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Site preparation of abandoned fields and early establishment of naturally and direct-seeded birch in Sweden

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Abstract

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Field experiments were carried out at four sites in Sweden to investigate the possibility of establishing downy birch (*Betula pubescens* Ehrh.) and silver birch (*Betula pendula* Roth) on abandoned fields by natural regeneration, direct seeding or both. The effects of six soil preparation methods on the vegetation cover, seedling survival, dominant seedling height and seedling establishment were studied up to four years after seedling emergence. The methods were: no preparation, ordinary ploughing, rotary cultivation, deep ploughing, soil inversion, removal of topsoil. Five additional treatments were applied: no treatment, herbicide, peat litter, wood ashes, slaked lime. Both a split–plot design and a randomised complete block design were used.

Seedling survival and establishment without preparation, and with rotary cultivation, were close to nil, while the other soil preparation methods generally were more effective. Best seedling survival and establishment were obtained on seedbeds created by removing topsoil or by transposing it by deep ploughing or inversion. These seedbeds also suppressed competing vegetation, compared to seedbeds with topsoil at the surface. Seedling establishment after removal of topsoil, amounting to 8% of sown germinable seed, was outstanding on sandy soil, but much poorer on silty soil. The tallest dominant seedlings were found on seedbeds with topsoil within the soil profile. Application of peat litter to the seedbed promoted seedling establishment.

Key words: afforestation, arable land, *Betula pendula*, *Betula pubescens*, seedling establishment, seedling survival, soil preparation.

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Abbreviations

Soil preparation	Methods
SNO	no preparation
SOP	ordinary ploughing
SDP	deep ploughing
SRC	rotary cultivation
SRT	removal of topsoil
SIN	soil inversion
Additional treatments	
ANO	no treatment
APL	peat litter
AWA	wood ashes
ASL	slaked lime
AHA	herbicide application
Response variables	
PZS	percentage of zero spots
VCP	vegetation cover percentage
SSP	seedling survival percentage
EP	seedling establishment percentage
DSH	dominant seedling height
FD	frequency of damage

Introduction

Background

There is at present interest in using hardwood species for farmland afforestation in Sweden (Elfving, 1986). Hardwoods are preferred for reasons of aesthetics and biodiversity (Gustavsson, 1991), and are increasingly in demand for industrial purposes (Ekström, 1987). Downy birch (*Betula pubescens* Ehrh.) and silver birch (*B. pendula* Roth), the two most common hardwood species in Sweden (Kempe, 1991), are of interest for farmland afforestation. Birch planting has often failed because of competing ground vegetation and foraging mammals (Bäcke, 1991). Successful regeneration of planted birch requires intensive protection (Johansson, 1990), which may weaken the financial incentive to plant. Natural regeneration and direct seeding may instead be feasible low-cost regeneration methods. Stands successfully established in this way may be dense enough to withstand damage. However, experience with natural regeneration or direct seeding on abandoned fields is limited (Karlsson, 1994).

Establishment ecology

Downy birch and silver birch are ecologically similar to the North American species, paper birch (*Betula papyrifera* Marsh.) and yellow birch (*Betula alleghaniensis* Britton) (Perala & Alm, 1990*a*, *b*). Soil preparation promotes seedling emergence on both forest sites (Godman & Krefting, 1960; Raulo & Mälkönen, 1976) and abandoned fields (Nash, Duda & Gray, 1951; Karlsson, 1996). Good seedbeds may be prepared by burning (Sarvas, 1948; Bjorkbom, 1972), by mechanical soil preparation (Raulo & Mälkönen, 1976; Perala & Alm, 1989) and sometimes by logging activity (Safford, 1983). Drainage encourages birch regeneration on peatland (Seppälä & Keltikangas, 1978). Soil preparation and fertilisation with PK or NPK further promote the recruitment and growth of birch seedlings on peatland (Moilanen & Issakainen, 1981).

However, environmental conditions which favour seedling emergence may be less suitable for seedling growth (Marquis, 1969). Seedling emergence and initial survival are usually best on seedbeds with bare mineral soil at the surface (Raulo & Mälkönen, 1976; Perala & Alm, 1989) and in shaded positions (Marquis, Bjorkbom & Yelenosky, 1964; Horsley & Abbott, 1970), owing mainly to favourable soil moisture. Growth and development are, on the other hand, better on seedbeds with a thin layer of humus on top of mineral soil (Marquis et al., 1964; Winget & Kozlowski, 1965) or on seedbeds where mineral soil is mixed with organic matter (Godman & Krefting, 1960; Perala & Alm, 1989) and in positions with full sunlight or moderate shade (Marquis et al., 1964; Kinnaird & Kemp, 1970).

Seedling mortality is likely to be high, both in the first growing season (Horsley & Abbott, 1970; Miles, 1973; Karlsson, 1996) and during subsequent years (Bjorkbom, 1972; Kinnaird, 1974). According to Sarvas (1948), it takes at least three years to establish birch regeneration.

Damage and mortality are often caused by abiotic factors such as drought (Linteau, 1948; Miles & Kinnaird, 1979), high seedbed temperatures (Vaartaja, 1954; Marquis et al., 1964), mechanical injuries from heavy rainfall (Linteau, 1948; Karlsson, 1994), frost (Linteau, 1948; Godman & Krefting, 1960), and frost-heaving (Horsley & Abbott, 1970; Miles & Kinnaird, 1979). Mortality and damage can also be caused by biotic factors, such as fungi (Vaartaja, 1962), insects (Linteau, 1948), rodents (Rousi, 1988), browsing mammals (Godman & Krefting, 1960; Kinnaird, 1974), and competing vegetation (Godman & Krefting, 1960; Miles & Kinnaird, 1979).

Competition from ground vegetation is a primary reason for recommending against natural regeneration or direct seeding of birch on abandoned fields (Bjorkbom, 1969; Kaunisto & Päivänen, 1985). Vole damage in farmland plantations is reduced if ground vegetation is removed (Bärring, 1967) or checked (Ferm, Hytönen, Lilja & Jylhä, 1994). Since seeds and vegetative reproductive organs are found in the topsoil, it may prove possible to reduce competing vegetation by soil preparation methods that remove or transpose the topsoil and bring bare subsoil to the seedbed surface (cf. Örlander, Gemmel & Hunt, 1990). Herbicides may also be used to control competing vegetation (Perala & Alm, 1989; Ferm et al., 1994).

Aims

The aim of this study was to investigate different methods of establishing stands of downy and silver birch on abandoned fields by means of natural regeneration, direct seeding or both. Effects of different site treatments on seedling emergence, on competing vegetation, on seedling survival and seedling development, were investigated. The effects on seedling emergence in the first growing season are reported by Karlsson (1996). The present paper focusses on seedling survival and seedling development during the two to three subsequent years. The main questions addressed were: (1) What kinds of seedbed will suppress competing ground vegetation? (2a) What kinds of seedbed give high seedling survival? (2b) What kinds of damage will affect the various seedbeds? (3) What kinds of seedbed promote good height development of seedlings? (4) What kinds of seedbed encourage abundant and uniform seedling establishment?

Materials and methods

Sites and treatments

Four field experiments were carried out (Table 1). Experiment 1 (Expt. 1) was established at Stöcke in 1988, Expt. 2 at Sävar in 1989, Expt. 3 at Asa in 1989, and finally Expt. 4 at Asa in both 1989 and 1990. All experimental sites were grassy, abandoned fields, uncultivated for at least five years before the experiments were established. Where it occurred, woody vegetation was removed.

To study the effect of topsoil or subsoil at the seedbed surface and the influence of different soil profiles, different seedbeds were created using six soil preparation methods. No preparation (SNO) was used as a control. Ordinary ploughing to a depth of 20–30 cm (SOP), and rotary cultivation to a depth of 10–15 cm (SRC), left topsoil at the seedbed surface, the latter method creating a looser seedbed. Deep ploughing to a depth of 40–50 cm (SDP) brought subsoil to the surface and transported topsoil downwards in the soil profile. Inversion of the profile by means of an excavator (SIN) reversed the position of topsoil and subsoil, putting ca.

Table 1. *Location and site description, according to definitions of Hägglund & Lundmark (1977)*

	Experiment			
	1	2	3	4
Latitude (°N)	63°44′	63°55′	57°10′	57°10′
Longitude (°E)	20°15′	20°33′	14°46′	14°46′
Altitude (m a.s. l.)	10	25	180	180
Soil-texture	silty till	sand-fine sand	silt	silt
Soil-moisture	moist	moist	mesic-moist	mesic-moist

15 cm of subsoil above the topsoil. Removal of topsoil (SRT) left subsoil at the surface and a profile without topsoil.

Five additional treatments were used to modify the seedbeds. No treatment (ANO) was used as a control. Herbicide application (AHA), before soil preparation with Roundup® (glyphosate 360 g l^{-1}: 0.015 litres of Roundup® per litre of water at a dosage rate of 0.06 l m^{-2}), was carried out to control weeds. Peat litter (APL: 0.3 kg(dw) m^{-2}) was applied to the seedbed surface to obtain a favourable germination substrate, which may also reduce splash effects. To simulate a burned site, wood ashes, including small pieces of charcoal (AWA: 1.1 kg(dw) m^{-2}), were applied to the seedbed surface. Since wood ashes largely consist of calcium, the application of slaked lime (ASL: 0.2 kg m^{-2}), to the seedbed surface was also tested.

Experimental design

A split-plot design, with whole plots in a randomised complete block design (RCBD), was used in Expt. 1 (Table 2). The area was divided into blocks on the basis of expected seedfall. The blocks were divided into whole plots and the whole plots were split into subplots. The soil preparation methods 'No preparation', 'Ordinary ploughing' and 'Deep ploughing' were randomly assigned to whole plots inside each block and the additional treatments 'No treatment', 'Peat litter', 'Wood ashes' and 'Slaked lime' were randomly assigned to the subplots within the whole plots (Fig. 1). On each subplot, six pairs of rectangular spots were systematically aligned (Table 2 and Fig. 1). Each pair of rectangular spots consisted of one spot with, and one spot without, direct seeding. These spots were set out before seeding took place. Seedlings originating from direct seeding were estimated as the difference between the two spots in every pair of rectangular spots. Although the variability in natural seedfall could overwhelm the results on single spots, the mean for the spots was assumed to be an accurate estimate of the expected value (Karlsson, 1996).

A split-plot design similar to that of Expt. 1 was used in Expt. 2 (Table 2). The soil preparation methods 'No preparation', 'Rotary cultivation', 'Deep ploughing' and 'Removal of topsoil' were randomly assigned to the whole plots and the additional treatments 'No treatment' and 'Herbicide application' were randomly assigned to the subplots. Herbicide was not applied where the soil treatment was to be removal of topsoil (Fig. 2). Each subplot consisted of eight replicates, with pairs of rectangular spots as in Expt. 1.

The same experimental design as in Expt. 2 was used in Expt. 3 (Table 2). The soil preparation methods 'No preparation', 'Ordinary ploughing', 'Rotary cultivation' and 'Removal of topsoil' and the additional treatments 'No treat-

Table 2. *Description of experimental design*

	Experiment			
	1	2	3	4a and b
No. of blocks	3	5	5	6
No. of whole plots	3	4	4	4
Plot size, m	2.5 × 20	4 × 20	4 × 20	4 × 20
No. of subplots	4	2[a]	2[a]	2[a]
Plot size, m	2.5 × 5	4 × 10[b]	4 × 10[b]	4 × 10[b]
No. pairs of rectangular spots	6	8	8	6
Spot size, m	0.25 × 1	0.2 × 0.5	0.2 × 0.5	0.2 × 0.5
Soil preparation methods[c]	SNO, SOP SDP	SNO, SRC SDP, SRT	SNO, SOP SRC, SRT	SNO, SRC SIN, SRT
Additional treatments[d]	ANO, APL AWA, ASL	ANO, AHA	ANO, AHA	ANO, AHA

[a] Whole plots having no herbicide application had only one subplot, size 4 × 20 m.
[b] Divided into 8 parts of 4 × 1.25 m (sites 2 and 3) or into 6 parts of 4 × 1.67 m (site 4a and b).
[c] The following soil preparation methods were tested: SNO = No preparation; SOP = Ploughing to 20–30 cm; SRC = Rotary cultivation to 10–15 cm; SDP = Ploughing to 40–50 cm; SIN = Profile inversion, 15 cm of subsoil above the topsoil; SRT = Removal of topsoil.
[d] The following additional treatments were tested: ANO = No treatment; AHA = Herbicide application; APL = Peat litter; AWA = Wood-ashes; ASL = Slaked lime.

Experiment 1

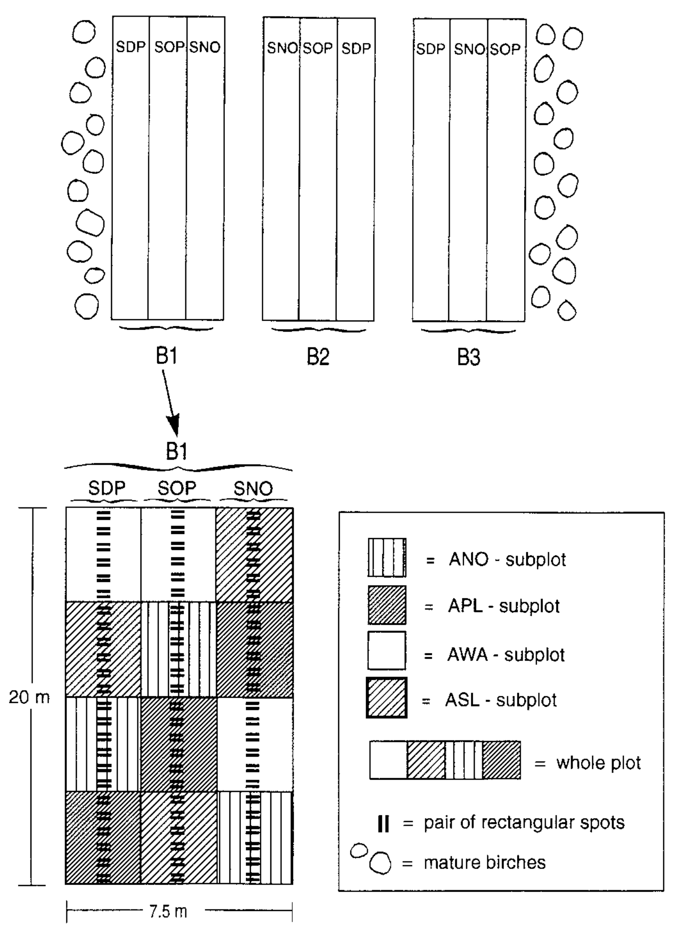

Fig. 1. Experimental layout for Expt. 1, showing three blocks (B1-B3) with the following soil preparation methods and additional treatments: SNO, no preparation; SOP, ordinary ploughing; SDP, deep ploughing; ANO, no treatment; APL, peat litter; AWA, wood ashes; ASL, slaked lime.

ment' and 'Herbicide application' were tested. Field establishment was carried out following the same procedures as for Expt. 2. Since only natural seeding was studied, there was only one rectangular spot per replicate within subplots.

The design of Expt. 2 was used in Expt. 4 (Table 2). Only direct seeding was studied. The soil preparation methods 'No preparation', 'Rotary cultivation', 'Inverted soil' and 'Removal of topsoil' and the additional treatments 'No treatment' and 'Herbicide application' were used. Herbicide was not used where the soil treatment was to be soil inversion or removal of topsoil (Fig. 3). However, since the effects of herbicide application proved questionable, owing to rainy weather shortly after spraying, only subplots with no treatment were used in the analyses, implying that this experiment was treated as a RCBD experiment. In addition, since the soil-inversion treatment was delayed, the experiment had to be divided into three parts: (4a) Downy and silver birch were sown in autumn on plots with no preparation, rotary cultivation or removal of topsoil; (4b) Downy and silver birch were sown in spring on plots with inverted soil or the topsoil removed; (4c) The effect of seed-sowing time was tested on whole plots from which the topsoil was removed. These plots were split into an autumn subplot and a spring subplot (Fig. 3). Before the

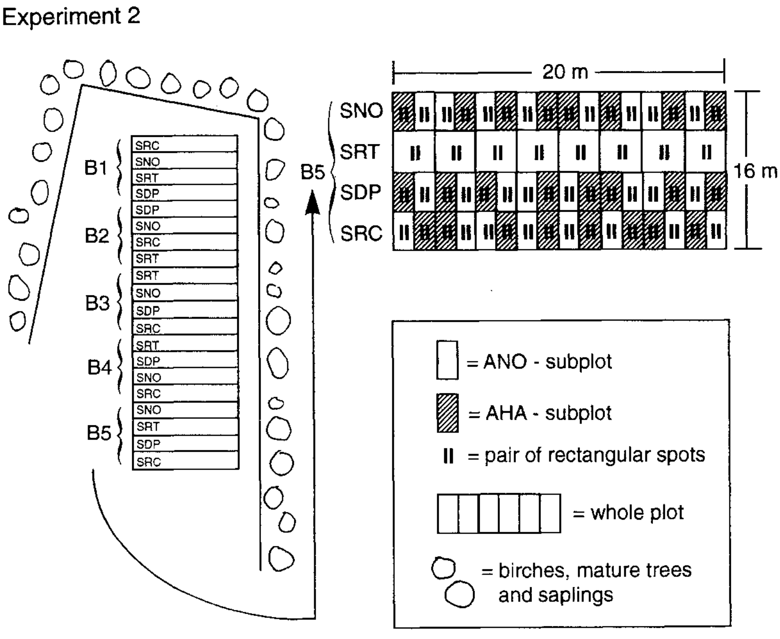

Fig. 2. Experimental layout for Expt. 2, showing five blocks (B1-B5) with the following soil preparation methods and additional treatments: SNO, no preparation; SRC, rotary cultivation; SDP, deep ploughing; SRT, removal of topsoil; ANO, no treatment; AHA, herbicide application.

spring sowing, seedbed surfaces were loosened with a rake.

Seed material and initial results

The seed material used, sowing times and natural seedfall have been described by Karlsson (1996), as well as the effects in the first growing season of different treatments on: (1) percentage seedling emergence; (2) the percentage of zero spots (PZS), i.e. the percentage of spots without seedlings; (3) percentage cover of living vegetation.

Inventory and measurement

In the second growing season, two inventories were carried out, one in June ('after the first winter') and the other in late September or early October. For Expt. 1, the autumn inventory was the only one carried out. The number of living seedlings was counted on the rectangular spots. New germinants, i.e. small seedlings showing only cotyledons, probably originating from the natural seedfall in the previous year, were removed with forceps.

The cover of living vegetation on the rectangular spots was estimated visually and rounded to the nearest 10%. To make the rectangular spots more distinct, they were demarcated with a frame. Dominant seedling height was estimated for each spot, by measuring with a ruler the height of the tallest seedling to the nearest millimetre. On every spot, primary injuries were investigated. The following causes of damage were recorded: none, insects, fungi, competing vegetation, voles, mammals, rainfall, drought, waterlogging, frost, frost-heaving, unknown.

To describe weather and soil conditions, minimum temperature 25 cm above ground was measured weekly throughout the growing season (minimum thermometers, Geraberg Termometerwerk, Thüringen, Germany) as was groundwater level (plastic groundwater tubes). Precipitation was recorded at the nearest meteorological station (at most 7 km distant) for all sites except Expt. 2, where a rain-gauge (Pronamic, Them, Denmark) was used on the site itself.

In the third growing season (all experiments) and in the fourth growing season (Expt. 1), inventories, using the same procedures, were carried out only in late September or early October.

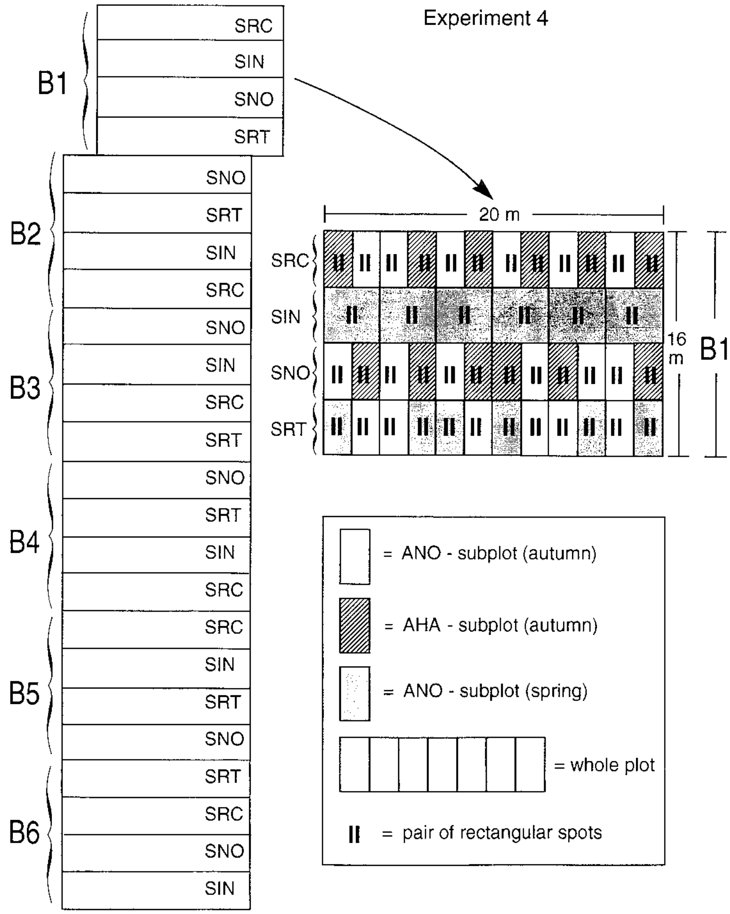

Fig. 3. Experimental layout for Expt. 4, showing six blocks (B1-B6) with the following soil preparation methods and additional treatments: SNO, no preparation; SRC, rotary cultivation; SIN, soil inversion; SRT, removal of topsoil; ANO, no treatment; AHA, herbicide application.

Calculation and analysis

For each spot and inventory, seedling survival percentage was computed by:

Seedling survival % = (Number of living seedlings/ Number of living seedlings in the First autumn)*100 (1)

For every treatment and inventory occasion, the frequency of damage i (Fd_i) was calculated as:

Fd_i = (Number of spots with damage i/ Total number of spots in the treatment) *100 (2)

At the last inventory, the percentage of zero spots (PZS) in each treatment was recorded. Additionally, the percentage seedling establishment for each spot was calculated by:

Seedling establishment % = (Number of living seedlings/ Number of seeded germinable seeds) *100 (3)

To analyse the effects of the treatments, t-tests and analyses of variance were performed by means of SAS Procedures TTEST and GLM (SAS, 1988*a*). The following variables were used to estimate the treatment response: Per cent seedling survival, living vegetation cover, dominant seedling height, per cent seedling establishment and PZS. The residuals were studied by plotting (Sabin & Stafford, 1990), and by the Shapiro-Wilk test for normality in SAS

Procedure UNIVARIATE (SAS, 1988*b*). In some cases, the assumptions of normality and constant variance for the residuals were violated. This made it necessary to transform the variables before analysis of variance. The logarithmic transformation was used, as it resulted in a good distribution of the residuals. Correction for logarithmic bias was performed when values were retransformed, by calculating a constant (C) (S. Holm, personal communication, 1994), thus:

$$C = \frac{\sum_{i=1}^{n} y_i}{\sum_{i=1}^{n} \widehat{y_i}} \qquad (4)$$

where y_i is the antilogarithmic transformation of the predicted logarithmic value and $\widehat{y_i}$ is the original value. Finally, the new predicted means, in terms of the original units are:

$$Y = C * y \qquad (5)$$

Analyses of variance were performed using two models. The first model was the split-plot model:

$$Y_{ijk} = S_i + B_j + (SB)_{ij} + A_k + (BA)_{jk} + (SA)_{ik} + E_{ijk} \qquad (6)$$

This model was used for Expt. 1, Expt. 2 and Expt. 3. Y_{ijk} is the response variable and the model is a mixed model. The soil preparation effects, S_i, the additional treatment effects, A_k, and their interactions, $(SA)_{ik}$, were regarded as fixed effects. The block effects, B_j, and the interactions, $(SB)_{ij}$ and $(BA)_{jk}$, were regarded as random effects. The interaction $(SB)_{ij}$ can be regarded as an area effect (cf. Fig. 1). E_{ijk} is the remaining error, which is at random. The following mean squares (MS) were used as denominators for the fixed effects and their interaction: (1) MS (SB) for the S-effect; (2) MS (BA) for the A-effect; (3) MS E for the (SA) interaction effect (Table 3).

To determine differences between treatments, Tukey's studentised range test (HSD) was used with the above MS as error terms. When the design was unbalanced, due to missing values, least-squares means were calculated for S_i, A_k and $(SA)_{ik}$, using the above MS as error terms. To determine differences between treatments in these cases, multiple t-tests with Bonferroni corrections were performed.

The second model was the following randomised complete block design (RCBD) model:

$$Y_{ij} = S_i + B_j + E_{ij} \qquad (7)$$

This model was used for Expt. 2, Expt. 3 and Expt. 4. The terms have the same meanings and effects as in model (6). This is a mixed model, comparing soil preparation methods using only subplots with no treatment. In this model, MS E was used as denominator for the S-effect (Table 4).

For examining strong ($p < 0.05$) $(SA)_{ik}$-interactions, found with model (6), a modified model (7) was used. Each soil preparation method was separately analysed and the S_i-effect was replaced by the A_k-effect, with MS E as denominator. Effect of seed-sowing time (T_m) in Expt. 4c was tested with a modified model (7), where the S_i-effect was replaced by the T_m-effect, with MS E as denominator.

To determine differences between treatments, Tukey's studentised range test (HSD) was used with MS E as error term. When only two treat-

Table 4. *ANOVA for a randomised complete block design (RCBD)*

Source of variation	d.f.	MS	F-value
Soil preparation (S)	s−1	MSS	MSS/MSE
Blocks (B)	b−1		
Error (E)	(s−1) (b−1)	MSE	
Total	sb−1		

Table 3. *ANOVA for a split-plot design with whole plots in a randomised complete block design*

Source of variation	d.f.	MS	F-value
Soil preparation (S)	s−1	MSS	MSS/MSE (1)
Blocks (B)	b−1		
Error (1) (S × B)	(s−1) (b−1)	MSE (1)	
Additoinal Treatments (A)	a−1	MSA	MSA/MSE (2)
(S × A)	(s−1) (a−1)	MSSA	MSSA/MSE (3)
Error (2) (A × B)	(a−1) (b−1)	MSE (2)	
Remaining error (3)	(s−1) (a−1) (b−1)	MSE (3)	
Total	sab−1		

ments were compared, the *t*-test was used. When the design was unbalanced, due to missing values, least-squares means were calculated for S_i using MS E as error term. To determine differences between treatments in these cases, multiple *t*-tests with Bonferroni corrections were performed.

Results

Environmental conditions

The sites for Expts. 1 and 2 were exposed to frost several times during the whole of the second growing season, while July and August were free from frost at the sites of Expts. 3 and 4 (Table 5). During the third growing season, minimum temperatures were recorded only for Expt. 1, where frosts were frequent. The groundwater level occasionally fell below one metre during the second growing season at the sites of Expts. 3 and 4, but never at the sites of Expts. 1 and 2. In the third growing season, the groundwater level was below one metre during the whole summer at the sites of Expts. 3 and 4. Precipitation during the second growing season was high in June but low in July, compared with mean precipitation (Table 5), for Expts. 2, 3 and 4. In the third growing season, the rainfall was high in June and low in July for Expt. 1, while it was very low in May and June and high in August for Expts. 2, 3 and 4.

Experiment 1

In the second growing season, there was a strong interaction ($p = 0.018$) between soil preparation and additional treatments on vegetation cover. Additional treatments were ranked differently ($p > 0.105$) within the several soil preparation methods. In the third and fourth growing season, the interaction effect was weaker ($p > 0.056$), while soil preparation exerted a strong effect ($p < 0.006$; Fig. 4a) and additional treatments had a weak effect ($p > 0.059$; not shown in Fig. 4) on vegetation cover. The sparsest vegetation cover was obtained following deep ploughing.

In the second growing season, both soil preparation and additional treatments had weak effects ($p > 0.059$) on seedling survival, but in the following growing seasons soil preparation exerted a strong effect ($p < 0.004$; Fig. 4b), while additional treatments had a weak effect ($p > 0.073$; not shown in Fig. 4). The highest seedling survival was observed in the deep-ploughed treatment. Causes of damage mainly varied among the various soil preparation methods (Table 6).

Both soil preparation ($p = 0.005$) and additional treatment ($p = 0.036$) strongly affected seedling establishment (Fig. 4c,e). The best establishment percentages were observed after deep ploughing and after the application of peat litter, while the lowest values were observed in

Table 5. *Climate data for the experimental sites*

	1			2			1 and 2	3			4			3 and 4
Site	GL[a]	MT[a]	PR[a]	GL[a]	MT[a]	PR[a]	MP[b]	GL[a]	MT[a]	PR[a]	GL[a]	MT[a]	PR[a]	MP[b]
Growing season 2														
May	2–5	−5.1	27	4–5	−7.7	62	41	8–11	−8.5	50	5–10	−10.1	50	48
June	4–6	−5.7	27	4–5	−5.8	81	44	8–10	−4.7	142	5–8	−2.0	142	55
July	5–7	−1.1	73	5–7	−0.6	24	53	7–12	0.6	21	6–13	2.0	21	75
Aug	6–8	−1.7	56	4–8	−1.3	96	78	11–12	0.1	62	11–12	0.6	62	57
Sept	5–8	−5.9	85	4–6	−6.8	70	73	11–13	−5.8	118	10–13	−5.2	118	71
Growing season 3														
May	1–4	−4.6	64	–[c]	–	28	41	7–10	–	17	5–11	–	17	48
June	3–5	−3.7	101	–	–	16	44	11–16	–	1	12–17	–	1	55
July	5–8	−0.9	20	–	–	67	53	16–18	–	59	16–18	–	59	75
Aug	5–7	−1.9	104	–	–	139	78	14–18	–	125	10–17	–	125	57
Sept	5–7	−6.0	63	–	–	74	73	11–12	–	49	8–11	–	49	71

[a] The following abbreviations are used: Groundwater levels (GL), dm below ground surface; Minimum temperatures (MT), °C; Precipitation (PR), mm.
[b] Mean precipitation for the years 1961–1990, mm, at the closest stations of the Swedish Meteorological & Hydrological Institute (SMHI) in Umeå (Lat. 63°48′N, Long. 20°17′E) and Växjö (Lat. 56°52′N, Long. 14°48′E).
[c] — = not recorded.

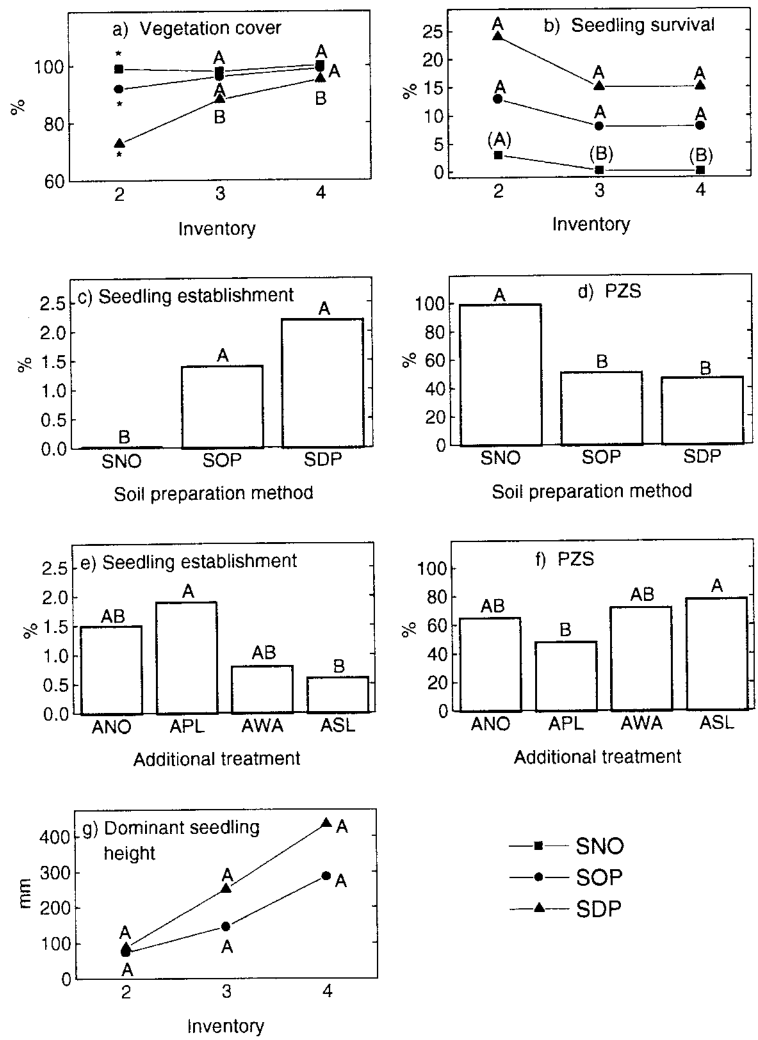

Fig. 4. Vegetation cover, seedling survival and seedling establishment of downy birch *(Betula pubescens)*, percentage of zero spots (PZS) and dominant seedling heights for different soil preparation methods and additional treatments in Expt. 1. Different capital letters above bars, or at the same inventory (2, after 2nd growing season; 3, after 3rd growing season; 4, after 4th growing season) indicate differences ($p<0.05$) according to Tukey's studentised range test (balanced designs) or *t*-test or multiple *t*-tests with Bonferroni corrections (unbalanced designs). Asterisks indicate a strong ($p<0.05$) interaction, and letters within parentheses represent means not significantly ($p<0.05$) different from 0.

the treatments with no preparation and after application of slaked lime. Both soil preparation ($p=0.001$) and additional treatment ($p=0.040$) exerted strong effects on the PZS-values (Fig. 4d,f). Deep ploughing and peat litter gave the lowest PZS-values. Because of missing values, dominant seedling height could be estimated only for ordinary ploughing and deep ploughing. The tallest seedlings were found on the treatment involving deep ploughing (Fig. 4g).

Experiment 2

There were strong interactions ($p<0.001$) between soil preparation and additional treatments on vegetation cover, both in the second and in the third growing season. In these cases, herbicide application effectively reduced the vegetation cover ($p<0.005$) only where there was no soil preparation (Fig. 5a,b,c). When soil preparation methods alone were analysed, using model (7), soil preparation exerted a strong effect ($p<0.001$) on the vegetation cover

Table 6. *Primary causes of damage, by classes of frequency, for various soil preparation methods at different inventories in Expt. 1*

Soil prep.	Frequent damage (10–35% of the spots)	Very frequent damage (35–65% of the spots)	Dominant damage (>65% of the spots)
After 2nd growing season			
SNO[a]		vegetation, voles	
SOP[a]	vegetation		voles
SDP[a]	vegetation		voles
After 3rd growing season			
SNO			voles
SOP	no damage, voles	vegetation	
SDP	vegetation, voles	no damage	
After 4th growing season			
SNO			vegetation
SOP	no damage		vegetation
SDP	no damage		vegetation

[a] The following soil preparation methods were used: SNO = No soil preparation; SOP = Ordinary ploughing to 20–30 cm; SDP = Deep ploughing to 40–50 cm.

(Fig. 6a,b). The least vegetation cover was observed after removal of topsoil.

In almost all analyses, soil preparation exerted a strong effect ($p<0.020$) on seedling survival. The highest survival percentages were observed for deep ploughing or removal of topsoil (Fig. 6c, d, e, f). Additional treatments had no effect on seedling survival ($p>0.160$; not shown in Fig. 6). Primary causes of damage varied mainly between different soil preparation methods, but also marginally between different additional treatments (Table 7).

Soil preparation exerted a strong effect ($p<0.012$; Fig. 7a,d,g,j), while additional treatments had no effect on seedling establishment ($p>0.600$; not shown in Fig. 7). The highest establishment percentages (7.5%–8.0%) were observed after removal of topsoil. Soil preparation also had a strong effect ($p<0.001$; Fig. 7b,e,h,k), while additional treatments had no effect on the PZS-values ($p>0.250$; not shown in Fig. 7). The lowest PZS–values were observed following removal of topsoil and deep ploughing. Soil preparation mostly exerted a strong effect on dominant seedling height ($p<0.025$; Fig. 7f,i,l). In some cases, analyses

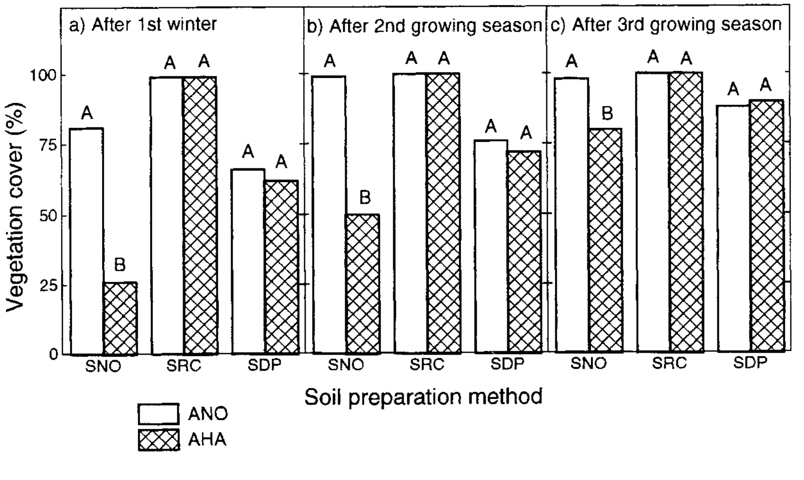

Fig. 5. Vegetation cover for different combinations of soil preparation method and additional treatments at different inventories in Expt. 2. Each soil preparation method is separately analysed regarding differences between additional treatments. Different capital letters above bars, within the same soil preparation method, show differences ($p<0.05$) according to t-test.

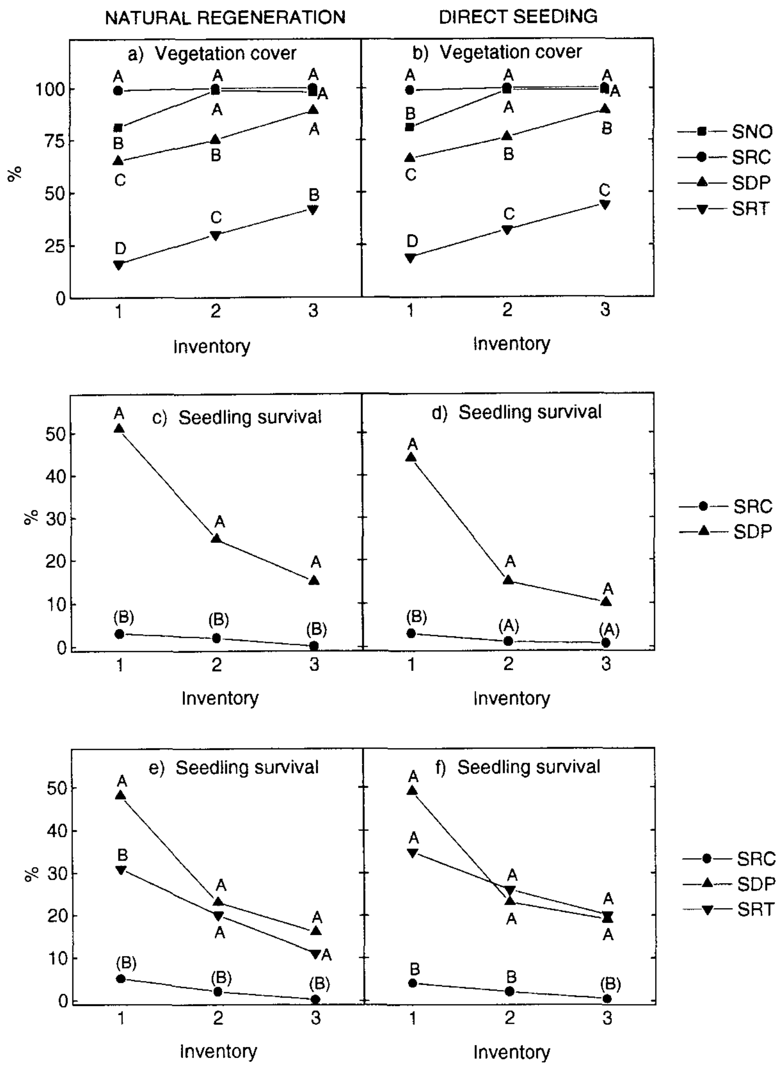

Fig. 6. Vegetation cover, and seedling survival of downy birch *(Betula pubescens)*, for different soil preparation methods at different inventories (1, after the 1st winter; 2, after the 2nd growing season; 3, after the 3rd growing season) in Expt. 2. Different capital letters at the same inventory show differences ($p<0.05$) according to Tukey's studentised range test (balanced designs) or *t*-test or multiple *t*-tests with Bonferroni corrections (unbalanced designs). Missing lines (SNO in c, d, e, f) are due to missing values. Letters within parentheses represent means not evidently ($p<0.05$) different from 0. First and third rows show the randomised complete block analyses while second row shows the split-plot analyses.

could not be performed because values were missing (Fig. 7c,f). Deep ploughing resulted in the tallest seedlings, while removal of topsoil resulted in the shortest.

Experiment 3

In the second growing season, there were strong interactions ($p<0.035$) between soil preparation and additional treatments on vegetation cover. Herbicide application, together with no preparation, reduced vegetation cover ($p<0.045$) and, on one occasion, herbicide application, together with ordinary ploughing, also reduced the vegetation cover (Fig. 8a,b). In the third growing season, no interaction effect was found ($p=0.449$), while both soil preparation ($p=$ 0.028; Fig. 8c) and additional treatments ($p<0.001$; Fig. 8d) exerted strong effects on vegetation cover. In these cases, the lowest veg-

Table 7. *Primary causes of damage, by classes of frequency, for various soil preparation methods at different inventories in Expt. 2*

Soil prep.	Frequent damage (10–35% of the spots)	Very frequent damage (35–65% of the spots)	Dominant damage (>65% of the spots)
After 1st winter			
SNO[a]	unknown (ANO, AHA)[b]		vegetation (ANO), frost (AHA)
SRC[a]			vegetation
SDP[a]	frost, rainfall	vegetation	
SRT[a]	rainfall, waterlogging		frost-heaving
After 2nd growing season			
SNO	vegetation (ANO), frost (AHA)		voles (ANO, AHA)
SRC	voles		vegetation
SDP	vegetation	voles	
SRT	waterlogging		rainfall
After 3rd growing season			
SNO	unknown (ANO, AHA)	vegetation (ANO, AHA), voles (ANO, AHA)	
SRC			vegetation
SDP		vegetation, voles	
SRT	frost-heaving, rainfall	unknown	

[a] The following soil preparation methods were used: SNO = No soil preparation; SRC = Rotary cultivation to 10–15 cm; SDP = Deep ploughing to 40–50 cm; SRT = Removal of topsoil.
[b] Additional treatments (ANO = No treatment; AHA = Herbicide application) exerted an effect only for SNO.

etation cover was observed after ordinary ploughing and after herbicide application. When soil preparation methods alone were analysed, using model (7), soil preparation exerted a strong effect on vegetation cover ($p<0.001$; Fig. 8e). The lowest cover was observed following removal of topsoil.

Only after the second growing season did soil preparation ($p<0.035$; Fig. 9a,c) and additional treatments ($p=0.019$; Fig. 9b) strongly affect seedling survival. The effects were weak ($p>0.075$) on the other inventory occasions. The highest seedling survival followed ordinary ploughing and herbicide application. Major causes of damage mainly varied among the several soil preparation methods (Table 8).

Neither soil preparation ($p>0.120$; Fig. 9d,f: $p>0.295$; Fig. 9e,g) nor additional treatments ($p>0.512$; not shown in Fig. 9) affected seedling establishment or PZS-values, respectively. Because values were missing, dominant seedling heights could be estimated only by model (7) (Fig. 9h). Soil preparation exerted a weak effect ($p=0.119$) after the first winter, a strong effect ($p=0.015$) after the second growing season and a weak effect ($p=0.159$) after the third growing season. The tallest dominants were found after ordinary ploughing.

Experiment 4

In Expt. 4a and b, soil preparation exerted a strong effect ($p<0.005$) on vegetation cover (Fig. 10a–d). The lowest vegetation cover was observed following removal of topsoil. The effect of sowing time on the vegetation cover in Expt. 4c was much weaker ($p>0.075$; not shown in Fig. 10).

In Expt. 4a, the effect of soil preparation on seedling survival was weak after the first winter ($p=0.212$, silver birch; $p=0.057$, downy birch) but became stronger after three growing seasons ($p=0.060$, silver birch; $p=0.020$, downy birch: Fig. 10 e,f). Seedlings survived best after the removal of topsoil. In Expt. 4b, the effect of soil preparation on seedling survival was strong after the first winter ($p=0.008$, silver birch; $p=0.003$, downy birch) but became weaker after three growing seasons ($p=0.034$, silver birch; $p=0.231$, downy birch: Fig. 10 g,h). The highest seedling survival was on inverted soil. In Expt. 4c, sowing time affected seedling survival only after the first winter for silver birch ($p=0.023$; Fig. 10j); autumn sowing was better than spring sowing. On the other inventory occasions, there was little evidence for an effect of sowing time ($p>0.360$; Fig. 10i,j). Primary

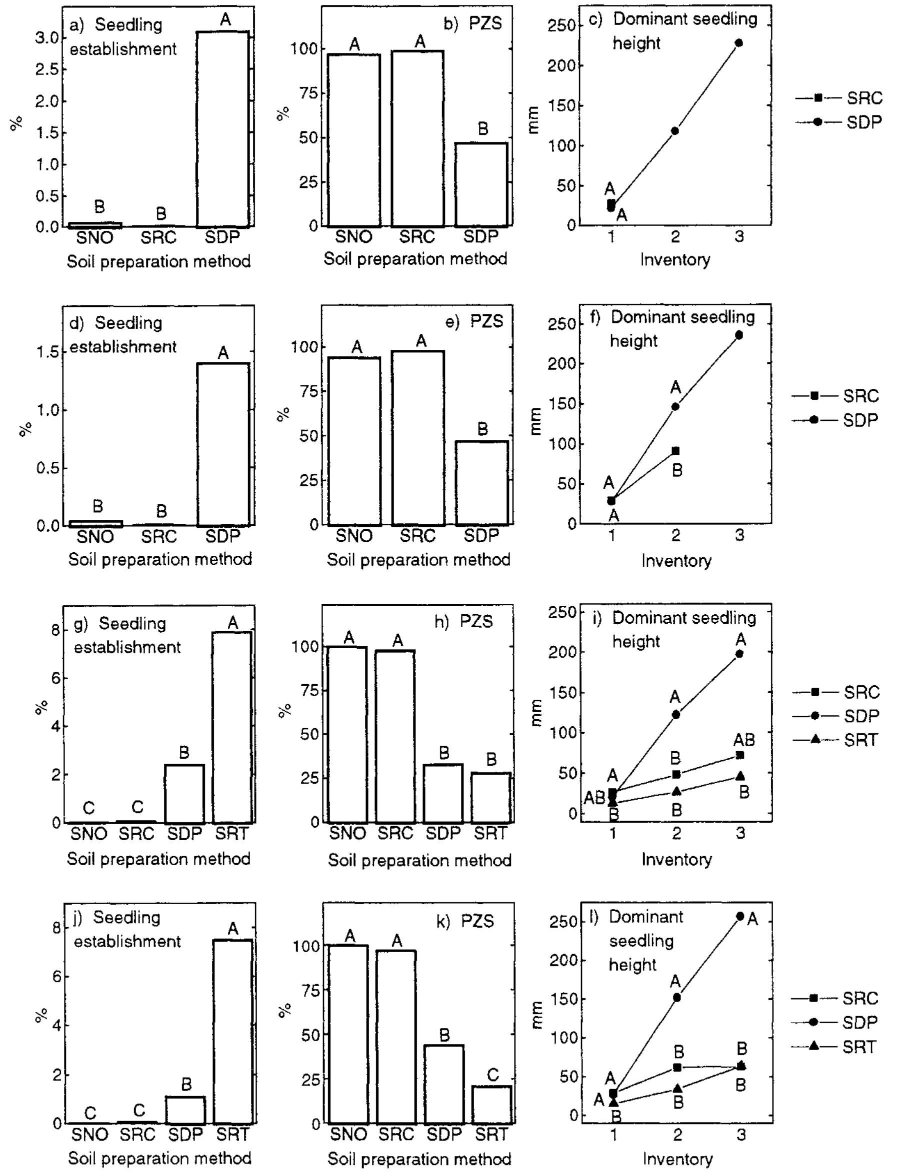

Fig. 7. Seedling establishment of downy birch *(Betula pubescens)*, percentage of zero spots (PZS) and dominant seedling height for different soil preparation methods in Expt. 2. Different capital letters above bars, or at the same inventory, show differences ($p < 0.05$) according to Tukey's studentised range test (balanced designs) or *t*-test or multiple *t*-tests with Bonferroni corrections (unbalanced designs). Missing lines (SNO in c, f, i, l) are due to missing values. First and second rows show the split-plot analyses for natural regeneration and direct seeding, respectively, while third and fourth rows show the randomised complete block analyses for natural regeneration and direct seeding, respectively.

causes of damage varied among soil preparation methods (Table 9).

In Expt. 4a, soil preparation exerted a strong effect on seedling establishment ($p = 0.033$, silver birch; $p = 0.009$, downy birch: Fig. 11a,b). The highest establishment values were obtained following removal of topsoil. In Expt. 4b, soil preparation had no effect on seedling establishment in downy birch ($p = 0.755$; Fig. 11c) but a strong effect on seedling establishment in silver birch ($p = 0.033$; Fig. 11d). The highest establishment value for silver birch was observed for inverted soil. In Expt. 4c, the effect of sowing time on seedling establishment was weak ($p = 0.103$,

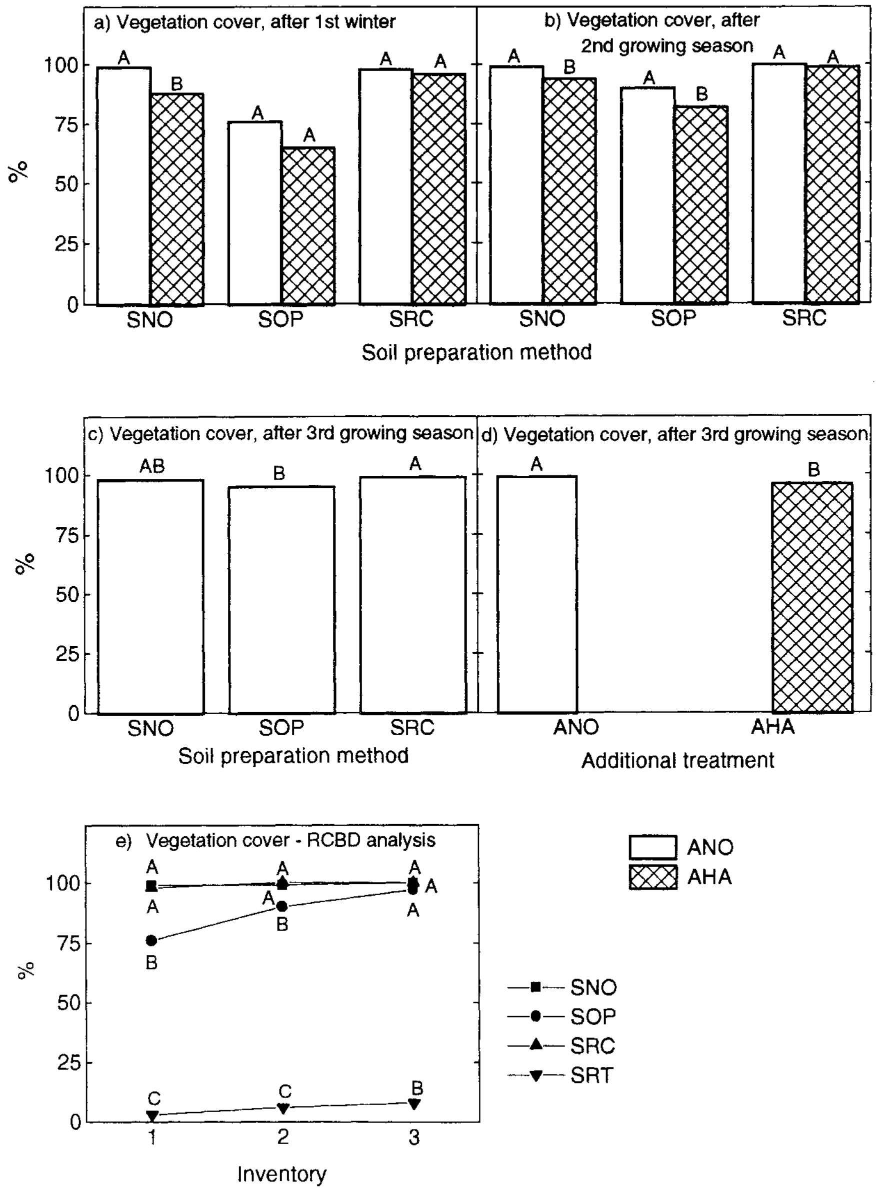

Fig. 8. Vegetation cover, either for different combinations of soil preparation methods and additional treatments (a, b), for soil preparation only (c) or for additional treatment (d) in Expt. 3. In a and b, each soil preparation method was separately analysed as regards differences between additional treatments, and different capital letters above bars, within the same soil preparation method, show differences ($p < 0.05$) according to the *t*-test. In c, d and e, different capital letters above bars, or at the same inventory, indicate differences ($p < 0.05$) according to the *t*-test or Tukey's studentised range test. First and second rows show the split-plot analyses, while the third row shows the analysis of the randomised complete block.

silver birch; $p = 0.369$, downy birch: Fig. 11e,f). Soil preparation exerted a strong effect on PZS-values for both silver birch and downy birch in Expt. 4a ($p < 0.005$; Fig. 11g,h), whereas no effect was found in Expt. 4b ($p > 0.185$; Fig. 11i,j). In Expt. 4a, the lowest PZS-values were observed following the removal of topsoil, while the lowest PZS-values in Expt. 4b were observed following soil inversion. In Expt. 4c, sowing time had no effect on PZS-values for downy birch

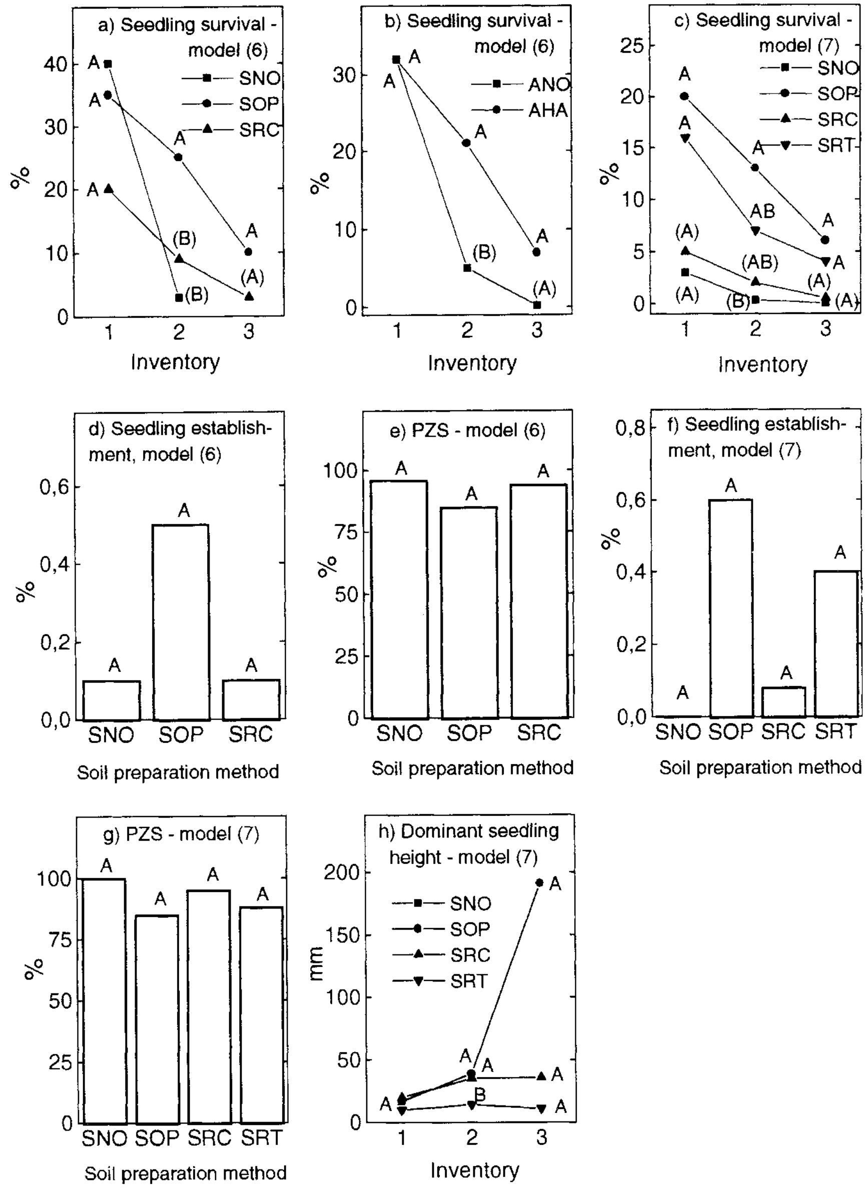

Fig. 9. Seedling survival and seedling establishment of downy birch (Betula pubescens), percentage of zero spots (PZS) and dominant seedling height for different soil preparation methods and additional treatments in Expt. 3. Different capital letters above bars, or at the same inventory show differences ($p<0.05$) according to Tukey's studentised range test (balanced designs), the *t*-test or multiple *t*-tests with Bonferroni corrections (unbalanced designs). Letters within parentheses represent means not significantly ($p<0.05$) different from 0. Missing line (SNO in h) is due to missing values. Model (6) represents the split-plot analyses, while model (7) represents the randomised complete block analyses.

($p=0.518$; Fig. 11k), but had a strong effect on silver birch ($p=0.013$; Fig. 11l); the lowest values were for the spring sowing.

In Expt. 4a, the effect of soil preparation on dominant seedling height was strong after the first winter ($p=0.002$, silver birch; $p=0.019$, downy birch) but became weak after three growing seasons ($p=0.205$, silver birch; $p=0.164$, downy birch). The tallest seedlings were found after rotary cultivation (Fig. 12a,b). In Expt. 4b, soil preparation exerted a strong effect on dominant seedling height for both silver and downy birch on all inventory occasions ($p<0.015$; Fig. 12c,d). The tallest seedlings were on in-

Table 8. *Primary causes of damage, by classes of frequency, for various soil preparation methods at different inventories in Expt. 3*

Soil prep.	Frequent damage (10–35% of the spots)	Very frequent damage (35–65% of the spots)	Dominant damage (>65% of the spots)
After 1st winter			
SNO[a]	unknown		vegetation
SOP[a]	frost-heaving, unknown	vegetation	
SRC[a]	unknown		vegetation
SRT[a]	waterlogging		frost-heaving
After 2nd growing season			
SNO	no damage		vegetation
SOP	no damage		vegetation
SRC	no damage		vegetation
SRT	no damage		rainfall
After 3rd growing season			
SNO			vegetation
SOP	unknown		vegetation
SRC	unknown		vegetation
SRT	frost-heaving, rainfall	unknown	

[a] The following soil preparation methods were used: SNO = No soil preparation; SOP = Ordinary ploughing to 20–30 cm; SRC = Rotary cultivation to 10–15 cm; SRT = Removal of topsoil.

verted soil. In Expt. 4c, sowing time exerted no effect on dominant seedling height for downy birch ($p > 0.490$; Fig. 12e), but a strong effect for silver birch ($p < 0.030$; Fig. 12f). The tallest seedlings were obtained following autumn seeding.

Discussion

Seedbeds which suppress competing ground vegetation

The vegetation cover percentages following rotary cultivation were close to 100% at the onset of the second growing season (Figs. 5, 6, 8, 10), while those observed following ordinary ploughing were close to 100% after two or three growing seasons (Figs. 4, 8). Seedbeds created by deep ploughing, soil inversion or by the removal of topsoil were colonised by ground vegetation at a slower rate (Figs. 4, 5, 6, 8, 10). Deep ploughing and soil inversion, which bury the topsoil in the profile, suppressed competing vegetation (cf. Örlander et al., 1990). The strongest effect on vegetation cover was observed following the removal of topsoil (Figs. 6, 8, 10), forcing the vegetation to colonise through seed dispersal. It is clear that topsoil must be covered by subsoil, or removed, if ground vegetation is to be suppressed for a long period.

Herbicide application was the only additional treatment that affected vegetation cover (Figs. 5, 8). The herbicide effect was strong almost only when combined with no preparation, and the glyphosate treatment was clearly of little effect when followed by mechanical soil preparation. Two herbicide treatments would probably be more effective, the one before soil preparation, to kill the rhizomatous weeds, the other after soil preparation, to kill seed-propagated weeds.

Seedling survival and causes of damage

The intensity of soil preparation was positively related to seedling survival (Figs. 4, 6, 10), probably by reducing the chances of injury. The seedling survival percentages observed after the first winter (SSP1 values) were less than 55% for all soil preparation methods. High SSP1 values were associated with deep ploughing (Fig. 6) and soil inversion (Fig. 10), while the SSP1 values for no preparation and rotary cultivation were especially low (Figs. 6, 9, 10).

The SSP1 values observed following no preparation and following rotary cultivation may have been slightly underestimated, since small seedlings are difficult to find in dense vegetation. Most probably, the small seedlings were smothered by competing vegetation. Seedlings also

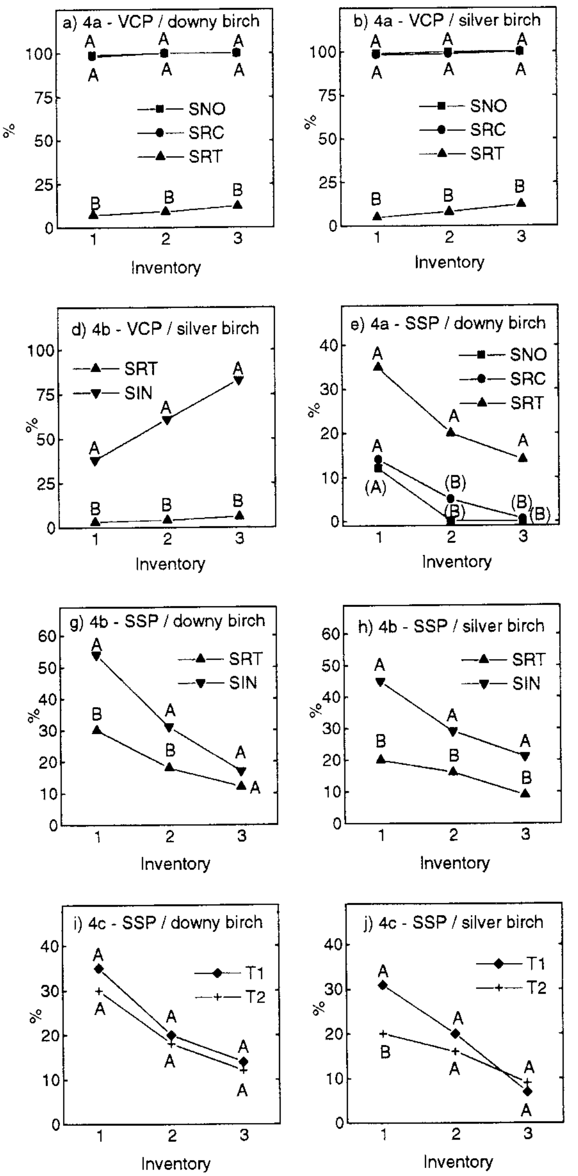

Fig. 10. Vegetation cover percentage (VCP), and seedling survival percentage (SSP) for downy birch (Betula pubescens) and silver birch (Betula pendula), for different soil preparation methods in Expts. 4a and 4b, and for different sowing times (T1, autumn; T2, spring) in Expt. 4c. Abbreviations for inventories as in Fig. 6. Different capital letters at the same inventory show differences ($p < 0.05$) according to Tukey's studentised range test (balanced designs), the *t*-test or multiple *t*-tests with Bonferroni corrections (unbalanced designs). Missing line (SNO in f) is due to missing values. Letters within parentheses represent means not significantly ($p < 0.05$) different from 0.

succumbed to competing vegetation after ordinary ploughing and deep ploughing, but to a lesser extent, since the vegetation cover associated with these methods was sparser. Frost-heaving was the main cause of damage after removal of the topsoil, a result which was to be expected on the fine-textured soils in Expts. 3 and 4 (cf. Penner, 1957), but which was more noteworthy on the soil of coarser texture in Expt. 2. However, not only soil texture, but also soil water and freezing conditions, must be considered in the context of frost action (Penner, 1976). Although the capillary pathways of the soil were probably broken or disturbed by the transposition of the topsoil layer (cf. Pohtila, 1977) on both inverted soil and following deep

Table 9. *Primary causes of damage, by classes of frequency, for various soil preparation methods at different inventories in Expt. 4*

Soil prep.	Frequent damage (10–35% of the spots)	Very frequent damage (35–65% of the spots)	Dominant damage (>65% of the spots)
After 1st winter			
SNO[a]			vegetation
SRC[a]	unknown		vegetation
SDP[a]	no damage		frost-heaving
SRT[a]			frost-heaving
After 2nd growing season			
SNO	–[b]	–[b]	–[b]
SRC			vegetation
SDP	rainfall, no damage	vegetation	
SRT	no damage		rainfall
After 3rd growing season			
SNO	–	–	–
SRC			vegetation
SDP	unknown		vegetation
SRT	rainfall, unknown	frost-heaving	

[a] The following soil preparation methods were used: SNO = No soil preparation; SRC = Rotary cultivation to 10–15 cm; SIN = Soil inversion, 15 cm of subsoil placed above the topsoil; SRT = Removal of topsoil.
[b] – = No evaluation, as no seedlings were alive after the first winter.

ploughing, frost-heaving was still shown to be the primary cause of damage after soil inversion (Expt. 4b), probably owing to the properties of the silty soil (cf. Penner, 1957). Although frosts were frequent (Table 5), they caused barely visible damage, apart from frost-heaving. According to Christersson, von Fircks & Sennerby–Forsse (1982), new silver-birch shoots can tolerate growing-season temperatures of $-3°$ to $-5°C$. In Expt. 2, some seedlings developed forked stems after damage to the foliage, probably as a result of frost (cf. Langhammer, 1982).

The seedling survival percentages after the second growing season (SSP2 values) were often halved or more than halved, as compared to the SSP1 values, for the treatments no preparation, rotary cultivation and deep ploughing (Figs. 6, 9, 10). Competing vegetation was the main cause of damage after rotary cultivation, but continued also to smother seedlings in all other seedbeds except those in which the topsoil had been removed. Voles, probably *Microtus agrestis* L., caused great damage to both seedbeds and seedlings in Expts. 1 and 2. Since no damage by voles was found following the removal of topsoil, this study supports the finding of Bärring (1967), that vole damage is reduced if ground vegetation is removed. Mechanical damage from rain was the primary cause of damage following the removal of topsoil. This was expected, since the vegetation cover was very sparse (Figs. 6, 8, 10), giving little shelter from rain, and no organic matter was left to cushion splash effects. Raindrop impact leads to soil erosion (Sharma, Gupta & Rawls, 1991) and mortality caused by splash and flooding effects could readily be seen. In addition, many of the living seedlings appeared to have been slightly sandblasted.

The best seedling survival after the third growing season (SSP3 values, 10%–20%) occurred after deep ploughing (Expts. 1 and 2; Figs. 4, 6), removal of topsoil (Expt. 2 and for downy birch in Expt. 4a and b; Figs. 6, 10) and soil inversion (Expt. 4b; Fig. 10), i.e. on seedbeds with predominantly bare mineral soil at the surface. For seedbeds which mainly had topsoil at the surface, high SSP3 values (5–10%) were observed only after ordinary ploughing (Expts. 1 and 3; Figs. 4, 9). Competing vegetation continued to be the most important cause of damage for almost all seedbeds, except those from which the topsoil had been removed. Exceptionally, voles were the main cause of damage on some seedbeds in Expts. 1 and 2, but as noted above, vegetation and voles interact closely. In addition to frost-heaving and mechanical damage, much of the damage following removal of the topsoil was classified as unknown, which indicates that

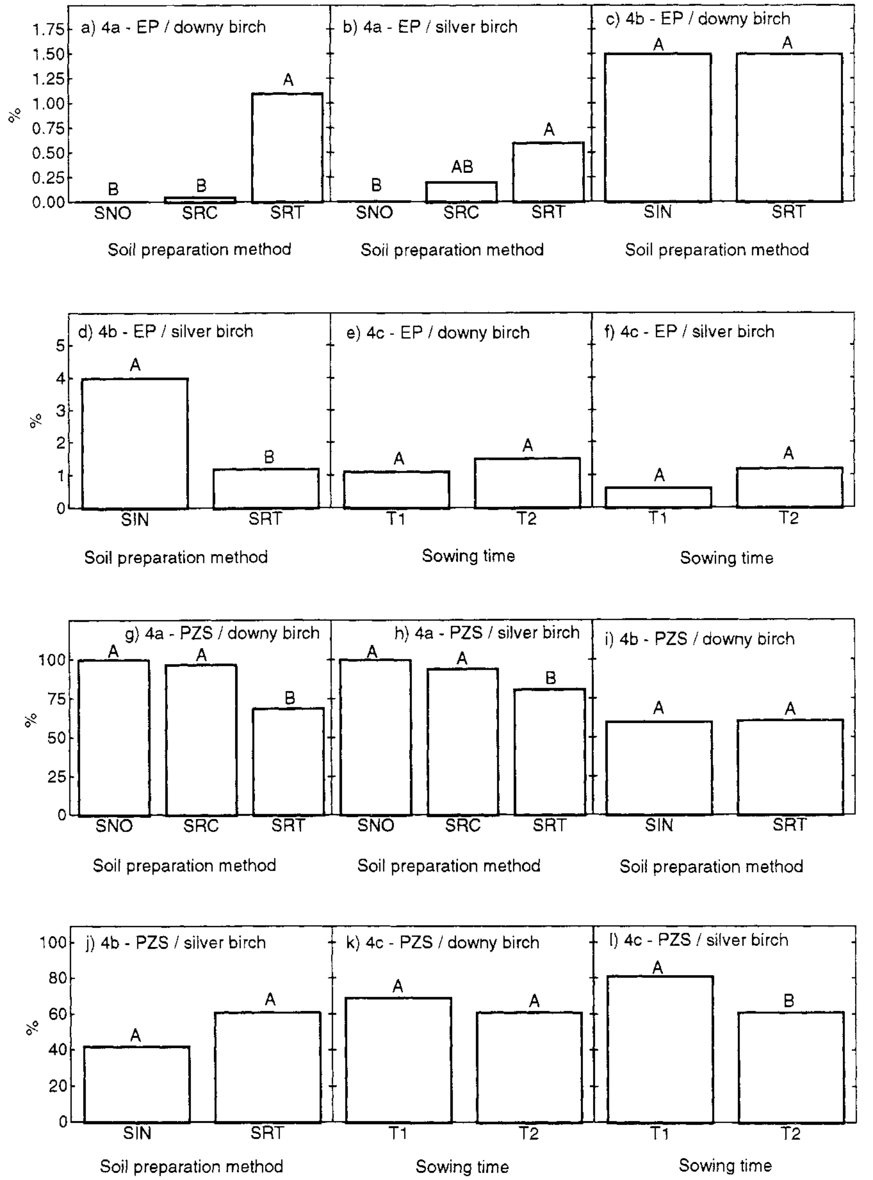

Fig. 11. Seedling establishment percentage (EP) of downy birch (Betula pubescens) and silver birch (Betula pendula) and percentage of zero spots (PZS) for different soil preparation methods in Expt. 4a and b, and for different sowing times in Expt. 4c. Different letters above bars show differences ($p<0.05$) according to the t-test or Tukey's studentised range test.

causes of damage should be observed more frequently. Notably, the SSP values for deep ploughing and ordinary ploughing, in Expt. 1, were the same after four growing seasons as the SSP3 values. These results indicate that the seedlings were established after three growing seasons. However, mortality may remain high for many years (Bjorkbom, 1972; Kinnaird, 1974), and its cause may change with age.

Seedbeds which promote seedling height development

The dominant seedling heights after the first winter show that 1-year-old seedlings are small, ca. 1–3 cm tall, irrespective of the soil preparation method (Figs. 7, 9, 12). The differences appeared after two and three growing seasons (Figs. 7, 9, 12). Thus this study supports earlier findings that growth is better on seedbeds where

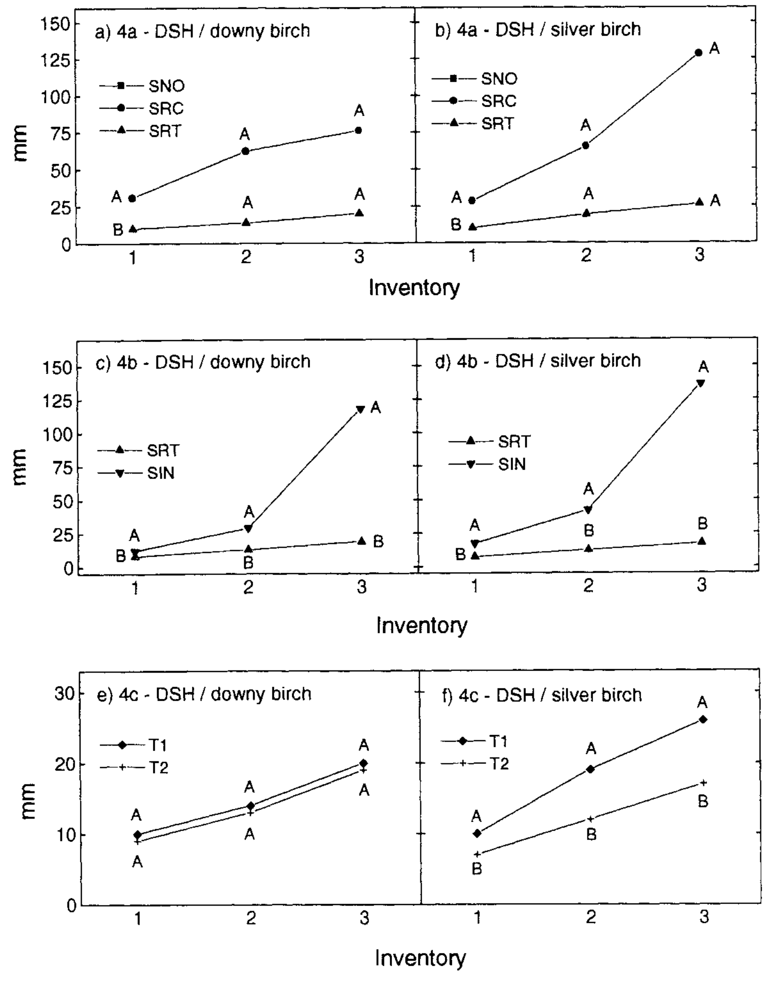

Fig. 12. Dominant seedling height (DSH) of downy birch (Betula pubescens) and silver birch (Betula pendula) for different soil preparation methods in Expt. 4a and b, and for different sowing times in Expt. 4c. Different letters at the same inventory show differences ($p<0.05$) according to the *t*-test. Missing lines (a, b) are due to missing values.

organic matter is accessible to the roots, compared with seedbeds which have bare mineral soil only (Marquis et al., 1964; Winget & Kozlowski, 1965; Perala & Alm, 1989).

The tallest dominants were observed following deep ploughing (Expts. 1 and 2; Figs. 4, 7), ordinary ploughing (Expt. 3; Fig. 9), rotary cultivation (Expt. 4a; Fig. 12) and profile inversion (Expt. 4b; Fig. 12). Had there been no vole damage in Expts. 1 and 2, the dominant seedling heights resulting from the two ploughing methods would have been far greater. The generally shorter seedlings which grew after rotary cultivation probably resulted from suppression of the seedlings by competing vegetation. Dominant seedlings which grew after profile inversion were surprisingly short. However, the seedlings were disturbed by frost-heaving during the first winter, and suffered from competing vegetation in the dry third growing season (Table 5). The short dominant seedlings observed after removal of topsoil were probably the result of: (1) repeated damage caused by frost-heaving; (2) lack of organic matter, and consequently, also of nutrients, in the soil; (3) a fine-grained soil texture (Expts. 3 and 4), which is a difficult medium for rootlets to penetrate (Palo, 1986).

Seedbeds and seedling establishment

Mechanical soil preparation is a prerequisite for obtaining abundant and uniform seedling emergence in the first growing season (Karlsson, 1996). Development during subsequent years showed that mechanical soil preparation did not always lead to abundant and uniform seedling establishment. After three growing seasons, the establishment percentages and PZS-values observed for plots treated with rotary cultivation were as unsatisfactory as those obtained with no preparation (Figs. 7, 9, 11). The values of seedling establishment and PZS observed for plots subjected to ordinary ploughing finally fell into an intermediate position, whereas the corresponding values observed for methods involving the transposition or removal of the topsoil generally were best (Figs. 4, 7, 11).

It seems necessary to suppress competing vegetation during seedling establishment. Very high establishment values were observed following removal of topsoil in Expt. 2 (Fig. 7), and these attained outstanding 3-year seed crop efficiencies (seedling: seed ratios) of 1:13 (cf. Perala & Alm, 1990*a*). However, such seedlings were still very small. The establishment values observed following deep ploughing in Expts. 1 and 2 were also high; if both seedling establishment and seedling growth are taken into consideration, deep ploughing may be a more interesting method than total removal of the topsoil. In Expt. 3, overall establishment percentages were low, partly because seedfall was poor, leading to low seedling emergence (Karlsson, 1996). In Expt. 4, high establishment values were only observed following soil inversion and after removal of the topsoil (Fig. 11). During the second and third growing seasons, seedling establishment and growth were better following soil inversion than for topsoil removal, probably because roots reached the buried topsoil.

Cover may be essential to protect seedlings from frost-heaving (Ledgard, 1976); the vegetation cover developed after soil inversion (Fig. 10) probably reduced frost-heaving. Vegetation cover exerts both a negative effect on seedling establishment, through competition, and a positive effect, by reducing frost-heaving and by giving some shelter from rain. Since soil capillary pathways were most probably broken as a result of soil inversion, the site may have become more mesic. This offers another possible explanation — in addition to the reduction of frost-heaving — of the high establishment values observed for silver birch following soil inversion (Fig. 11), since silver birch is better adapted to mesic sites than is downy birch (Gimingham, 1984).

The establishment values obtained from spring sowing, following removal of the topsoil, were higher than those for autumn sowing. In addition, the PZS-values for spring sowing, after removal of the topsoil, were lower than those for autumn sowing. However, the differences decreased after the first growing season (cf. Karlsson, 1996).

Sandy soil was better than silty soil, and there are indications that coarse soil textures may be more favourable than fine soil textures (Palo, 1986; Karlsson, 1994).

In Expt. 1, where additional treatments are concerned, the application of peat litter maintained the highest establishment percentages from the first growing season and, in addition, resulted in lower PZS-values (Fig 4). Besides being a favourable germination substrate (Palo, 1986), which may moderate splash effects during seedling emergence (Karlsson, 1996), peat litter probably continued to cushion splash effects during seedling establishment.

Conclusions

For reasons of economy, natural regeneration or direct seeding of birch or both, are of interest as regeneration methods on abandoned fields. Seedling survival and early seedling establishment are promoted by radical soil preparation methods. Analyses up to four years after seedling emergence show that:

- seedbeds with mainly bare mineral soil at the surface, i.e. where the topsoil was removed or transposed (e.g. by deep ploughing), could suppress competing vegetation;
- seedbeds having mainly bare mineral soil at the surface resulted in the highest seedling survival, and the highest and most uniform seedling establishment;
- seedbeds from which the topsoil was removed had the highest seedling establishment on sandy soil;
- seedbeds from which the topsoil was removed, and seedbeds with buried topsoil, showed equally good seedling establishment on silty soils;
- the tallest seedlings were on seedbeds with topsoil within the soil profile;
- application of peat litter to the seedbed surface promoted seedling establishment.

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