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Site index curves for Norway spruce plantations on farmland with different soil types

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Abstract

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Growth data were collected from 157 Norway spruce (*Picea abies* (L.) Karst.) stands planted on farmland in Sweden. The stands ranged in latitude from 55°N to 66°N. The mean age of the stands was 41 years (range, 25–91), and the mean stand density was 1 640 stems ha^{-1} (range, 400–3 722). The mean diameter at breast height (on bark) was 25 cm (range, 12–48). Classified soil types from northern Sweden were united into five groups: coarse sand ($n = 10$), the fine sand and silt group (14), till clay (12), sandy till (6) and fine sandy-silty till (6). Those from southern Sweden (lat. 55–61°N) were grouped as follows: coarse sand ($n = 14$), the fine sand and silt group (7), the light and medium clay group (16), heavy clay (11), till clay (13), sandy till (16), fine sandy-silty till (24) and peat (6). As there was only one stand growing on soils in the light and medium clay group, and one stand growing on peat soils in northern Sweden, growth curves for these stands are not presented.

Soil samples from 74 stands, 46 in northern and 28 in southern Sweden, were analysed to determine soil type, pH and content of P, Ca, K and N, dry matter content and ignition loss. The dominant height of spruces growing north of lat. 62°N was 3 m and 5 m less than that of more southerly trees at age 50 and 90 years, respectively. The dominant height of the trees varied with soil type. At age 50 years in northern Sweden, the tallest spruces grew on sandy till soils (20.3 m) and the shortest (15.2 m) on fine sandy-silty till soils. At age 50 years in southern Sweden, spruces tended to be tallest on till clay soils (25.2 m), and shortest on soils in the fine sand and silt group (21.7 m) and on peat soils (21.6 m).

Survival in young spruce plantations was lower on heavy clay soils than on other soil types. Seedling height 5 years after planting was lowest on heavy clay soils.

Keywords: Picea abies, soil type, dominant height, nutrient content, Sweden

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Introduction

In Sweden, trees have been planted on abandoned farmland for at least 200 years (Malmström, 1939). A large programme aimed at reducing farm production was implemented in 1960. In connection with this programme, about 530 000 ha of farmland was planted with forest trees, mainly Norway spruce (*Picea abies* (L.) Karst). In 1987, a second period of farmland afforestation began, intended gradually to remove 800 000 to 900 000 ha of farmland, e.g. cereals, from production. Some of this area has been planted or will be planted with forest trees, including birches (*Betula pendula* Roth and *B. pubescens* Ehrh.), hybrid aspens (*Populus tremula* (L.) × *P. tremuloides* Michx.), alders (*Alnus glutinosa* (L.) Gaertn. and *A. incana* (L.) Moench.), oaks (*Quercus robur* L.), wild cherry (*Prunus avium* L.), beech (*Fagus sylvatica* L.), Norway spruce, Scots pine (*Pinus sylvestris* L.) and larches (*Larix decidua* Mill., *L. sibirica* Ledeb. and *L. leptolepis* (Sib. et Zucc.) Gord.).

Several studies have been made with the aim of improving methods for planting forest tree seedlings on farmland. Bärring (1967) focussed on site preparation methods prior to planting Norway spruce on farmland. He showed that weeding not only increased seedling survival but also reduced desiccation-related stress in early spring by accelerating soil thawing. This type of stress develops in cases where aboveground parts of the seedling begin transpiring before the soil has thawed enough to allow roots to take up water. Haugberg (1971) studied traditional methods of planting spruce as well as post-planting procedures aimed at increasing seedling survival. He found that weed removal through the use of herbicides or scarification enhanced seedling growth and survival, probably because weeding leads to an increase in soil temperature and a decrease in competition.

Norway spruce stands growing on fertile soils, which dominate in agricultural areas, generally show rapid growth early in the rotation and eventually produce a high yield (Johansson & Karlsson, 1988). Braathe (1952) reported the importance of dense stands for stand development, i.e. annual ring width and branch diameter. These stands are also more frequently damaged by root rot (*Heterobasidion annosum* (Fr.) Bref.) and are more susceptible to windthrow. In Sweden there has been only limited experience with such problems, and most of the knowledge obtained applies to the southern parts of the country. Most of the Norway spruce stands planted on farmland in Sweden are 30–40 years old. However, there are some 60–80-year-old plantations in south Sweden. Reports from various sources indicate that, throughout southern and middle Sweden, the growth of Norway spruce stands on heavy clay soils has slowed down or ceased.

Dominant-height curves have been constructed for Norway spruce growing on forest land by Møller (1933), Pettersson (1950), Vuokila (1956), Lundquist (1957), Fries (1969), Tveite (1969), Vestjordet (1972) and Hägglund (1972, 1973), among others. However, in these studies, height growth was not related to mineral soil type. Bowling & Zelazny (1992) presented a forest site classification in New Brunswick, Canada. They constructed an on-site, preharvest assessment tool for use in mature and overmature natural stands. The classification is based on vegetation and soil characteristics. Forest management and silvicultural interpretations are given for each treatment unit, the primary interpretation being site productivity.

The primary aim of this report is to present dominant-height curves for Norway spruce planted on farmland. Furthermore, variation in height increment is related to mineral soil type and geographical location. A secondary aim is to study the relationship between the survival and height increment of young (4 to 10 years old) Norway spruce and mineral soil type, using data from Bärring (1967).

Material and methods

Height increment study

Planted stands of Norway spruce of native origin were identified throughout much of Sweden. Among the identified stands 157, ranging in age from 25 to 91 years, were used in the study (Fig. 1). In all stands the year of planting was known. The trees were 3–4 years old at the

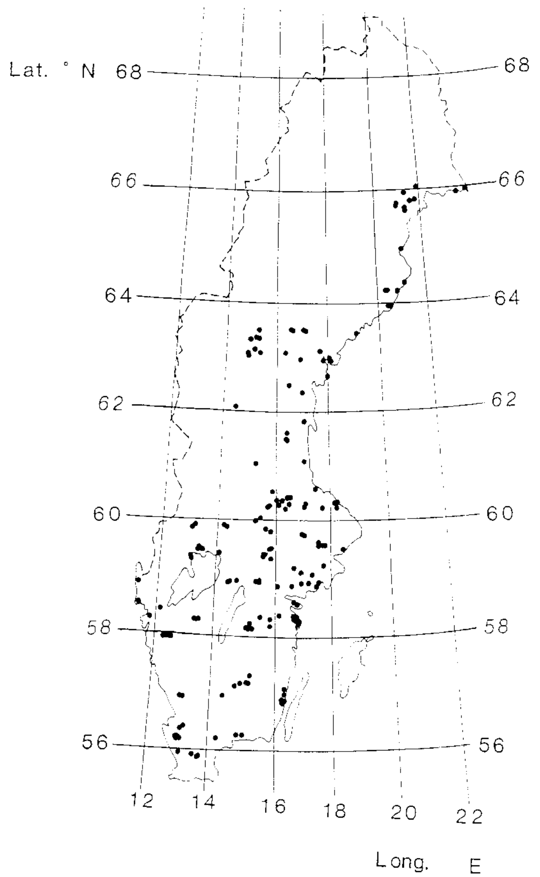

Fig. 1. Geographical location of the studied plantations of Norway spruce (*Picea abies* (L.) Karst.) planted on farmland.

time of planting, and in most cases bare-root seedlings were used. Thus the total age of the stand was known. Early growth and damage to the plantation were assessed on the basis of information provided by the forest owner. If a plantation had been seriously damaged by frost, it was excluded from the study. The mean number of stems per hectare was calculated using the number counted on five 100 m^2 plots. Most of the stands had been thinned twice prior to the study, and a smaller number had been thinned once or not at all. The rooting depth was 25–35 cm, and in most cases water availability was sufficient, the groundwater level being at 30–50 cm depth.

Each stand, usually 0.5–1.5 ha in area, was divided into 100 m^2 plots, i.e. 5–10 plots per stand. On each of the plots, one dominant tree was chosen for sampling and analysis. The largest tree on each of the plots (determined on the basis of diameter at breast height) was chosen if it had an undamaged, straight stem without double leaders. The tree must also to be free from *H. annosum* root rot. Furthermore, trees growing in large openings were excluded.

The chosen tree was felled. Tree height (m) was measured (Table 1), and diameter at breast height (dbh, cm) were measured (Table 2). Bark thickness was measured (Table 2) and cores were taken at intervals corresponding to 1, 10, 20, 30, 50, 70 and 90% of tree height. A core was also taken at breast height. All cores reached from bark to pith. Total age and years to reach breast height was recorded (Table 1).

Height increment curves, based on the cores, were constructed. In the analysis, a function presented by Chang (1984) were used:

$$H = A^*\mathrm{EXP}((B/t^2) + (C/t)) \qquad (1)$$

where
H = Dominant height (m)
t = Total age (plant age + stand age)
A, B, C = Parameters
Other functions were tested:

$$H = A^*\mathrm{EXP}(-B^*\mathrm{EXP}(-C^*t)) \qquad (2)$$
(Gompertz, 1825; Hackett & Rawson, 1974)

$$H = A^*\mathrm{EXP}(-B/t) \qquad (3)$$
(Schumacher, 1939)

$$H = A^*\mathrm{EXP}(B^*\ln(1 + C^*\mathrm{EXP}(-D^*t))) \qquad (4)$$
(von Bertalanffy, 1941; 1957)

$$H = A^*(1 - \mathrm{EXP}(-B^*t))^{(1/(1-C))} \qquad (5)$$
(Richards, 1959)

$$H = A^*(1 - \mathrm{EXP}(-B^*(t)^C)^D \qquad (6)$$
(Bailey, 1980)

$$H = A/(1 + B^*\mathrm{EXP}(-C^*t)) \qquad (7)$$
(Verhulst, 1838)

For spruces aged 50 years and older, the curves described by the functions underestimated their actual height. This became apparent when the 'true' heights were plotted against the fitted curves.

The soil profile of each of the stands was analysed and the soil type was recorded. Soil was sampled from ground level to below the former ploughing depth. An average texture for 0–30 cm depth was assessed. Soil type was classified in the field, following the instructions provided by Atterberg (Ekström, 1926), and the

Table 1. *Dominant height (single trees), age, years to reach breast height (1.3 m) and stand density for Norway spruce (*Picea abies *(L.) Karst.) planted on farmland at different latitudes*

	Tree height, m		Age, year		Years to reach breast height (1.3 m)		No. of stems ha^{-1}		
Lat. °N	Mean ± SD	Min.–Max.	Mean ± SD	Min.–Max.	Mean ± SD	Min.–Max.	Mean ± SD	Min.–Max.	No. of plots
55	15.5 ± 3.5	12.5–18.8	30.0 ± 3.4	25–32	9.5 ± 3.1	7.0–14.0	2050 ± 520	1600–2500	4
56	19.4 ± 4.1	12.1–28.9	36.9 ± 8.5	27–64	8.1 ± 1.9	3.0–11.0	1480 ± 564	500–2500	16
57	23.1 ± 4.5	18.1–30.4	47.7 ± 12.2	33–68	8.6 ± 0.9	7.0–10.0	800 ± 265	400–1300	9
58	19.2 ± 5.2	11.8–30.3	40.1 ± 14.1	28–74	8.6 ± 1.4	6.0–11.0	1885 ± 1053	520–3722	38
59	21.3 ± 4.2	14.5–28.5	47.9 ± 15.0	28–80	8.9 ± 1.5	7.0–12.0	1389 ± 786	500–3500	28
60	19.7 ± 5.4	13.6–33.2	44.8 ± 18.5	32–91	9.0 ± 1.7	6.0–12.0	1669 ± 835	500–3708	17
61	16.0 ± 1.4	14.5–18.2	32.8 ± 2.8	28–35	7.6 ± 2.2	5.0–11.0	1380 ± 45	1300–1400	5
62	16.3 ± 3.4	12.0–22.7	37.7 ± 4.6	31–45	9.2 ± 1.9	7.0–13.0	1478 ± 353	1000–2000	9
63	15.4 ± 3.0	11.4–20.5	41.3 ± 7.4	30–52	10.4 ± 1.3	9.0–13.0	1944 ± 588	1300–3000	16
64	12.7 ± 1.5	11.0–14.9	36.0 ± 2.8	34–40	10.4 ± 0.9	9.0–11.0	1880 ± 179	1600–2000	5
65	12.1 ± 3.1	6.1–15.7	34.3 ± 7.1	27–46	11.0 ± 1.7	9.0–15.0	1611 ± 267	1300–2000	9
66	8.0 ± –	8.0–8.0	27.0 ± –	27–27	13.0 ± –	13.0–13.0	1200 ± –	1200–1200	1
Mean	18.4 ± 5.1	6.1–33.2	41.1 ± 13.0	25–91	9.1 ± 1.8	3.0–15.0	1620 ± 784	400–3722	157

soils were classified as either sediments or tills. The soil sample (500 g) was then classified by particle size in the laboratory. The particle-size distribution was determined mechanically, using sieves according to Atterberg (Troedsson & Nykvist, 1973). Soil types were classified as sediments; gravel, coarse sand, fine sand, silt, clay: as tills; gravel, sandy, fine sandy and silty, clay: and as organogenic types of soil; fen peat and moss peat. The soil samples did not contain a single particle size, but the most frequent size determined the classification into a soil type, with the addition of one or two prefixes for other less frequent soil types. The clay content was estimated using the hydrometer method. The clay soils were then classified depending on the percentage of clay, as follows: light clay (13–29%), medium clay (30–40%) and heavy clay (41–60%) and till clay soils (13–60%).

As there were few stands on each soil type, they were grouped to provide a larger sample size for the statistical procedure. In southern Sweden, the soil types were assorted into the following groups: coarse sand (14 stands), fine sand and silt (7), light and medium clay (16), heavy clay (11), till clay (13), sandy till (16), fine sandy-silty till (24) and peat (6). In northern Sweden, five groups were used: coarse sand (10), fine sand and silt (14), till clay (12), sandy till (6) and sandy-silty till (6). Of the studied stands in northern Sweden, only one was growing on soils in the group light and medium clay and one on a peat soil. Data from these stands were therefore excluded from the height growth study (Table 3).

Soils from 74 stands, 46 from northern and 28 from southern Sweden, were sampled and taken to the laboratory for analysis of nutrient content, dry matter content and pH-value (Table 4). These analyses were carried out to test for a relationship between height growth and soil nutrient content. Samples were taken only during the last inventory period, when the inventory of stands was concentrated to northern Sweden. In all measured stands in northern Sweden (50), a soil sample was taken, two of which were destroyed before analysis. As only one sample from organogenic soil remained, this was not presented. Soil samples were collected from a reduced number of stands in southern Sweden. For each soil type, a number of stands was selected, according to the percentage rep-

Table 2. *Diameter at breast height (1.3 m) on bark, under bark and bark thickness of Norway spruce (*Picea abies *(L.) Karst.) stands planted on farmland at different latitudes*

	DBH, cm ob		Dbh, cm ub		Bark thickness, mm		
Lat. °N	Mean ± SD	Min.–Max.	Mean ± SD	Min.–Max.	Mean ± SD	Min.–Max.	No. of plots
55	22.6 ± 4.5	18.6–28.8	20.2 ± 3.9	16.8–25.7	12 ± 3	9–15	4
56	26.1 ± 4.7	18.5–36.1	23.7 ± 5.4	16.9–32.9	12 ± 3	7–16	16
57	29.9 ± 5.3	23.3–38.3	27.6 ± 5.1	21.3–35.6	12 ± 2	10–14	9
58	26.1 ± 7.8	15.5–47.6	23.8 ± 7.4	13.6–45.6	11 ± 3	5–21	38
59	27.7 ± 6.3	16.6–42.3	25.3 ± 5.9	14.5–38.5	12 ± 3	7–19	28
60	27.6 ± 7.3	19.7–28.2	25.3 ± 5.9	17.7–45.6	12 ± 3	9–16	17
61	23.4 ± 2.5	20.1–28.1	21.3 ± 2.5	18.1–24.3	10 ± 2	8–13	5
62	23.7 ± 2.5	20.7–28.1	21.7 ± 2.5	18.5–25.9	10 ± 1	9–11	9
63	22.9 ± 2.9	16.8–27.3	20.6 ± 2.9	14.9–25.3	11 ± 3	8–11	16
64	19.2 ± 4.2	14.7–25.7	17.2 ± 3.9	12.9–23.0	10 ± 2	9–13	5
65	18.5 ± 4.5	11.8–26.2	16.5 ± 4.3	10.0–23.6	10 ± 2	9–13	9
66	13.1 ± –	13.1–13.1	11.0 ± –	11.0–11.0	11 ± –	11–11	1
Mean	25.4 ± 6.5	11.8–48.2	23.1 ± 6.2	11.0–45.6	11 ± 3	5–21	157

Table 3. *Number of Norway spruce (*Picea abies *(L.) Karst.) stands, dominant height (single trees), density and mean age, growing on different soil types in southern (lat. 55–61°N) and northern (lat. 61–66°N) Sweden*

Soil type Group	Height, m		No. of stems ha^{-1}		Age, years		No. of stands
	Mean ± SD	Min.–Max.	Mean ± SD	Min.–Max.	Mean ± SD	Min.–Max.	
	Northern Sweden (Lat. 61–66°N)						
Coarse sand	13.06 ± 3.68	6.1–19.0	1600 ± 327	1200–2000	35 ± 5	28–43	10
Fine sand and silt	16.87 ± 2.91	11.4–22.7	1708 ± 690	1000–3708	43 ± 7	30–52	14
Light and medium clay	14.80 ±	14.8–14.8	3206 ±	3206–3206	32 ±	32–32	1
Heavy clay							0
Till clay	13.88 ± 2.18	11.6–18.7	1681 ± 322	1400–2500	33 ± 3	27–40	12
Sandy till	15.40 ± 3.01	12.0–18.5	1500 ± 283	1200–2000	37 ± 4	31–42	6
Fine sandy-silty till	13.80 ± 2.32	10.4–16.5	2383 ± 531	1800–3000	37 ± 7	30–46	6
Peat	16.50 ±	16.5–16.5	2000 ±	2000–2000	36 ±	36–36	1
Total	14.68 ± 3.22	6.1–22.7	1762 ± 563	1000–3708	37 ± 7	27–52	50
	Southern Sweden (Lat. 55–61°N)						
Coarse sand	19.64 ± 3.95	15.4–28.9	1612 ± 617	500–2592	39 ± 13	29–73	14
Fine sand and silt	22.64 ± 4.26	15.8–27.4	1157 ± 553	500–1800	55 ± 21	32–91	7
Light and medium clay	17.79 ± 5.28	11.8–29.1	2097 ± 984	600–3591	37 ± 15	25–79	16
Heavy clay	14.51 ± 1.35	12.3–16.5	2531 ± 749	1400–3722	30 ± 1	28–31	11
Till clay	22.60 ± 3.67	15.5–27.1	1031 ± 406	600–1900	51 ± 14	34–84	13
Sandy till	21.88 ± 3.85	17.1–28.9	1327 ± 846	520–3611	47 ± 14	28–74	16
Fine sandy-silty till	24.14 ± 5.20	12.1–33.2	1102 ± 572	400–2300	46 ± 13	27–77	24
Peat	18.21 ± 4.19	13.6–25.9	2182 ± 854	1000–3200	39 ± 16	32–71	6
Total	20.21 ± 4.92	11.8–33.2	1554 ± 862	400–3722	43 ± 15	25–91	107

resentation of that soil type in the overall frequency of soil types in southern Sweden.

The particle-size distribution was determined mechanically. The soil type of the sample was then classified using the above categories and grouped as described above. In the laboratory, determinations were made of pH ($CaCl_2$), using a glass electrode. Dry matter content (%) was determined by drying the soil sample to 105°C, the sample being weighed after cooling. The ignition loss (%) was determined by drying at 105°C, cooling, weighing, followed by ignition

Table 4. *Content of phosphorus (P_{tot} %), nitrogen (N_{tot} %), Calcium (Ca mg/100 g) and potassium (K mg/100 g), and pH ($CaCl_2$), dry matter content % and ignition loss % in coarse sand and till soils, and in fine sand and silt and light and medium clay groups planted with Norway spruce (* Picea abies *(L.) Karst.) on farmland. Test of significance (*t*-test)*

Locality (*n*)	P_{tot} mg/ 100 g	N_{tot} mg/ 100 g	Ca^+ mg/ 100 g	K^+ mg/ 100 g	pH	Dry matter content, %	Ignition loss, %
Coarse sand							
Northern Sweden (10)	37 ± 18	59 ± 49	250 ± 152	234 ± 140	5.32 ± 0.47	98.95 ± 0.68	2.29 ± 1.48
	ns	*	ns	ns	ns	*	ns
Southern Sweden (2)	30 ± 9	21 ± 4	322 ± 79	157 ± 24	5.02 ± 0.06	99.88 ± 0.01	0.78 ± 0.57
Fine sand and silt							
Northern Sweden (14)	62 ± 19	54 ± 22	509 ± 189	594 ± 448	5.35 ± 0.29	99.06 ± 0.20	2.41 ± 0.58
	ns	ns	ns	ns	ns	*	ns
Southern Sweden (2)	35 ± 15	51 ± 32	368 ± 184	529 ± 362	4.55 ± 0.60	99.02 ± 0.04	2.37 ± 1.24
Till clay							
Northern Sweden (11)	58 ± 21	77 ± 40	512 ± 140	989 ± 458	5.80 ± 0.42	98.25 ± 1.04	3.25 ± 1.18
	*	ns	ns	ns	***	ns	ns
Southern Sweden (12)	39 ± 17	122 ± 20	424 ± 166	1042 ± 365	4.58 ± 0.47	97.96 ± 0.92	5.71 ± 4.07
Sandy till							
Northern Sweden (6)	34 ± 20	45 ± 26	240 ± 135	335 ± 123	5.64 ± 0.33	97.29 ± 3.82	1.92 ± 1.12
	ns	**	ns	ns	***	ns	*
Southern Sweden (6)	34 ± 9	91 ± 22	299 ± 139	353 ± 189	4.35 ± 0.18	98.91 ± 0.24	4.08 ± 1.45
Fine sandy-silty till							
Northern Sweden (5)	42 ± 11	80 ± 37	476 ± 131	955 ± 688	6.04 ± 0.43	98.86 ± 0.39	3.33 ± 1.21
	ns	ns	*	ns	***	ns	ns
Southern Sweden (6)	41 ± 34	86 ± 37	290 ± 111	322 ± 225	4.45 ± 0.21	99.00 ± 0.29	3.12 ± 0.95

ns = not significant; * = significant at 5% level; ** = significant at 1% level; *** = significant at 0.1% level.

at 750°C. Loss on ignition is expressed as a percentage by weight. Soil samples were then analysed for total concentrations of P, N, K and Ca. Following wet oxidation in H_2SO_4, P and N were determined spectrophotometrically by autoanalyser, P by the modified ascorbic acid method (John, 1970) and N by the indophenol method. K and Ca were determined on an atomic-absorption spectrophotometer (Perkin-Elmer 603), K by imission. For Ca, the analyses were made in a 0.3% $LaCl_3$ solution.

Seedling study

In the present study, 56 stands were used (sediments: sand (9), light-medium clay (10), heavy clay (20); tills (4) (sandy (1), fine sandy (2) and till clay (1); peat (13)), drawn from the stands in which Bärring investigated the influence of planting method on the survival and growth of Norway spruce seedlings on farmland (Bärring, 1967). Among other results, Bärring presented data on the survival and height increment of spruces 1 to 5 years after planting. In his study, 3–4 year-old, bare-root seedlings were planted. Results from Bärring's study were used to construct height increment curves for young spruces growing on different types of mineral soil. The function used was:

$$H = A + B^*t + C^*t^2 \quad (8)$$

where
H = Plant height (cm)
t = Age, years (Plant-age when planted (4 years) + No. years after planting)
A, B, C = Parameters

The relationship between survival rates one to five years after planting, and mineral soil type, was also analysed.

Bärring's data were analysed by regression (SAS/STAT program GLM), while data from the height increment studies were subjected to non-linear regression using the SAS/STAT system for personal computers. A parametric two-sample t-test for independent groups (the TTEST-procedure in SAS) was used for testing the differences among nutrient contents, pH-values, dry matter contents and ignition losses in the soil samples. A measure of the fit of the nonlinear regressions was based on the coefficient of determination,

$$R^2_{est} = 1 - (\text{SSE/SStotal (corrected)}),$$
(Zar, 1974).

Results

The increment cores were used for estimating age at various stem heights and at breast height and for obtaining ring width measurements. The time required to reach breast height (1.3 m) was 9.1 ± 1.8 years (range 3–15 years), with some variation related to latitude (Table 1). The mean height of the dominant trees was 18.4 ± 5.1 m (range, 6.1–33.2 m; Table 1). The tallest spruces occurred in southern and middle Sweden (lat. 56–61°N). However, older stands were also more frequent in these areas than in the north, which could partly explain why trees tended to be taller in the former. The mean age of the trees examined was 41 ± 13 years (range, 25–91 years; Table 1). The mean age for spruces growing in northern Sweden was 37.1 ± 6.5 years (range, 27–52) and in southern Sweden 42.9 ± 14.8 (range, 25–91; Table 3). The mean diameter on bark at breast height was 25.4 ± 6.5 cm (range, 11.8–48.2 cm), and the bark thickness averaged 11 ± 3 mm (range, 5–21 mm; Table 2). There was a positive curvilinear association between the height (m) and dbh (cm) of the spruces (Fig. 2). This relationship varied geographically; i.e. trees growing in northern Sweden had a thicker stem at a certain stem height than those in southern Sweden, especially at low heights. Stand density varied both in northern and southern Sweden. There were no significant differences in density between stands growing in the north and in the south.

The dominant-height curve for all trees, based on a second-order polynomial model, is shown in Fig. 3. The differences in height increment over tree age between spruces growing in the south (lat. 55–56°N) and those growing in the north (lat. 65–66°N) was 7 m for 40-year-old and 10 m for 70-year-old spruces (Fig. 4). The decrease in height increment with increasing

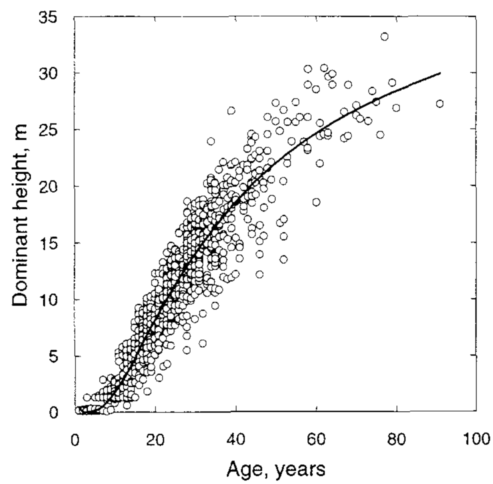

Fig. 3. Dominant height (m) for Norway spruce (*Picea abies* (L.) Karst.) planted on farmland. H = 43.862*EXP((30.507/t^2) + (−35.197*t)). R^2 = 0.928. 157 stands.

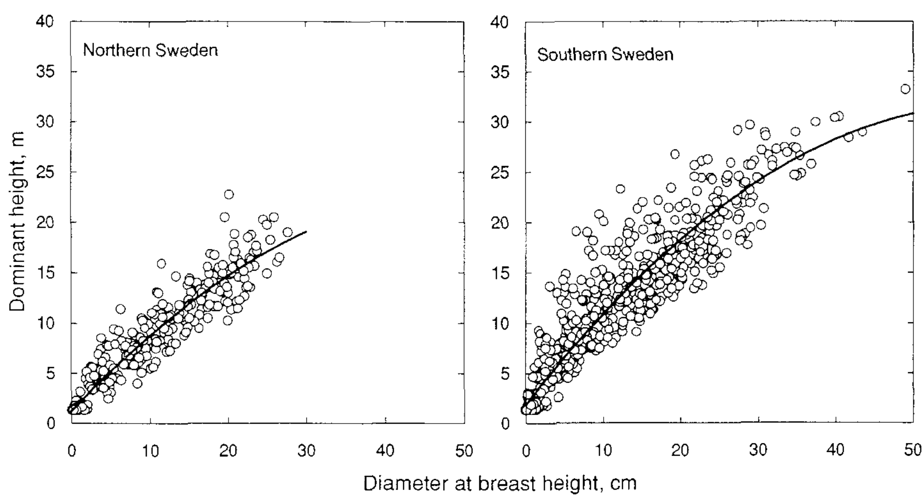

Fig. 2. Relation between dominant height (m) and breast height diameter (cm) of single trees of Norway spruce (*Picea abies* (L.) Karst.) planted on farmland in northern (lat. 61–66°N), left, and southern (lat. 55–61°N) Sweden, right. H = 1.220 + 0.834*d − 0.008*d^2, R^2 = 0.903 (Northern Sweden); H = 1.849 + 0.979*d − 0.008*d^2, R^2 = 0.888 (Southern Sweden). 50 and 107 stands respectively.

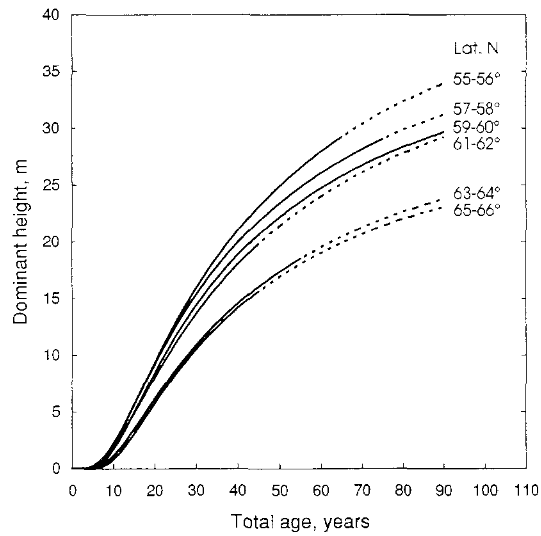

Fig. 4. Dominant height (m) of Norway spruce (*Picea abies* (L.) Karst.) planted on farmland in relation to latitude. 157 stands. Parameter and R^2 values for the function used, $H = A*EXP((B/t^2) + (C/t))$, are given in Table 5. The curves are extrapolated.

latitude was most pronounced north of 62°N. There were differences in height between trees growing north and south of lat. 62°N (Table 5). This conclusion is based both on graphical analysis and on comparison of the confidence intervals at the 95% level for the parameter values of the presented curves.

The total P content was higher in northern than in southern soils (Table 4). The content of P was highest for the fine sand and silt group. For till clay soils, there were significant differences in P content between southern and northern Sweden. The content of total N was significantly higher in coarse sandy soils in northern than in southern Sweden. In till clay and sandy and fine sandy-silty till soils, N content was higher in the south than in the north, with significant differences on sandy till soils, whereas the reverse was true for coarse sand and the fine sand and silt group; however, no statistically significant differences were demonstrated. In both southern and northern Sweden, the highest content of Ca was found in till clay soils and the lowest in sandy till soils. The content of K was highest in till clay soils, and higher for southern than for northern Sweden (Table 4). Soils from southern Sweden had lower pH-values than soils from the north. For till clay and sandy till and fine sandy-silty till soils, pH-values were significantly higher in the north. Dry-matter content in coarse sand and in the fine sand and silt group was significantly higher for northern than for southern soils. The lowest dry-matter content was found in sandy till soils in northern Sweden. Till clay soils had the highest ignition loss, especially in southern Sweden.

The fitted dominant height of the sampled spruces differed both with latitude and with soil types (Figs. 4–6). The stated differences between curves for soil types are based on graphical analysis, and on comparison of the confidence interval at the 95% level for the presented curves (Table 6). The actual height is also shown (dotted line) in Figs. 5–6.

In northern Sweden, the highest growth rate for Norway spruce was found on sandy till soils and clay till soils. The mean height of 50-year-old Norway spruces growing on sandy till soils was 20.4 m. Where this is taken as 100, corresponding relative values for the height of 50-year-old spruces on other soil types were: on coarse sandy soils 89, on soils in the fine sand and silt group 91, on till clay soils 99 and on fine sandy-silty till soils 75 (Fig. 5). The height of spruces growing on fine sandy-silty till soils differed significantly from that on sandy till soils and till clay soils (Table 6).

In southern Sweden, the tallest spruces were found on fine sandy-silty till soils and till clay soils. The height of 50-year-old spruces growing on till clay soils in southern Sweden was 25.3 m (100). Corresponding values relative to those on till clay soils, for the height of 50-year-old spruces, were: on coarse sandy soils 93, on soils in the fine sand and silt group 86, on soils in the light and medium clay group 90, for those on heavy claysoils 92, on sandy till soils 89, on fine sandy-silty till soils 96 and on peat soils 86. The corresponding relative values for 90-year-old spruces were (till clay soils—31.6 m = 100) 97, 91, 97, 101, 89, 107 and 87, respectively (Fig. 6). There were significant differences between heights for spruces growing on fine sandy-silty till soils and on all other soils; and between spruces growing on heavy clay soils and those on sandy till soils (Table 6).

Discussion

Although the rate of height growth of the 60 to 70-year-old spruces was much lower than that

Table 5. *Parameter- and* R^2*-values for the function* H = A*EXP((B/t²) +)C/t)) *(Chang, 1984) describing dominant height for Norway spruce (*Picea abies *(L.) Karst.) growing on farmland representing different latitudes (°N). Asymptotic standard error (SE) and confidence interval (95%) for the parameters are presented*

	Parameters					Parameters				
	A	B	C	R^2	No. of stands	A	B	C	R^2	No. of stands
	Lat. 55–56°N					*Lat. 61–62°N*				
Estimate	50.504	51.145	−36.332	0.956	20	43.582	55.465	−36.654	0.945	14
SE	2.214	13.757	1.664			2.601	13.575	2.056		
Conf. interv., 95% lower–upper	46.130–54.878	23.973–78.318	−39.619–−33.045			38.427–48.737	28.559–82.372	−40.729–−32.579		
	Lat. 57–58°N					*Lat. 63–64°N*				
Estimate	44.982	28.068	−33.202	0.964	47	35.335	16.495	−35.852	0.941	21
SE	0.844	5.672	0.719			2.872	46.787	4.134		
Conf. interv., 95% lower–upper	43.323–46.641	16.915–39.220	−34.617–−31.788			29.665–41.005	−75.884–108.874	−44.014–−27.690		
	Lat. 59–60°N					*Lat. 65–66°N*				
Estimate	42.637	6.016	−32.759	0.964	45	33.790	−32.210	−33.940	0.910	10
SE	1.208	20.254	1.604			6.084	97.606	8.653		
Conf. interv., 95% lower–upper	40.262–45.012	−33.817–45.848	−35.913–−29.604			21.675–45.904	−226.568–162.149	−51.170–−16.709		

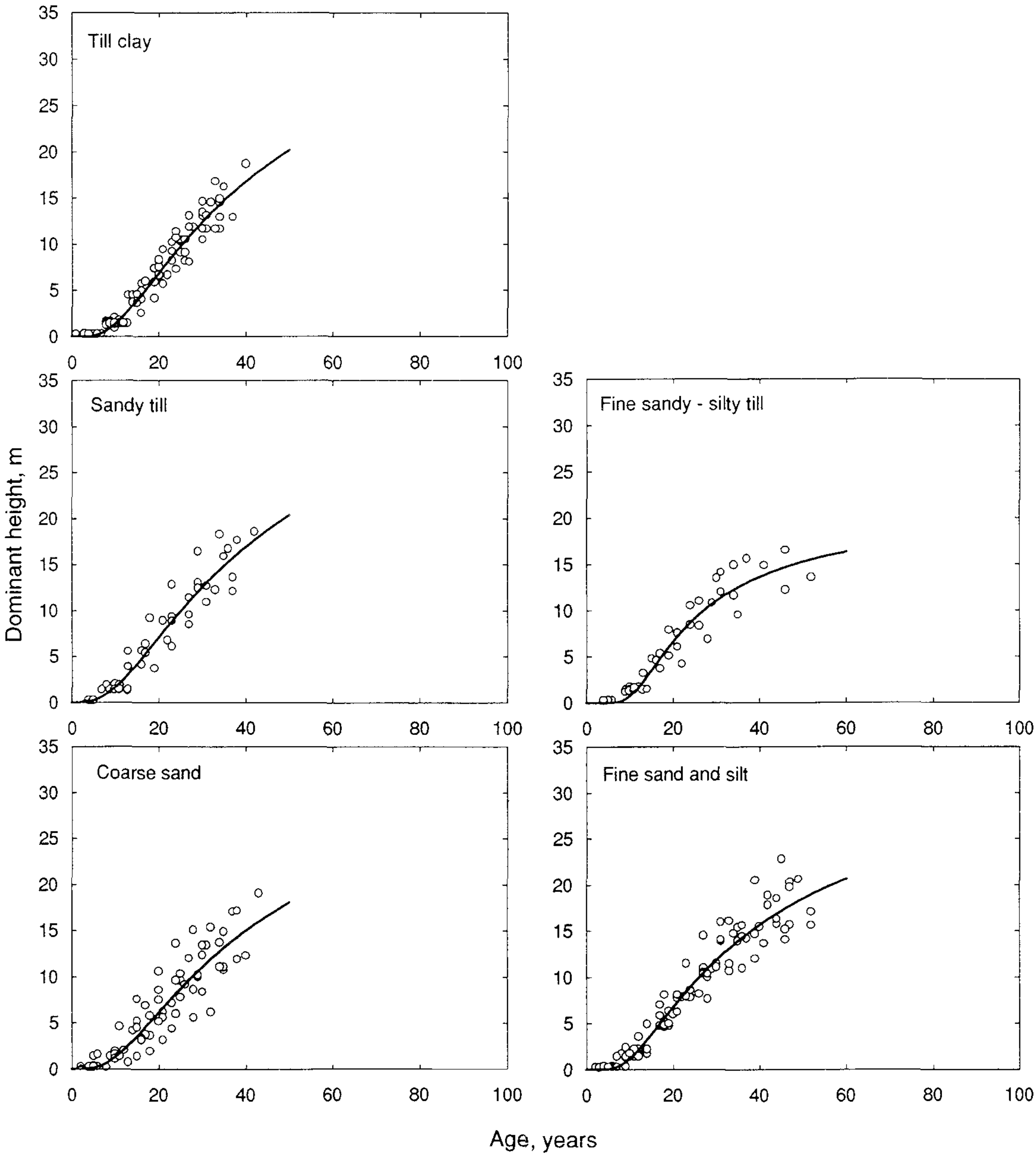

Fig. 5. Dominant height (m) of Norway spruce (*Picea abies* (L.) Karst.) planted on farmland of different soils in northern (lat. 61–66°N) Sweden. $n = 47$. Parameter and R^2 values for the function used, $H = A^*((B/t^2) + (C/t))$, are given in Table 6.

of trees under 50 years of age, the former were still growing (Fig. 3). On fertile sites, such as those on former farmland, the potential for rapid height and volume growth is great. In the present study, the mean height of Norway spruce stands was 22.7 m (range 12.3–27.4 m), which agrees with that presented by Jokela, Jack & Nowak (1988) for old-field plantations in the Allegheny Plateau region of central New York State, USA. They reported a mean height of 22.5 m (range 11.4–27.9 m) for 38 unthinned, 51-year-old Norway spruce stands. Soils on the studied area were primarily acidic, channery silt loams. On most fertile sites, however, the incidences of disease and distortion caused by wind increase substantially with age. Thus, most

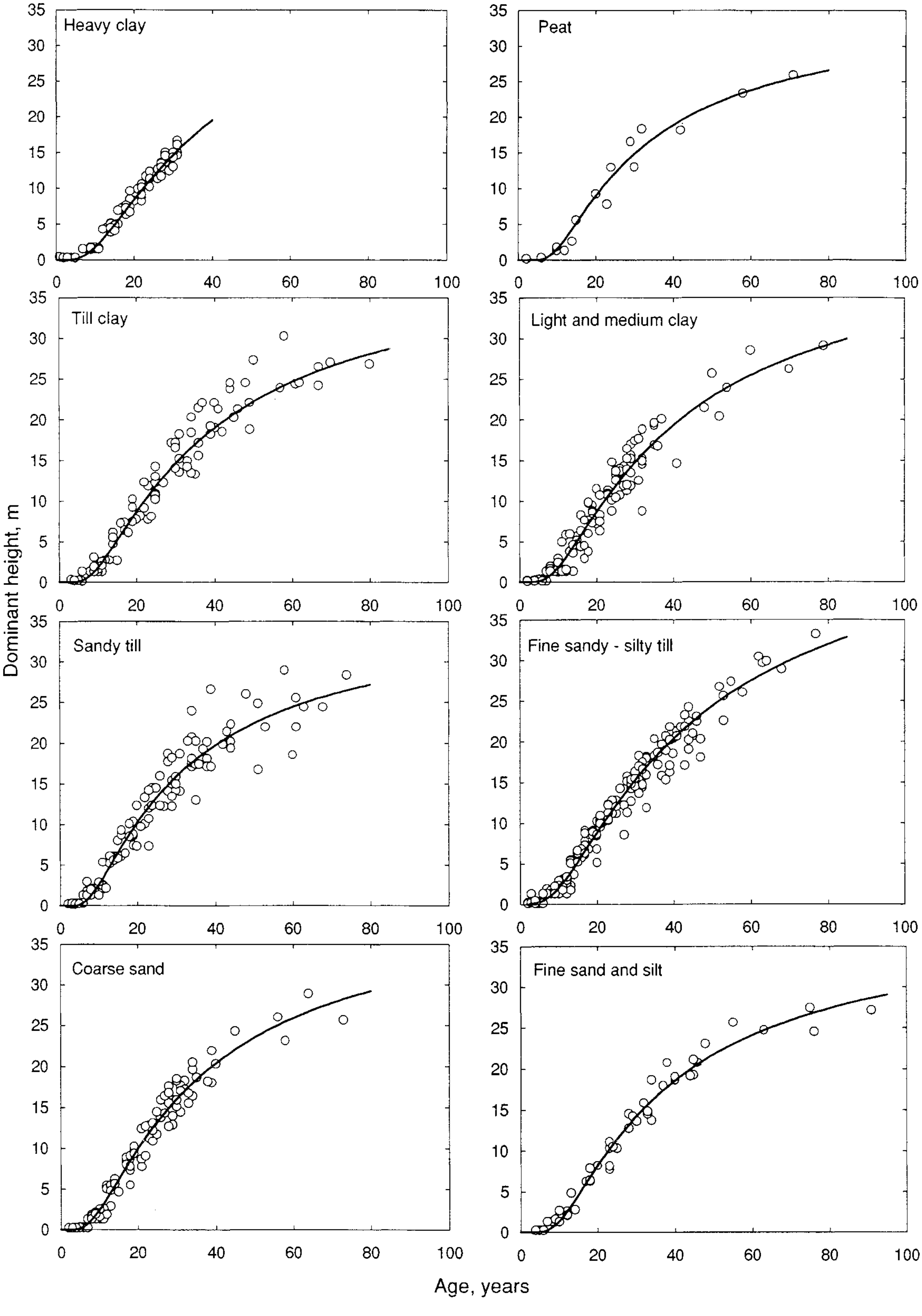

Fig. 6. Dominant height (m) of Norway spruce (*Picea abies* (L.) Karst.) planted on farmland of different soils in southern (lat. 55–61°N) Sweden. $n = 107$. Parameter and R^2 values for the function used, $H = A^*EXP((B/t^2) + (C/t))$, are given in Table 6.

Table 6. *Parameter- and* R^2*-values for the function* $H = A^*EXP((B/t^2) +)C/t))$ *(Chang, 1984) describing dominant height for Norway spruce (*Picea abies *(L.) Karst.) growing on farmland of different soil types. Asymptotic standard error (SE) and confidence interval (95%) for the parameters are presented*

	Northern Sweden (Lat. 61–66°N) Parameters				No. of	Southern Sweden (Lat. 55–61°N) Parameters				No. of
	A	B	C	R^2	stands	A	B	C	R^2	stands
	Coarse sand					*Coarse sand*				
Estimate	39.328	61.530	−40.082	0.841	10	41.979	3.723	−29.010	0.972	14
SE	5.019	26.999	4.289			1.997	24.457	2.262		
Conf. interv., 95% lower–upper	29.334–49.323	7.767–115.293	−48.622– −31.542			38.021–45.938	−44.750–52.197	−33.493– −24.527		
	Fine sand and silt					*Fine sand and silt*				
Estimate	35.765	−9.784	−32.806	0.936	14	39.856	−39.571	−29.584	0.983	7
SE	3.744	64.276	5.519			1.917	42.757	3.042		
Conf. interv., 95% lower–upper	28.344–43.186	−137.177–117.610	−43.744– −21.867			36.011–43.701	−125.331–46.189	−35.686– −23.481		
	Till clay					*Till clay*				
Estimate	42.850	32.666	−38.666	0.945	11	42.589	−10.219	−30.812	0.962	13
SE	2.725	8.202	1.848			2.448	42.761	3.359		
Conf. interv., 95% lower–upper	37.439–48.261	16.378–48.955	−41.908– −34.567			37.733–47.445	−95.045–74.607	−37.474– −24.149		
	Sandy till					*Sandy till*				
Estimate	44.118	71.071	−40.039	0.913	6	37.128	−19.686	−24.800	0.946	16
SE	8.362	76.047	8.122			2.184	34.355	3.055		
Conf. interv., 95% lower–upper	27.276–60.960	−82.096–224.237	−56.398– −23.680			32.806–41.450	−87.680–48.308	−30.847– −18.753		
	Fine sandy-silty till					*Fine sandy-silty till*				
Estimate	21.451	−211.942	−12909	0.920	6	49.751	58.534	−37.838	0.974	24
SE	4.282	123.295	10.282			1.172	6.480	0.950		
Conf. interv., 95% lower–upper	12.827–30.075	−460.269–36.386	−33.620–7.802			47.438–52.063	45.752–71.316	−39.712– −35.964		
						Light and medium clay				
Estimate						44.286	14.452	−33.492	0.943	16
SE						2.768	38.391	3.220		
Conf. interv., 95% lower–upper						38.808–49.765	−61.529–90.434	−39.866– −27.119		
						Heavy clay				
Estimate						47.711	31.156	−36.508	0.981	11
SE						1.984	3.749	1.100		
Conf. interv., 95% lower–upper						43.766–51.657	23.701–38.611	−38.695– −34.321		
						Peat				
Estimate						36.534	−72.044	−24.647	0.954	6
SE						3.666	64.038	5.227		
Conf. interv., 95% lower–upper						29.151–43.918	−201.023–56.935	−35.175– −14.120		

spruce stands on former farmland are clearfelled after growing for 80–100 years. Johansson & Karlsson (1988), who studied 17 Norway spruce stands on farmland, reported that the age at which mean annual volume increment culminated was lowest (82 years) for stands on the most fertile sites (100 = 39 m) and highest (106 years) for stands on the poorest sites (100 = 29 m). These 17 stands are included in the present study.

The northernmost of the spruce stands studied (lat. >62°N) grew markedly more slowly, both relatively and absolutely, than those growing in the south, even though the former were younger (Fig. 4). This difference is pronounced from age 20 onwards. With increasing latitude the climate becomes colder. Most of the farmland in the north is still used for agricultural purposes, with the result that the greater part of the former arable land planted with trees is in areas where agricultural crops grow poorly or where, for technical or economic reasons (small, irregular, stony areas), they are less valuable.

Norway spruces growing on sandy till and till clay soils in northern Sweden were taller than spruces growing on other soil types (Fig. 5). Especially on fine sandy-silty till soils, the trees grew slowly. The differences in height, between spruces growing on fine sandy-silty till and other soil types, were significant. As noted above, only the total content of soil nutrients was analysed (Table 4). There are no clear indications from the nutrient analyses that fine sandy-silty till soils have a lower content of nutrients than other soils. However, other abiotic factors may exist, such as climatic differences between the types of farmland on which the different soil types are represented. In southern Sweden, the difference in height between the faster-growing spruces on fine sandy-silty till soils and the slow-growing trees on the sandy till soils, peat soils and soils in the fine sand and silt group, was 2 m at 50 years of age and 4 m at 90 years of age (Fig. 6).

In Wisconsin, USA, Wilde, Mackie, Mackie & Rausch (1965) presented results for forest plantations which confirm those of the present study. They reported that fine-textured soils are capable of producing 50-year-old Norway spruce stands of site index 65 (20 m), and sandy soils stands of site index 37 (11 m). They constructed an equation expressing the minimum satisfactory content of silt and clay particles for high survival and rapid height growth. The equation is as follows: $0.3S + 0.7C > 12$ m.e.; where S is the percentage of silt particles (0.05–0.005 mm), C is the percentage of clay particles (<0.005 mm) and m.e. refers to the exchange capacity of the soil. In an example, the soil analysis showed 15% silt and 11% clay, giving m.e. = 12.2, which indicates that the texture is satisfactory for planting Norway spruce.

In the Wisconsin study, the importance of a high humidity in addition to the soil texture as an important factor for a high growth, was discussed. The higher the humidity, the taller were the spruces. On a superior clay site, Norway spruce has a high growth rate, attaining site index 80 (24 m) at 50 years of age. In the case in point, the high humidity was caused by the fog belt bordering Lake Superior. Similarly high growth rates have been reported from other stands in the fog belt of the Bay of Fundy, New Brunswick, Canada.

The results for heavy clay soils do not confirm observations made by practising foresters, who have noted that the growth rate for Norway spruce plantations older than 40 years on heavy clay soils sharply decreases. But the mean age of the spruces growing on heavy clay soils was only 30 years (range 28–31). Fitted curves show the correct height growth for spruces younger than 50 years. Relative growth rate, RGR, on height for the spruces was calculated by the formula:

$$RGR = (\ln(H_2) - \ln(H_1))/(t_2 - t_1)$$

where H_1 = height at the beginning of the period and H_2 = height at the end of the period, $t_2 - t_1$ the length of the growth period (Evans, 1972).

For northern Sweden, the mean RGR in the interval 1–10 years was highest, 0.62, for spruces growing on sandy till soils and lowest for those on till clay soils, 0.46 (Fig. 7). In the next interval (11–20 years), spruces growing on sandy till soils had the highest RGR, 0.18, and those growing on soils in the fine sand and silty group the lowest, 0.13. For southern Sweden the highest RGR in the interval 1–10 years was found for spruces growing on sandy till and fine sandy-silty till soils, 0.57, and the lowest for those growing on soils in the light and medium clay group, 0.44 (Fig. 7). Spruces growing on soils in

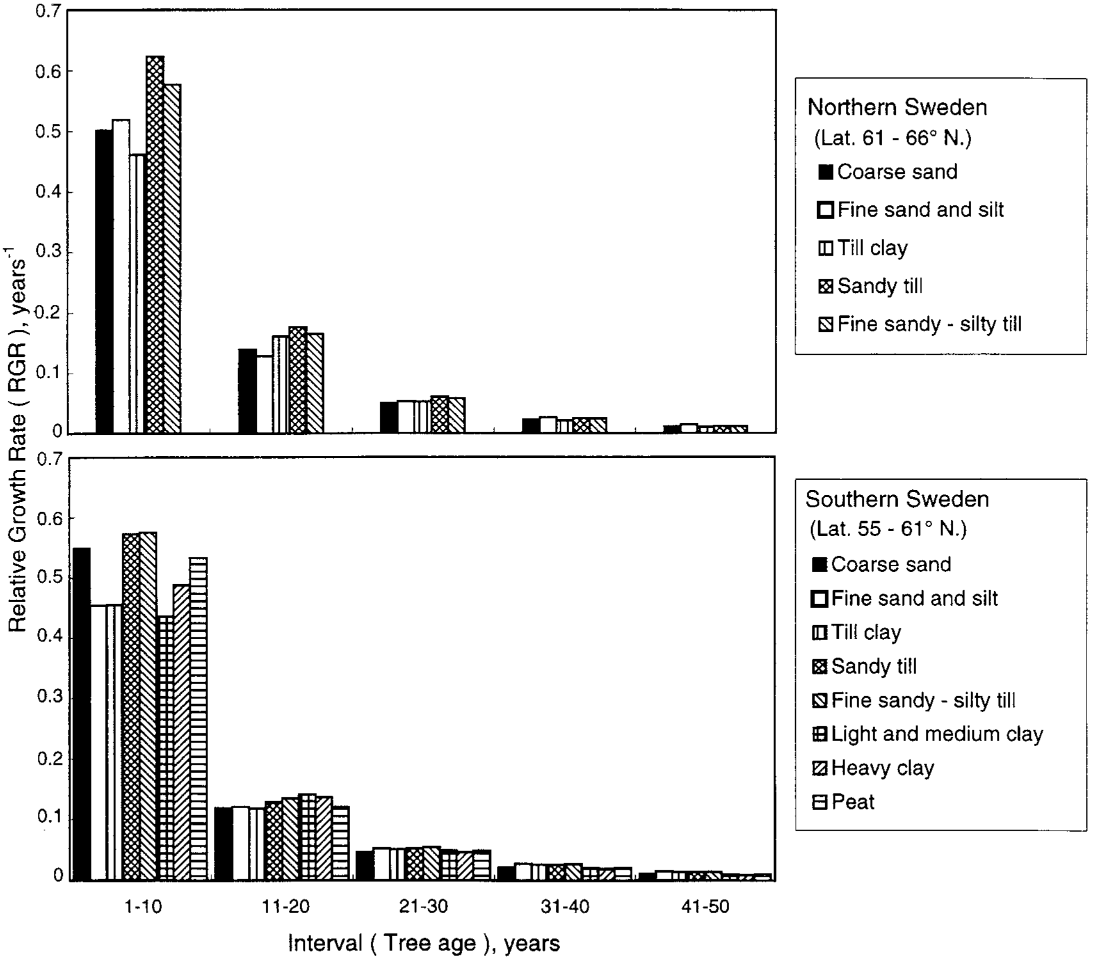

Fig. 7. Mean relative growth rate, RGR, (year^{-1}) at 10-year-interval for Norway spruces (*Picea abies* (L.) Karst.) gorwing on farmland on different soil types in northern (lat. 61–66°N) and southern Sweden (lat. 55–61°N).

the light and medium clay group had the highest *RGR*, 0.13, in the interval 11–20 years and those growing on coarse sandy soils the lowest, 0.12. The *RGR* in the intervals 1–10 and 11–20 years for spruces growing heavy clay soils, lies between the lowest and the highest values presented above. The *RGR* for heavy clay is rapidly reduced in the intervals 31–40 and 41–50 years, being 0.019 and 0.009, compared with the highest *RGR* values (soils in the fine sand and silt group), 0.027 and 0.015 (Fig. 7).

Evaluation of *RGR* values for mature trees is difficult, and irrelevant when the trees are old. The results discussed above indicate only a tendency for spruce growing on heavy soils to decline more rapidly in growth than spruce growing on other soil types.

Especially in Denmark, foresters and researchers have noted that the growth rate of Norway spruce on heavy clay soils sharply decreases at ca. 40 years of age (Hansen, 1981; Magnussen, 1983). Observations made by foresters on spruce stands planted on heavy soils in Sweden confirm the Danish results, decreasing growth rate also being reported; spruce may occasionally even cease height growth after about 40 years. Observations and experimental results indicating that in such stands growth decreases, sometimes sharply, while the incidence of damage increases, have also been reported by Bryndum (1964, 1965) and Magnussen (1983). There are many hypotheses which attempt to account for the damage and slow growth. Holmgaard (1955) and Bavngaard (1962) found that with age, spruce became increasingly sensitive to a dry period in June–July, which retarded its growth. Holstener-Jørgensen (1973) reported increasing dryness depending on clay content in the clay till soils; as the clay content increases, the availability of water decreases. It is not possible to drain the heavy clay areas by ditching (Holstener-Jørgensen & Kjersgaard, 1982). However, as the soil water content decreases there is an increase in the number of spruce that blow down before commercial thinning. The root system is too shallow, and when the soil dries out, the spruces become unstable, and highly susceptible to windthrow (Magnussen, 1983). A comparison between yield tables based on studies of Norway spruce growing on clay tills, and commonly used tables published by Møller (1933), revealed that the decline in height growth is more pronounced for spruces growing on clay. This difference was especially marked in medium-aged stands, where annual increment and thinning intensity were 5 and 10% lower, respectively, in spruce stands growing on clay compared with stands growing on other types of soil.

The ranking of till soil types, in terms of the height growth they support, did not differ between southern and northern Sweden (Figs. 5–6). In southern Sweden, the frequencies of the various types of till soils (of 40 stands) were as follows: sandy tills, 39%; fine sandy tills, 51%; silty tills, 10%. Corresponding values for northern Sweden (of 12 stands) were 40, 47 and 13%, respectively. Of the stands growing on till soils, the proportion situated on sandy and fine sandy tills was 88% in the south and 67% in the north. The fertility of these till soil areas is higher in the south, explaining why a higher percentage of farmland has been reforested there. As mentioned above, most of the farmland reforested in northern Sweden from 1940 to 1960 is situated in low-productive areas of little agricultural value, and most such stands are small, i.e. 0.5–1.0 ha. Today, plantations on farmland in the north will be made on more fertile sites and on larger areas than was the case in the 1960s.

In the present study, correlations were found between the level of the height growth curve for a given soil type and the content of any of the analysed nutrients (Table 4). However, only the total content of nutrients was determined. Had the analysis taken nutrient availability into account, stronger correlations might have been found between growth and soil type or between soil type and geographical location.

Results from Bärring (1967) indicate that the survival rate during the first five years after planting in southern and middle Sweden depends on soil type (Fig. 8). The results are based on control plots, i.e. the plots were not weeded. After five years' growth, i.e. nine-year-old plants, a survival rate $>65\%$ was shown by seedlings growing on till soils (80%) and on peat soils (67%). Mean height at an age of nine years was greatest for seedlings growing on till soils, 99.9 ± 11.8 cm, and lowest for seedlings growing on heavy clay soils, 55.2 ± 14.4 cm. The fitted heights of the seedlings growing on different soil types are shown in Fig. 9. In the study, the seedlings were not sufficiently assorted by height before planting. On the average, those planted on till soils were 10 cm taller at the time of planting, than those planted on other types of soil. However, seedlings growing on sandy soils had a growth rate similar to that of seedlings on till soils. Seedlings growing on other soil types had a slower growth rate (Fig. 9).

Bärring (1967) studied the influence of site preparation methods on the survival and growth of Norway spruce seedlings. He found that ridge planting enhanced survival three and five years after planting by 8% and increased height increment by 28 and 15%, respectively. In Fig. 10, the height increment of stands growing on control plots is compared with that of stands growing on ridge plots. The 'ridge' curve was constructed using Bärring's data. The mean difference in height between ridge and control plots five years after planting, i.e. nine-year-old plants, was found to be 11 cm (Fig. 10). This is probably a sufficient difference significantly to influence growth and survival, since tall seedlings are better able to compete with weeds. Thus competition from weeds should be moderate, i.e. weeding has been carried out successfully and only remnants of vegetation are left.

Another possible factor which may have been important, as regards the analysis of height growth on different sites, is the genetic origin of the Norway spruce plants. As noted above, only provenances which were recommended for the locality were included in the measured material. No plants of a genetic origin outside Sweden were used. The native plant material might be less valuable on some of the sites in the present

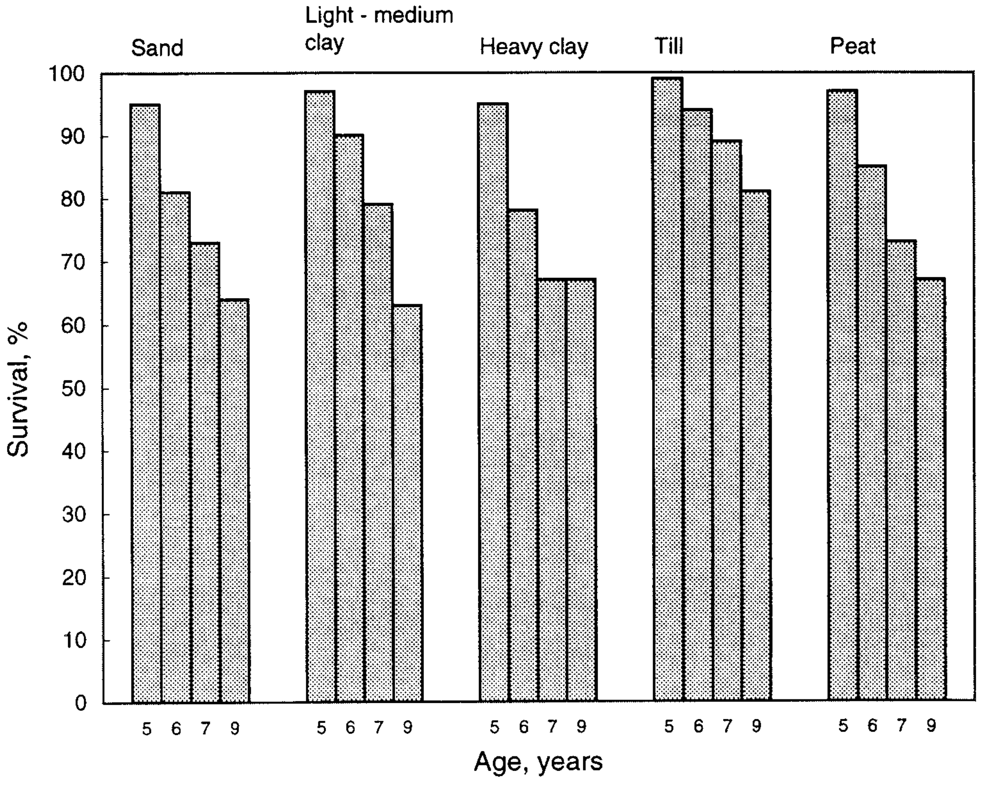

Fig. 8. Survival (%) of Norway spruce (*Picea abies* (L.) Karst.) planted on farmland on sand, the light-medium clay group, heavy clay, tills and peats. Based on data from Bärring (1967).

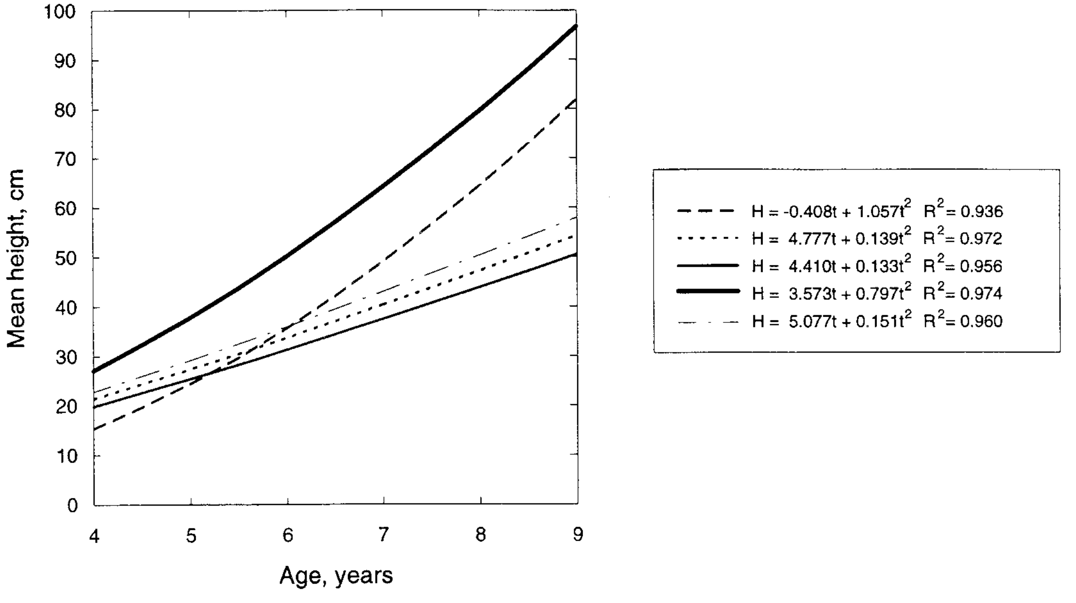

Fig. 9. Height (m) of Norway spruce (*Picea abies* (L.) Karst.) planted on farmland growing on sand $n=9$, on light-medium clay $n=13$, on heavy clay $n=20$, on till $n=4$ and on peat group $n=9$. Data taken from Bärring (1967).

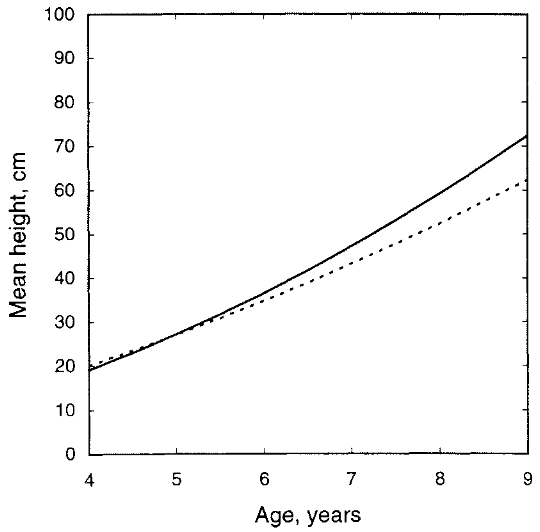

Fig. 10. Height (m) of Norway spruce (*Picea abies* (L.) Karst.) planted on farmland, on either control (---) or ridge (———) plots. $n=55$. Data taken from Bärring (1967).

study, but no such indications were given or have been observed. However, most of the plantations made in the 1970s and later contain provenances from eastern Europe. It may be of interest to analyse the height growth of these spruces after twenty years *in situ*.

A practical implication of the results presented here is the importance of soil type to successful establishment and rapid growth, with a high yield in older stands. In Sweden, foresters usually classify the site into classes of soil moisture and species occurrence in the field and bottom layers (Hägglund & Lundmark, 1977). On farmland, the soil type is the most important factor, together with the period (years) since the area was taken out of agricultural production, since weed species have a higher growth rate the longer is the interval between the last arable use and planting. The weeds will strongly compete with the forest plants. In the present study, plants and trees of Norway spruce established and grew best on soils in the light and medium clay group and on till soils. The number of weeds, and the severity of competition by the weeds with the spruces, will be reduced if the site is planted in the same year or in the spring of the year after, the field is withdrawn from agricultural production. Wilde et al. (1965) gave the same recommendations as those given above, concerning weeding and the types of soil suitable for planations. They also warned against windbreak, and injuries caused by fungi.

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