Rapport *Report*

Root biomass production in young birch stands planted at four spacings on two different sites

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ABSTRACT

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The spatial distribution of trees above ground influences on the amount of root biomass and a low root biomass might decrease the total biomass production. The amount of biomass for fractions and distribution of downy and silver birch root systems was studied including the root distribution in cardinal points. The allometric relationship between stump diameter (DSH) and stump weight and between DSH and root weight and length for the two species was quantified. The 12-year-old trees had been grown at four spacings on two sites: medium clay and fine sand soils. The dry root weight per stump differed significantly between species and spacings, but not for diameter class >5 mm and spacings. For both species the root weight was greatest at a spacing of 2.6 m on medium clay soil. The differences between cardinal points and root weight and length for all diameter classes and both birch species were not significant. Equations for estimating the stump weight, root weight and the root length from diameter at stump height (DSH) confirmed that DSH can be used as a simple variable to estimate the root biomass. Equations for estimating root biomass by DSH or diameter at breast height (DBH) is presented.

Key words: *Betula pendula*, *Betula pubescens*, Biomass equation, Root biomass, Soil types, Spacing

SAMMANFATTNING

Trädens antal och utbredning per arealenhet inverkar på dess rotbiomassa. Ett stamrikt bestånd kan medföra att produktionen av rötter hämmas om marken inte är tillräckligt näringsrik eller lider av brist på vatten. Glas- och vårtbjörkens rotsystem och dess biomassa för olika dimensioner av rötter och rotsystemets utbredning har studerats i detta projekt. I studien ingick att kvantifiera rötternas biomassa och längd beroende på i vilket väderstreck rötterna växte.

Sambandet mellan stubbdiameter (DSH) och stubbvikt samt mellan DSH och rotvikt respektive rotlängd studerades också. De planterade 12-åriga björkarna hade växt i bestånd på två jordarter: mellanlera och mo. Björkarna planterades i parceller omfattade fyra förband per art.

Rotvikten, t.s., per stubbe var signifikant olika mellan arter och förband, utanför rotdiameterklass >5 mm och förband. Hos båda björkarterna var rotvikten högst för björken planterad i 2,6 metersförband och växande på mark med mellanlera. Skillnaderna mellan väderstreck och rotvikt och rotlängd för alla rotdiameterklasser och båda björkarterna var inte signifikanta.

Framtagna ekvationer för att uppskatta stubbvikt, rotvikt och rotlängd med stöd av stubbdiameter (DSH) visade att detta är en enkel metod att uppskatta rotbiomassan. Ekvationer för uppskattning av rotbiomassa med stöd av diametern i brösthöjd (DBH) togs också fram.

CONTENT

INTRODUCTION

Reforestation of former farmland took place in Sweden in the late 1960s. The main species planted was Norway spruce (*Picea abies* (L.) Karst.). In the mid- 1980s the planting increased again, but the main species this time were broadleaves, mostly birches (*Betula pubescens* Ehrh. and *Betula pendula* Roth). When planting on a fertile site, such as former farmland, the level of tree density is important for a fresh and fast-growing stand producing high wood quality or high amounts of forest fuel. However, the wood quality, in terms of characters such as branch diameter and basic wood density, can be quite different for farmland trees compared to forest land trees. The stem density in the stand is another important factor affecting yield and wood quality. But the stem density also modifies the space and supply of nutrient and water for the roots. Knowledge of the spatial distribution of root fraction and biomass is therefore essential for a sustainable management of forest stands. The root distribution around the tree may also influence on the tree stability. Site conditions influence both horizontally and vertically root distribution (Laitakari 1934). Coarse fine roots (1-5 mm) constitute the structural root system, when the tree is 8 to 15 years old (Coutts and Lewis 1983). The horizontal distribution of roots is determined during the cleaning phase e.g. 7-15 year-old trees (Coutts 1987). The direction of growth and the differential development contribute to the final root form (Coutts 1989). Competition between individual root systems could therefore be increased if the space between the seedlings is small. The vertical extent of the root system may vary in different directions (cardinal points). In a study of Sitka spruce (*Picea sitchensis* (Bong) Carr.), the radius of the root system on leeward of the tree was found to be less than half that on the windward side (Coutts 1983). It is important to have knowledge about the spatial distribution and temporal dynamics of forest productivity in managing forest in sustainable (Chen 2002; Hall 2001).

Roots account for 15-25 % of total biomass (Harris et al. 1980) and according to Santantonio et al. (1977) the range of root biomass for individual stands extends from 9-44 % and the ratio between shoot and root biomass decreases with age and tree volume increment. No standard size or operational definition for fine roots exits, and the classification criteria vary from study to study (Hendrics et al. 2000). Most often, fine roots have been defined on the basis of diameter either <0.5 mm or <2 mm (Chen et al. 2004). The fine root biomass of single trees is difficult to determine but has been estimated to 5 % of the total root biomass (Drexhage and

Gruber 1999). More than half of the fine roots occur in the first 20-30 cm of the soil in temperate and tropical forests (López et al. 1998) and according to Harris et al. (1980) 90 % is distributed in the upper 30 cm of the soil. Methods for estimating the characteristics of root systems of young trees have been reported by Brække and Kozlowski (1977), Carlson and Harrington (1987), Langerud et al. (1988) and Canadell and Roda (1991).

Studies aimed at the prediction of root biomass for conifers and broad-leaved trees from diameter at breast height (DBH) have been reported by Drexhage and Gruber (1999), Petersson and Ståhl (2006) and Johansson (2007). Studies on the relation between diameter at stump height (DSH) and root biomass is less reported (Thies and Cunningham 1996). Harris et al. (1977) studied the relation between the biomass of root size classes and stump biomass in a hardwood stand (*Liriodendron tulipifera* L.) and a loblolly pine (*Pinus taeda* L.) forest type. They found the greatest percentage of hardwood root biomass for root size class <5 mm.

The ratio of stump biomass on total root biomass including the stump was 50%. According to Keays (1971), ”measurements of root biomass are the ecologist’s nightmare”. However, more information on root biomass and its relationship to other more easily measurable traits must be obtained. For instance, the growth rate of trees planted on farmland depends on their spacing and a relationship between foliage and root biomass could be used as a predictive tool (Johansson 2007). In addition, studies on the relationship between the root biomass of trees and stem density are needed to improve predictions of the amount of root biomass. The influence of soil type on growth of trees is another important factor that requires further attention. Estimates of tree biomass fractions including roots are the main measurements used for predicting stand growth, management planning in forest stands and modelling forest carbon uptake (Kurz et al. 1996). The above- and below-ground biomass production and the correlation between them are two factors, which influence total yield (Mäkelä 1990; Santantonio 1990). Birch, which is a light demanding species with a shallow root system, needs to develop the root system rapidly to be able to take up water and nutrients from the soil (Cheng et al. 2005). Low light intensities in birch stands might affect growth and therefore one of the key factors that could determine the way biomass is partitioned (Van Hees and Clerkx 2003).

Published results on the distribution of root biomass in diameter classes and on root length of birch planted at different spacings are scarce in the literature. The total biomass of root systems of young birch plantations has been studied among others by Ovington and Madgwick (1959), Mälkönen (1977), Petersson and Ståhl (2006) and Johansson (2007). Quantitative knowledge on the relation between above- and below-ground biomass and site conditions on farmland for birch will provide data for the management and further estimations of yield growth of this species. But, as a hypothesis, the relation between the growths of roots (biomass), the distance between the planted trees and site conditions will strongly influence the above-ground biomass growth. In the situation of a commercial use of stumps for forest fuel production the amount of root biomass could be important to estimate if the roots should are to be harvested when the stump is removed.

Based on findings reported, there are some factors which are important to study on birch:

- the relation between tree spacing and root weight has to be studied as the advantages with a dense stand for a high wood quality production might decrease the root growth as the further growth and yield of the stand is depending on the individual tree growth.
- the influence of spacing on the horizontal extent of the root system in different directions may cause weak and small roots. This factor could modify on the stability of trees and has to be studied as further growth and vitality is based on tree individual growing without disturbing factors.
- the relationship between diameter at stump height (DSH at 0.15 m) and root biomass is infrequently reported (Thies and Cunningham 1996) and its consideration can be valuable. Estimates of tree biomass from practical easily measured tree components such as stem, mostly called dimensional analysis (Whittaker and Woodwell 1968). A tool describing the relationship between diameter at stump height and breast height for root weight is valuable. Estimation of root biomass of previous cut trees by DSH is then possible. Previous competition by roots could support on the present growth of remaining trees.

OBJECTIVES

One objective was to quantify the amount of biomass for different root fractions and root distribution of silver (*Betula pendula* Roth) and downy birch *Betula pubescens* Ehrh.) planted at four spacings and growing on two soil types in an area of former farmland A second objective was to examine the allometric relationships between stump diameter (DSH) and stump weight and between DSH and root weight and length for the two species. Data from a previous field experiment (Johansson 2007) were used for the study.

MATERIAL AND METHODS

The study site was located close to Hedemora (Lat. 60° 10' N, Long. 16° 00' E, Alt. 60 m a.s.l.) in Sweden, and had been used for cattle grazing for the ten years prior to the start of the experiment. When the experiment with birches planted in different spacings on former farmland had been running for 12 years, the stands had to be felled because the user of the land wanted to use it for other purposes. Before planting the main soil type on the area was identified. Soil samples (20) were taken randomly across the experimental area (≈1 ha). Based on the soil sample data, the area clearly comprised two distinct parts close to each other. The experiment was, therefore, stratified into two blocks: one covered by fine sand soil and the other by medium clay soil. The rows were oriented in ?? direction.

After harrowing the ground, one-year-old silver and downy birch seedlings of local provenance were planted in parallels as monocultures of the two species. Totally 16 plots (8 plots of each of the two species) divided in two areas containing sand and light clay soil respectively. No replications could be made as the area was too small. There were four spacings (1.3, 1.5, 1.8 and 2.6 m) in plots of 80 seedlings (10 plants in 8 rows) spaced to farm squares. The experiment was fenced to exclude moose (*Alces alces* Lin.), roe deer (*Capreolus capreolus capreolus* Lin.) and hare (*Lepus capensis* Lin., *Lepus timidus* Lin.). The total height and the breast height diameter (DBH) of each tree were measured every autumn for the first five years, then every second year.

Estimation of stand and tree characteristics

When the trees were 12 years old, they were all felled and their height, crown length (the length of the green part of the crown), and DBH were measured. Then, five undamaged (without double tops, stem or branch damages, damaged by fungi) trees per plot were sampled for detailed measurements; these trees were representative of the diameter distribution in the plot. The trees selected represented: mean diameter, smallest diameter, largest diameter, upper and lower quartiles. For each tree, two crown diameters were taken, the first are at the widest part of the crown and the second one at right angle. The fresh weights of the stem, branches and leaves were measured in the field by a portable scale with a precision of ±0.1 kg. Details of the sampling method and dry weight estimation are presented in Johansson (2007).

Stump and root biomass estimation

In Table 1, main characteristics of the plots are presented. Stumps and their roots of the sampled trees were used for further estimations. The height of a stump was 15 cm. The diameter of the stumps at a height of 15 cm above ground level was measured. Before the stumps were removed, the north direction was marked on them. Stumps were removed carefully from the soil using an excavator and spades. The roots were separated from the soil by hand sorting. The finest roots, diameter < 1 mm, were not sampled because it was too time-consuming and laborious to identify them, and it was difficult to be sure that all the fine roots were collected. Stumps and roots were then transported to the laboratory where the roots were separated from soil by wet sluicing. The stump including the roots was then divided into four quadrants, each centred on a cardinal point (Figure 1).

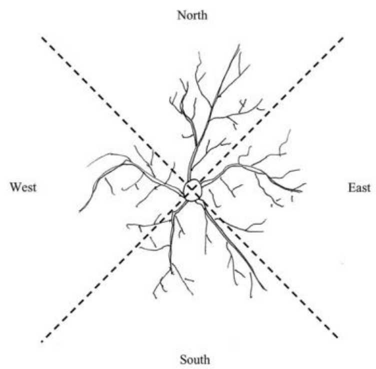

Figure 1. Cardinal sectors delimited for the analyses of birch root systems

If a part of a root was found in the neighbouring quadrant it was recorded as belonging to the quadrant from which it originated. The roots were cut into segments according to the following diameter classes, 1-2, 2-5, 5-10 and 10-20 mm. As the total number of root segments per stump in the 10-20 mm class was low (<10) or missing, the following root classes were finally retained: total, 1-2, 2-5, and >5 mm. Then, the length of each root segment was measured and root length summed to give values per diameter class and quadrant. The fresh weights of the root segments and stumps were measured in the laboratory. The root segments and stumps were then dried at 105° C for 4-5 days and their dry weight was determined.

Table 1. Main characteristics of birch plots on abandoned farmland (After Johansson, 2007)

Spacing m	Soil type	Diameter, DBH, mm	Diameter, DSH[1)], mm	Living trees, %[2)]	Height, m	Weight, kg d.w. Trees[3)]	Stumps	%[4)]
				Betula pendula Roth				
1.3*x*1.3	Fine sand	56±2	88±1	95	7.21±0.17	9.96±2.37	0.76±0.20	7
1.5*x*1.5	Fine sand	52±2	95±1	99	7.82±0.17	10.64±2.29	0.74±0.12	7
1.8*x*1.8	Fine sand	64±2	79±1	100	8.20±0.12	9.78±3.48	0.77±0.32	7
2.6*x*2.6	Fine sand	66±2	93±1	97	7.10±0.15	11.44±2.06	0.77±0.19	6
1.3*x*1.3	Medium clay	47±2	74±1	95	6.74±0.17	7.59±2.31	0.68±0.15	8
1.5*x*1.5	Medium clay	62±2	85±1	100	8.21±0.14	9.92±2.13	0.87±0.15	8
1.8*x*1.8	Medium clay	62±1	92±1	100	8.00±0.10	10.92±2.68	0.86±0.15	7
2.6*x*2.6	Medium clay	70±3	112±1	97	7.70±0.19	17.58±3.60	1.29±0.22	7
				Betula pubescens Ehrh.				
1.3*x*1.3	Fine sand	39±1	75±1	96	5.80±0.17	7.25±2.07	0.43±010	5
1.5*x*1.5	Fine sand	38±1	71±1	97	5.88±0.12	5.39±1.41	0.51±0.15	9
1.8*x*1.8	Fine sand	43±2	67±1	96	5.79±0.15	6.42±1.61	0.41±0.11	6
2.6*x*2.6	Fine sand	52±2	83±1	81	6.07±0.12	8.99±1.52	0.66±0.08	7
1.3*x*1.3	Medium clay	27±1	51±1	99	4.44±0.09	2.24±0.35	0.20±0.03	8
1.5*x*1.5	Medium clay	51±2	75±1	100	6.89±0.14	8.00±2.61	0.54±0.18	6
1.8*x*1.8	Medium clay	39±2	59±1	99	5.20±0.13	4.18±1.25	0.53±0.18	11
2.6*x*2.6	Medium clay	58±2	83±1	99	6.31±0.16	9.64±1.51	0.77±0.10	7

1) DSH = diameter at stump height
2) Living trees, % = Percentage living trees by total number of planted
3) Trees = stem+branches+leaves
4) % = Percentage stump weight based on total above-ground biomass (tree + stump)

Statistical analysis

Analysis of variance (ANOVA) was used to evaluate the differences at stand level between species, spacings, soil types and cardinal sectors.

The allometric relationships between DSH, stump biomass, root biomass and root length separated by soil type and birch species were also investigated. For foresters, the use of allometric relationships between DBH and DSH and between DBH and root biomass for each species were made. Data from both soil types were added as one site in the model.

The following power model is often used for examining allometric relationships (cf. Johansson 1999; Kittredge 1944; Satoo and Madgwick 1985; Payandeh 1981):

$Y = \beta_0 X^{\beta_1}$

where:

X is DBH or DSH (mm), β_0 is the intercept coefficient and β_1 is the slope coefficient.

The SAS/STAT Program for PCs (Anon 2006) was used for the analyses. The level of significance well hypothesis acceptance was $P \leq 0.05$ throughout the study. Residuals of all regressions were normally distributed according to normal probability plots of residuals. The goodness fit of the non-linear regressions was evaluated on the basis of the coefficient of determination R^2 (Zar 1999): $R^2 = 1 – (SSE/Sstotal (corrected))$.

RESULTS

Silver birches on all plots were taller than downy birches and also the mean diameter and dry weights of trees and stumps were larger (Table 1). Most of the planted seedlings were still alive (81-100%).

The root weight per stump was greatest at a spacing of 2.6 m for silver and downy birches and the greatest values recorded (2.59 and 1.33 kg d.w. respectively) were observed on medium clay soils (Table 2). The percentage of fine roots (1-2 mm) expressed as a proportion of total root weight was highest, 36-45 % at a spacing of 1.5 m for both species and on both soil types for silver birch and on fine sand for downy birch but at spacing of 1.3 m for downy birch on medium clay soil (see Table 2). The root length was greatest at a spacing of 2.6 m for both species and on both soil types (Table 3).

As shown in Table 2 no significant interaction effects between species, spacings and soil types explains root attributes variations. There were significant differences for root weight of different diameter classes betweem species and spacings except for roots >5 mm between spacing (Table 4). Root length including all diameter classes differed significantly between species and spacings but not between spacing for roots >5 mm (Table 2).

In Table 5 the means of root weight and root length for the different cardinal sectors are presented. The differences observed between sectors for root weight and root length, whatever the diameter class considered were not significant. The ANOVA test is not presented.

Table 2. Dry weight (kg d.w.± SE) per root diameter class for birch (Betula pendula Roth and Betula pubescens Ehrh.) growing on abandoned farmland area at different spacings.

Diameter class, mm	Spacing, m 1.3*x*1.3	1.5*x*1.5	1.8*x*1.8	2.6*x*2.6	Mean, %
		Betula pendula Roth			
	Fine sand				
1-2	0.29±0.03	0.36±0.08	0.28±0.08	0.55±0.13	
2-5	0.53±0.15	0.52±0.11	0.59±0.30	0.73±0.20	
>5	0.18±0.18	0.09±0.03	0.13±0.10	0.38±0.33	
Total	**1.00**	**0.97**	**1.00**	**1.66**	
%[1)]	30	37	28	33	32
		Medium clay			
1-2	0.37±0.07	0.40±0.08	0.50±0.12	0.67±0.13	
2-5	0.52±0.20	0.52±0.14	0.89±0.33	1.31±0.24	
>5	0.23±0.22	0.16±0.06	0.45±0.18	0.61±0.22	
Total	**1.12**	**1.08**	**1.84**	**2.59**	
%[1)]	33	37	27	26	31
Mean, %[2]	31	37	27	29	
		Betula pubescens Ehrh.			
		Fine sand			
1-2	0.26±0.06	0.24±0.07	0.22±0.07	0.41±0.05	
2-5	0.48±0.17	0.30±0.16	0.37±0.11	0.61±0.08	
>5	0.09±0.03	0.07±0.06	0.11±0.11	0.13±0.07	
Total	**0.83**	**0.61**	**0.70**	**1.15**	
%[1)]	31	39	31	36	34
		Medium clay			
1-2	0.26±0.06	0.35±0.12	0.24±0.06	0.40±0.07	
2-5	0.37±0.16	0.56±0.21	0.21±0.07	0.63±0.20	
>5	0.01±0.01	0.17±0.10	0.06±0.03	0.30±0.14	
Total	**0.64**	**1.08**	**0.51**	**1.33**	
%[1)]	41	32	41	30	36
Mean, %[2]	36	35	36	33	

1) Fine roots (1-2 mm contribution to total root weight (in %)
2) Mean % for the species and spacing

Table 3. Root length (m ± SE) root diameterclass^{-1} for birch (Betula pendula Roth and Betula pubescens Ehrh.) growing on abandoned farmland, at different spacing.

Diameter class, mm	Spacing, m 1.3*x*1.3	1.5*x*1.5	1.8*x*1.8	2.6*x*2.6	Mean, %
		Betula pendula Roth			
		Fine sand			
1-2	5.58±0.60	6.42±1.57	5.27±1.48	10.69±2.71	
2-5	2.43±0.75	2.53±0.54	2.78±1.27	3.67±1.00	
>5	0.18±0.21	0.09±0.01	0.15±0.09	0.70±0.65	
Total	**8.19**	**9.04**	**8.20**	**15.06**	
%[1]	68	71	64	71	69
		Medium clay			
1-2	5.53±1.18	5.71±1.03	7.10±1.77	11.31±2.27	
2-5	1.99±0.83	2.37±0.47	3.33±1.23	4.91±0.68	
>5	0.33±0.12	0.37±0.16	0.50±0.19	0.57±0.16	
Total	**7.85**	**8.45**	**10.93**	**16.79**	
%[1]	70	68	65	67	67
Mean, %[2]	69	69	65	69	
		Betula pubescens Ehrh.			
		Fine sand			
1-2	4.83±1.28	6.10±1.43	4.77±1.42	7.83±1.02	
2-5	2.14±0.76	2.55±0.83	2.11±0.67	2.84±0.33	
>5	0.13±0.03	0.09±0.05	0.15±0.12	0.13±0.05	
Total	**7.10**	**8.74**	**7.03**	**10.80**	
%[1]	68	70	68	73	70
		Medium clay			
1-2	2.71±0.35	5.55±1.82	3.80±1.09	7.89±1.91	
2-5	0.95±0.33	2.57±1.00	1.19±0.47	3.23±1.06	
>5	0.01±0.00	0.18±0.07	0.10±0.05	0.37±0.16	
Total	**3.67**	**9.30**	**5.09**	**11.49**	
%[1]	74	60	75	69	69
Mean, %[2]	71	65	71	71	

1) Fine roots (1-2 mm contribution to total root length (in %)
2) Mean % for the species and spacing

Table 4. Differences between species, soil types and spacings for of root weight and root length of different root diameter classes: results from ANOVA.

	Root Weight											
Source of variation	Total			1-2 mm			2-5 mm			>5 mm		
	Df	*F*	*p*	Df	*F*	*p*	Df	*F*	*p*	Df	*F*	*p*
A (Species)	1	8.74	0.0043	1	9.86	0.0026	1	7.18	0.0094	1	6.80	0.0129
B (Spacings)	3	3.96	0.0119	3	4.72	0.0049	3	2.91	0.0410	3	1.05	0.3833
C (Soil type)	1	2.31	0.1332	1	2.20	0.1429	1	1.20	0.2767	1	0.49	0.4882
A*x*B	3	0.90	0.4449	3	0.43	0.7325	3	0.94	0.4277	3	0.59	0.6249
A*x*C	1	1.34	0.2510	1	0.74	0.3944	1	1.14	0.2901	1	0.03	0.8591
B*x*C	3	0.70	0.7378	3	0.27	0.8473	3	0.65	0.5886	3	0.16	0.9243
A*x*B*x*C	3	0.66	0.5809	3	0.49	0.6906	3	0.96	0.4191	3	0.20	0.8986
Residual	64			64			64			38		

	Root length											
Source of variation	Total			1-2 mm			2-5 mm			>5 mm		
	Df	*F*	*p*	Df	*F*	*p*	Df	*F*	*p*	Df	*F*	*p*
A (Species)	1	5.37	0.0237	1	5.23	0.0255	1	3.88	0.0533	1	5.88	0.0202
B (Spacings	3	6.28	0.0008	3	7.66	0.0002	3	3.46	0.0213	3	0.41	0.7463
C (Soil type)	1	0.03	0.8692	1	0.10	0.7583	1	0.02	0.8813	1	0.02	0.8872
A*x*B	3	0.62	0.5921	3	0.59	0.6225	3	0.72	0.5434	3	0.19	0.9004
A*x*C	1	0.81	0.3724	1	0.72	0.3983	1	0.79	0.3760	1	0.15	0.7002
B*x*C	3	0.30	0.8226	3	0.23	0.8750	3	0.68	0.5703	3	0.08	0.9704
AxB*xC*	3	0.20	0.8967	3	0.19	0.9012	3	0.18	0.9127	3	0.56	0.6457
Residual	64			64			64			38		

Table 5. Mean dry weight (kg d.w. ± SE) and length (m ± SE) of roots of birch (Betula pendula Roth and Betula pubescens Ehrh.) growing on abandoned farmland area, at different spacings for each cardinal sector.

Cardinal points	Dry weight	Root length	Dry weight	Root length
	Betula pendula Roth		*Betula pubescens* Ehrh.	
	Fine sand			
North	0.32±0.07	2.93±0.65	0.23±0.05	2.30±0.46
East	0.31±0.07	2.43±0.73	0.23±0.05	2.40±0.48
South	0.27±0.06	2.56±0.57	0.17±0.04	1.92±0.40
West	0.28±0.07	2.20±0.53	0.18±0.04	1.80±0.37
	Medium clay			
North	0.47±0.11	2.93±0.69	0.22±0.05	1.78±0.41
East	0.39±0.08	2.68±0.61	0.20±0.04	1.52±0.39
South	0.37±0.08	2.73±0.63	0.22±0.04	1.71±0.49
West	0.39±0.09	2.66±0.66	0.25±0.10	2.13±0.48

The ratio of root dry weight on shoot dry weight (R:S) for the both birch species varied with soil type. The ratio was greater on medium clay soil than on fine sand for both species (Figure 2). Birches growing on medium clay soil had higher ratios than birches growing on fine sand soil. The highest ratio was found for spacing 2.6x2.6 m for both soil types and species. On medium clay, silver birch had the greatest mean ratio, 0.15±0.02, at 1.8 spacing and downy birch 0.14±0.03, at 2.6 m. But there were only significant differences between R:S for the two soils (Table 6).

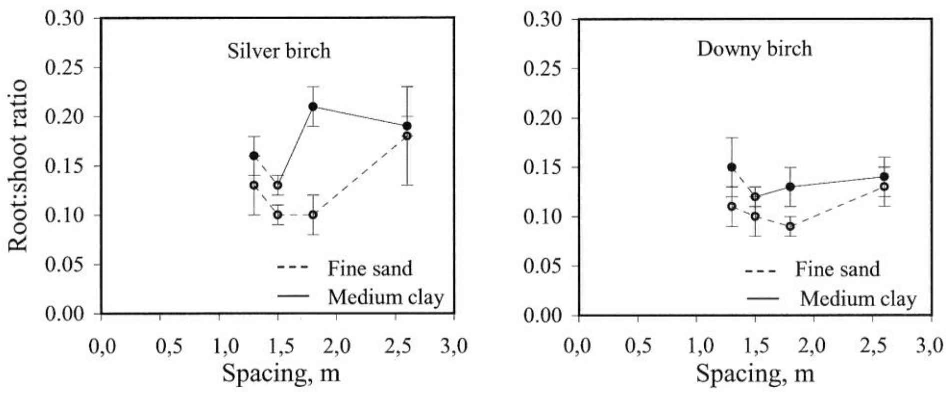

Figure 2. Root/shoot ratio for silver (Betula pendula Roth) ● and downy (Betula pubescent Ehrh.) ○ birches growing on fine sand - - - and medium clay soil —— .

Table 6. Differences between species, soil types and spacings for Root: Shoot ratio as exhibited by ANOVA.

		Root Shoot Ratio	
Source of variation	Df	F	p
A (Species)	1	0.06	0.8124
B (Soil type)	1	9.33	0.0025
C (Spacings)	3	2.25	0.0907
A*x*B	1	0.06	0.8124
A*x*C	3	0.41	0.7462
B*x*C	3	1.08	0.3641
A**x**B*x*C	3	0.35	0.7863
Residual	64		

The allometric model produced a good fit to the data. The relationship between DSH and stump weight was very similar for the two species in each soil type (Figure 3) and the coefficient of determination was 0.90-0.97 (Table 7). The coefficient of determination was 0.81-0.97 between DSH and root weight and 0.74-0.95 between DSH and root length (Table 7). At the same DSH, root weights and lengths were greater for downy birch than for silver birch (Figure 4). The model describing the relationship between DBH and DSH and root weight (Figure 5) fitted the data well (Table 7). The coefficients of determination were 0.91-0.96.

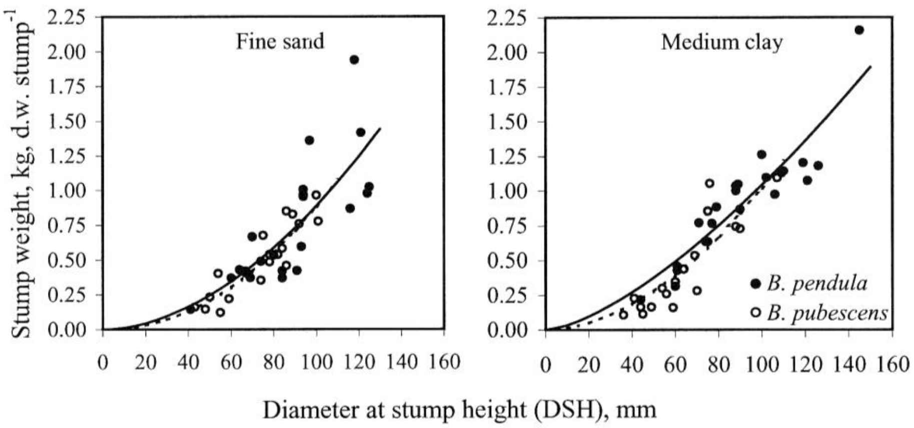

Figure 3. Relations between diameter at stump height (DSH), mm, and stump weight, kg, for silver (Betula pendula Roth) —— and downy birch (Betula pubescens Ehrh.) - - - growing on fine sand soil, (left), and, on medium clay soil (right).

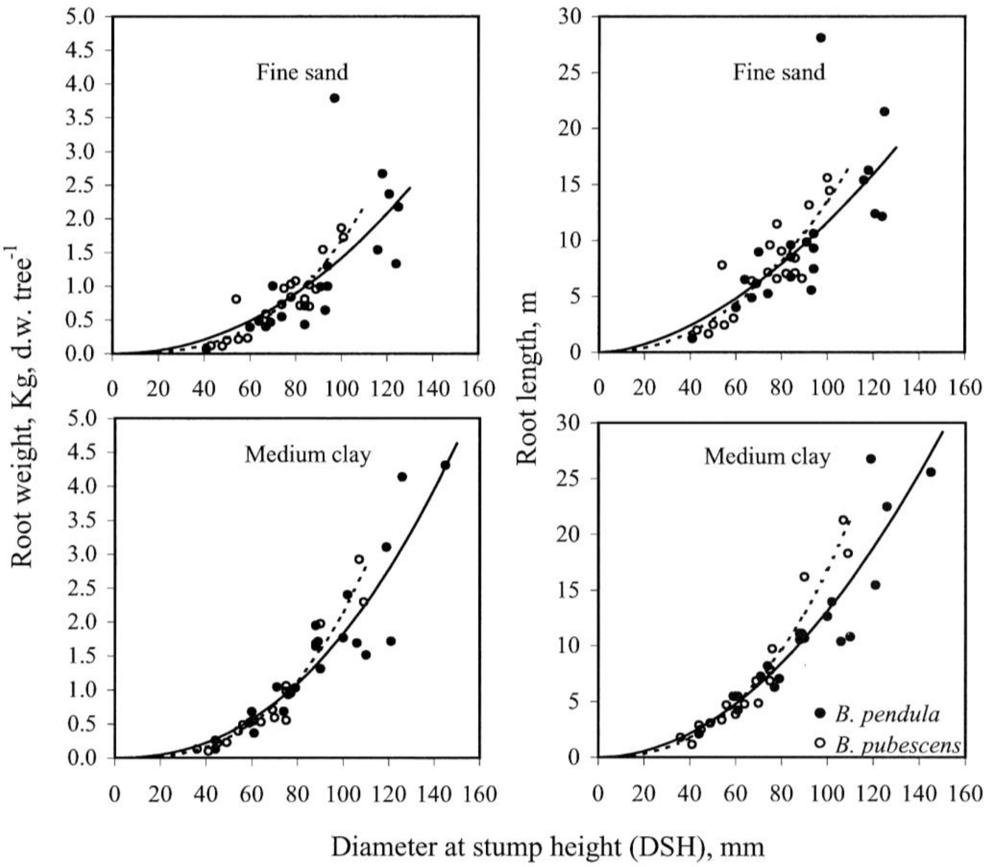

Figure 4. Relations between diameter at stump height (DSH), mm, root weight, kg d.w. tree^{-1}, (left), and root length, m tree^{-1}, (right), for silver (Betula pendula Roth) —— and downy birch (Betula pubescens Ehrh.) - - - , growing on fine sand soil (upper panels) and on medium clay soil, (lower panels).

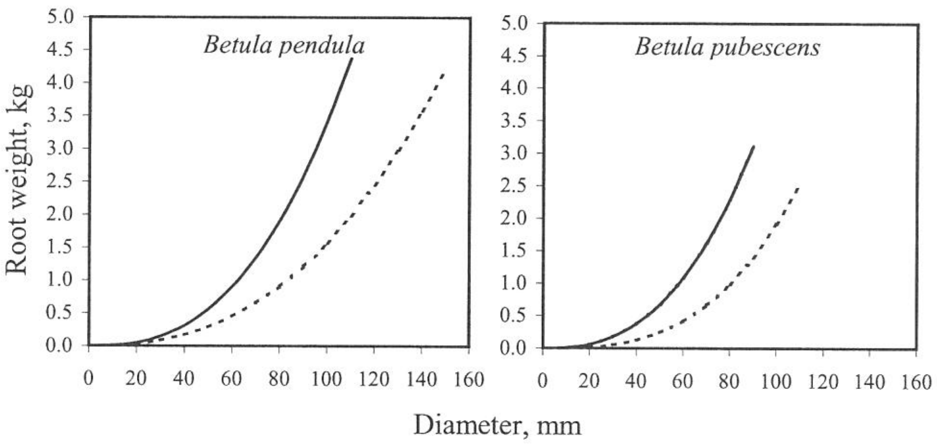

Figure 5. The relationship between root weight, kg d.w. tree^{-1} diameter at breast height (DBH) —— , and diameter at stump height (DSH) - - - , mm, and, for silver (Betula pendula Roth) left, and downy birch (Betula pubescens Ehrh.) right, based on data pooled for both soil types per specie.

Based on the number of surviving birches per plots, the total root biomass per hectare was calculated. The root biomass per hectare was greater for silver birch, 2.4-6.3 tonnes ha^{-1}, than for downy birch, 1.4-4.7 tonnes ha^{-1}, Figure 6. Moreover, the silver birch root biomass was greater for stands growing on medium clay (3.7-6.3) than on fine sand (2.4-5.6). For downy birch, the biomass was almost the same on the two soil types. Since there are more stems in stands with a spacing of 1.3 than 2.6 m the root biomass ha^{-1} is greatest for the densest stand. If the biomass per hectare is based on a survival of 100 % the biomass for silver birch ranged between 2.5 and 6.6 and for downy birch between 1.6 and 4.9 tonnes ha^{-1}.

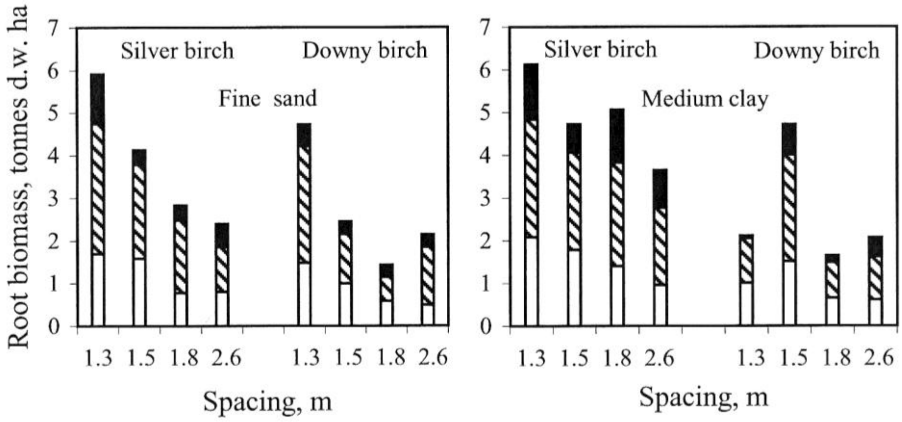

Figure 6. Total root biomass (tonnes d.w. ha^{-1}) upper panels and total root length (m ha^{-1}) lower panels for silver (Betula pendula Roth) and downy birch (Betula pubescens Ehrh.) growing at different spacings on fine sand and medium clay soil. □ 1-2mm, ◪ 2-5 mm and ■ >5 mm diameter class.

Table 7. Estimated parameters and their asymptotic standard errors for 12 tested models, examining the relationship between stump diameter, mm, and observed stump and root biomass, kg d.w., and root length, m, for silver (Betula pendula Roth.) and downy (Betula pubescens Ehrh.) birch growing on farmland. For each model the coefficient of determination (r^2) and root mean square error (Rmse) for biomass estimations are given. Four additional equations are given the root weight to DBH and DSH for each species with data from both soil types pooled.

No.	Soil type	*Y*	*X*	β_0	SE	β_1	SE	Rmse	r^2
Stump diameter – Stump weight									
				Betula pendula Roth					
1	Fine sand	Stump weight	DSH	1.8x10^{-4}	3.5x10^{-4}	1.8465	0.4210	0.0843	0.90
2	Medium clay	Stump weight	DSH	11.9x10^{-4}	5.7x10^{-4}	1.4713	0.1718	0.0317	0.97
				Betula pubescens Ehrh.					
3	Fine sand	Stump weight	DSH	5.7x10^{-5}	7.5x10^{-5}	2.0947	0.2948	0.0124	0.96
4	Medium clay	Stump weight	DSH	18.7x10^{-5}	22.0x10^{-5}	1.8678	0.2644	0.0280	0.93
Stump diameter – Root weight									
				Betula pendula Roth					
5	Fine sand	Root weight	DSH	6.1x10^{-5}	1.9x10^{-4}	2.1791	0.6628	0.4703	0.81
6	Medium clay	Root weight	DSH	4.8x10^{-5}	6.4x10^{-4}	2.2906	0.2793	0.2306	0.95
				Betula pubescens Ehrh.					
7	Fine sand	Root weight	DSH	3.5x10^{-6}	6.3x10^{-5}	2.8372	0.3978	0.0472	0.95
8	Medium clay	Root weight	DSH	4.6x10^{-5}	4.3x10^{-5}	2.8358	0.2047	0.0397	0.97
				Stump diameter – Root length					
				Betula pendula Roth					
9	Fine sand	Root length	DSH	4.1x10^{-3}	9.6x10^{-3}	1.7264	0.5009	21.7798	0.86
10	Medium clay	Root length	DSH	1.5x10^{-3}	1.6x10^{-3}	1.9710	0.2274	7.7239	0.84
				Betula pubescens Ehrh.					
11	Fine sand	Root length	DSH	5.2x10^{-4}	8.9x10^{-4}	2.2072	0.0009	4.4358	0.74
12	Medium clay	Root length	DSH	1.9x10^{-4}	1.3x10^{-4}	2.4734	0.1584	1.7793	0.95
				Stump and breast height diameter – Root weight					
				Betula pendula Roth					
13		Root weight	DBH	2.0x10^{-5}	2.5x10^{-5}	2.6160	0.2845	0.2642	0.91
14	Pooled	Root weight	DSH	1.9x10^{-5}	2.4x10^{-5}	2.4583	0.2699	0.2518	0.91
				Betula pubescens Ehrh.					
15		Root weight	DBH	2.5x10^{-5}	2.0x10^{-5}	2.6071	0.1834	0.0515	0.96
16	Pooled	Root weight	DSH	2.0x10^{-6}	2.1x10^{-6}	2.9895	0.2302	0.0583	0.95

DISCUSSION

In young and dense birch stands an early cleaning of trees is essential if a maximal individual growth is desired. Based on findings of the present study, there are relations between the spacing of trees and below-ground biomass growth. Individual 12-year-old birches growing in at a wide spacing (2.6 x 2.6 m) had a markedly greater below-ground biomass than birches growing at smaller spacings. In the same way, the root length for both species at both soil types was greatest for the largest spacing 2.6 m. In practice, the difference in competition between trees as a result of different spacings, was already obvious when considering diameter growth or height development according to the previous study (Johansson 2007). The downy birch root weight and length were greater than that of silver birch at the same DSH (>80 mm) when the birches were growing on the same type of soil or at least on the two types considered here. The reasons for the low root biomass of downy birch at 1.3 m spacing on medium clay soil are not apparent from what is known about conditions in the field. No damage was found and most of the birches had survived (99%). No other characteristics could explain the phenomenon.

In the present study the horizontal distribution of roots (length and biomass) in different directions around the tree did not differ significantly. Among the few published studies on spatial root distribution, Tubbs (1977) studied root-crown relation of young sugar maple (*Acer saccharum* Marsh.) and yellow birch (*Betula allehagensis* Britton) growing on forest land. The birch diameter at breast height ranged from 21 to 152 mm and the soil type was a sandy loam podsol. The root length extension considered the distance between the stem base into the root end in different cardinal sectors was measured. He concluded that the average lengths of the roots were greater than the average crown width. He observed that the root distribution was fairly regular. There are two possible explanations, which could be equal for the same conditions in the present study. Since the trees were equally spaced in all directions, the competition could be considered the same irrespective of distance between neighbours. Alternatively, the above-ground competition between the trees at different spacings had not reached the critical point when the stand was retarded the growth. Puri et al (1994) examined the distribution of coarse roots in Eastern cottonwood (*Populus deltoides* Bartram ex Marsh.) stands planted at spacings of 2*x*2, 4*x*4 and 6*x*6 m. They found that the roots were symmetrically distributed when the trees were planted 6 m apart but at the other spacings the distribution was asymmetrical with longer roots in the westerly and northerly directions for 4 and 2 m spacings, respectively. Based on the findings in the present study the difference in competition as a result of different spacings, in practice, was only apparent when considering diameter growth or height development (Johansson 2007). Reporting on the above-ground features of the studied stands, Johansson (2007) recorded no significant relationships between crown width and spacing. The projected leaf area (PLA) did not either differ between spacings. The lengths of the roots in the present study were greater than the crown width, see Johansson (2007). In Tubbs' study, irregularities in crown width caused by competition were not shown by the root distribution. But if a tree was leaning, the root system compensate by a greater development in the opposite direction of leaning of the tree. In the present study the root length and weight were significantly greater for wider spacings but the crown width was not significantly greater for larger spacings (Johansson 2007).

Few comparable studies have been published on the relation between root biomass, rootlength and DSH for young downy and silver birches. In a nursery study lastin over four years, the root characteristics of shaded (35 % of full light) and unshaded 2-year-old silver birches were measured (Van Hees and Clerkx 2003). The birches were grown in a medium to coarse sandy soil. After the study was completed, the mean DSH of the 6-year-old birches were 31 and 37 mm, the mean height of the birches 3.27 and 3.19 m and the total mean root biomass 0.27 and 0.43 kg for plants exposed to 35 % and 100 % light respectively. The corresponding root weight in the present study for silver birches growing in fine sand soils was 0.12 and 0.18 kg for DSH 31 and 37 mm respectively. In the understory of deciduous forests in southern Quebec, the percentage of coarse fine root biomass on the basis of total root biomass was 20 % for 4-14-year-old yellow birch (Cheng et al. 2005). Harris et al. (1977) found the greatest percentage hardwood root biomass by total root biomass for root size class <5 mm. Van Hees and Clerkx (2003) reported coarse fine root biomass percentages of 32 and 40 % for 6-year-old silver birches growing in shade (35 % of full light) and in full light respectively. In the present study, the biomass of coarse fine roots (1-5 mm) represented on the average 24-49 % of the total root biomass.

In the present study the root-shoot ratio (R:S) was greater for birches growing on medium clay soils than on fine sand soils. Then the amount of root biomass per unit above-ground biomass was greater on medium clay soils than on fine sand soils. The R:S for the 12-year-old silver and downy birches in the present study was lower than reported in other studies. One reason may be that the fine root fraction (<1 mm) was not sampled in this study. In a study of silver birch growing in Britain the ratio was 0.21 for 6-year-old birches (Ovington and Madgwick 1959). Gaucher et. al. (2005) studied 8-year-old yellow birch growing on forest land in Quebec, Canada (Lat. 45º 55’ N. and Long. 71º 40’ W.) and reported a R:S ratio of 0.44.

Since it is difficult to sample roots for estimating biomass, models for the root estimation are an alternative. There have been published some allometric models for estimating root biomass directly from diameter at breast height (Drexhage and Colin 2001; Drexhage and Gruber 1999; Johansson 2007). In the present study the allometric relationship between diameter at stump height (DSH) and root weight has been analysed. The allometric model produced a good fit to the data. Based on findings in this study it is possible to use the stump diameter as a predictor of root weight and length. The allometric models for the two birch species indicate a greater root biomass for downy birch than for silver birch stumps of DSH >80 mm. The same relationship was found for root length. The equations using diameter at breast height (c.f. Johansson 2007) and at stump height for predicting root biomass give quite similar results.

CONCLUSIONS

The density of trees (tree spacings) above ground influenced the amount of root biomass. Birches planted at a spacing of 2.6 x 2.6 m did not compete as much as at more narrow spacings. The root biomass and length were greater for birches growing at the spacing of 2.6 m than at smaller spacings.

Silver birch had a greater belowground biomass than downy birch growing on medium clay or fine sand soils.

The extension of roots in different directions around a tree was not found to differ depending on spacing. The stands may be too young for competition to develop between individuals.

DSH could be a valuable tool when predicting root biomass in stands with trees lower than 1.3 m. Then equations based on DBH could not be used. The equations for below-ground biomass of the two birch species based on DBH or DSH fitted the data well and could be used as a tool to estimate root biomass in the field. The results confirmed that DSH can be used as a simple variable to estimate the root biomass and root length. But in practice it is more comfortable to measure the DBH than the DSH.

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