging composition of soil seed banks and differences in soil preparation methods, for example.

Many herbicides have been shown to control weeds efficiently for at least one to three growing seasons in birch plantations (Hytönen and Jylhä 2005). In particular, terbuthylazine, chlorthiamid and dichlobenil have shown to control ground vegetation efficiently.

These herbicides are primarily soil-active herbicides, but they also have a foliar mode of action (Mukula and Salonen 1990). In the present study, chlorthiamid spread throughout the plots did not affect total vegetation coverage but it did change species composition by decreasing the coverage of grasses and increasing that of forbs. Creeping buttercup in particular colonised herbicide-treated plots rapidly. This is a low forb which acts like a cover crop by inhibiting the growth of taller grasses. Grasses can be greatly competitive due to their long active growth period (Davies 1987, Coll et al. 2003, Balandier et al. 2006) and very dense root system increasing their ability to compete for water and nutrients with tree seedlings (Balandier et al. 2006). Currently propaquizafop and cycloxydim are the only herbicides available to birch plantations in Finland (Kasvinsuojeluaineet 2012).

The efficacy of cover crops as an alternative weed management method is based on their ability to reduce competition for light (Hänninen 1998, Hänninen et al. 1999, Willoughby 1999). However, most results from the use of cover crops in forestry are discouraging (Willoughby 1999, Hytönen and Jylhä 2005). Many cover-crop species have been found to compete with tree seedlings for resources (Willoughby 1999). They can also attract voles and thereby increase mortality in birch stands (Hytönen and Jylhä 2005). Perennial clovers have also been suggested as a cover crop due to their ability to improve the nitrogen status of trees and soil. Ferm et al. (1994) and Hänninen et al. (1999), however, did not find any evidence to support this theory. In the present study, creeping buttercup was less competitive than the grass species; this was likely due to the fact that its root system is superficial and therefore does not compete for nutrients and water with birch seedlings to a great extent.

Mulching is another alternative to chemical weed control. Hytönen and Jylhä (2005) concluded that weed control methods with effects spanning more than two growing seasons promote the growth and decrease mortality of silver birch. They showed that the effect of the mulch type used in the present study lasts at least three years. In Hytönen and Jylhä (2005), single overall application of chlorthiamid controlled weeds at least two years and repeated application did not provide any advantage over single application. In Finnish conditions herbaceous vegetation had been concluded to compete more for underground resources (nutrients and water) than for light (Ferm et al. 1994). Davies (1988) and Samyn and de Vos (2002) have shown that the growth of deciduous tree seedlings is proportionate to the radius of the weed-free area. In the present study, the herbicide was spread throughout the experimental plots, excluding the bases of the seedlings. Davies (1987, 1988) has recommended that mulches should maintain a minimum weed-free area of 1.0 m^2 around each seedling for at least 3–5 years. Therefore the mulches of 0.25 m^2 used in the present study and in Hytönen and Jylhä (2005) were likely too small-sized to eliminate root competition efficiently. However, in some studies even the small-sized mulches (0.25 – 0.36 m^2) have slightly increased the height growth of silver birch (Siipilehto 2001, Hytönen and Jylhä 2005). The main contribution of these mulches to stand development, however, is their ability to decrease mortality (Ferm et al. 1994, Hytönen and Jylhä 2005). Estonian experiences from the use of larger polyethene mulches are encouraging. In addition to an efficient reduction in the competition from light, nutrients and water (Vares et al. 2001, 2003, Kund et al. 2010), they can promote the growth of silver birch by providing favourable soil moisture and temperature (Davies 1987, Vares et al. 2001, 2003).

Successful weed control also decreases the risk of vole browsing. In the present study, minor vole damage was only observed on the control plots. Weed control usually improves the nutrition of tree seedlings, in particular by increasing foliar N concentration (Davies 1985, Ferm et al. 1994). In the present study, however, weed control did not affect the concentrations of most foliar nutrients. This might be due to the low impact of weed control on the total weed coverage.

Our study affirms the great wood production potential of agricultural land. However, intensive soil preparation and efficient weed control are crucial to successful stand establishment on fertile soils with large seed banks. The need for developing alternative weed control methods is obvious now that there are only a few herbicides on the market. Mulching, when extensive enough, is a promising means for the reduction of competition from growth resources. The behaviour of creeping buttercup in the present study indicates potential for identifying appropriate cover crop species for vegetation management.

Acknowledgements

We thank Seppo Vihanta for help in the computations and the numerous other persons for participating data collection and laboratory analyses.

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Received 22 April 2013
Accepted 28 November 2013

ДОЛГОСРОЧНОЕ ВЛИЯНИЕ МЕР БОРЬБЫ С СОРНЯКАМИ НА ВЫЖИВАЕМОСТЬ И РОСТ БЕРЕЗЫ ПОВИСЛОЙ, ПОСАЖЕННОЙ НА ПАХОТНЫХ ЗЕМЛЯХ

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Резюме

На основании данных, полученных за 20 лет проведения полевого эксперимента в Центральной Финляндии, было проанализировано влияние конкурирующей растительности и мер борьбы с сорняками (использование древесноволокнистой мульчи, обработка гербицидом) на выживаемость и рост березы повислой (*Betula pendula* Roth). Рост берез соответствовал показателям самых продуктивных лесонасаждений в Финляндии. Обработка гербицидом не снизила общую площадь растительного покрова, при этом уменьшилась площадь, покрытая травами, и увеличилась покрытая полукустарниками. После 20 лет эксперимента средний объем стволов на обработанных гербицидом участках был на 38 % выше, чем на контрольных участках (148 $м^3 \cdot га^{-1}$ и 107 $м^3 \cdot га^{-1}$). Увеличение объема было связано в основном со снижением естественной убыли (24% и 43%). Борьба с сорняками привела к увеличению высоты сеянцев в течение первых семи лет, но не оказала значимого воздействия на окончательную высоту или диаметр сеянцев. Не обнаружено различий в среднем объеме древесины на корню (123 $м^3$ $га^{-1}$) и естественной убыли (31 %) на мульчированных и на прочих участках. Борьба с сорняками не привела к повреждению сеянцев и изменениям концентраций большинства веществ, обеспечивающих внекорневое питание.

Ключевые слова: борьба с сорняками, гербицид, хлортиамид, мульча, покрытие сорняками, *Betula pendula*