Biomass Production of Norway Spruce (*Picea abies* (L.) Karst.) Growing on Abandoned Farmland

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Biomass production of forests has been studied for at least a century. Tree biomass is used in Sweden both as industrial raw material and an energy source. Few studies dealing with biomass yield from Norway spruce (*Picea abies* (L.) Karst.) growing on farmland are published. Practical recommendations are sparsely. The aim of this study was to construct dry weight equations for Norway spruce growing on farmland.

Dry weight equations for fractions of Norway spruce trees were made. Biomass production was estimated in 32 stands of Norway spruce growing on abandoned farmland. The stands were located in Sweden at latitudes ranging from 58° to 64° N, and their total age varied from 17 to 54 years. A modified “mean tree technique” was used to estimate biomass production; i.e. the tallest tree was chosen for sampling.

The actual mean total dry weight above stump level for the 32 stands was 116 ton ha^{-1}, with a range of 6.0 to 237.4 ton d.w. ha^{-1}. When previous thinning removals were included, the mean biomass value was 127 ton ha^{-1} (6.0–262.8). In addition to estimating conventional dry weights of trees and tree components, basic density, specific leaf area, total surface area and leaf area index, among other measures, were estimated.

Norway spruce biomass yields on plots subjected to different thinning were compared. The total harvested biomass was 75–120 ton d.w. ha^{-1} in heavy thinnings from below. Stands were thinned four to five times, with the first thinning at 23–27 years and the last at 51–64 years. The harvested biomass obtained in the first thinning was 18–38 ton d.w. ha^{-1}. Total biomass production was 178–305 ton d.w. ha^{-1}. Stands thinned from above supplied 71–130 ton d.w. ha^{-1} in total and 17–42 ton d.w. ha^{-1} in the first thinning. The total biomass supply was 221–304 ton d.w. ha^{-1}. Unthinned stands produced a total of 155–245 ton d.w. ha^{-1}.

Keywords abandoned farmland, basic density, biomass production, LAI, Norway spruce, *Picea abies*, thinning
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1 Introduction

Biomass production of forests has been studied for at least a century. Amilon (1925) studied the relationships between different tree components and described tree growth as a function of needle weight and leaf area. In Young et al. (1973) biomass studies on different species growing in different parts of the world are reported. Pardé (1980) reviewed historical and methodological aspects of forest biomass studies together with some results. Cannell (1982) compiled data on the biomass production of various tree species throughout the world.

Tree biomass is used in Sweden both as industrial raw material and an energy source. Stem wood has always been the dominating part of the biomass utilised, but the use of biomass from other tree components has increased rapidly during the last few decades. For example, there has recently been an increased interest in utilising wood for biofuel. Slash (i.e. tops and branches) and small trees removed in cleanings account for most of harvested biofuel (Skogsstatistisk... 1998). Norway spruce (*Picea abies* (L.) Karst.) plantations on farmland constitute another potentially rich source of biofuel. Generally, spruce plantations on farmland grow very fast, especially if the soil is fertile and the area is weeded before plantation (Johansson and Karlsson 1988). There is currently a lack of knowledge about how site conditions affect production and the amount of biomass produced on abandoned farmland.

Some Nordic studies have dealt with dry weight estimation and biomass production of evenaged Norway spruces growing on abandoned farmland. Some researchers present dry weights for spruces growing on forest land. In Sweden, Tamm (1969) studied 50–85 year-old Norway spruce stands growing in southern and middle Sweden (Lat. 56–60° N). He presented standing volumes (m^3) and dry weights for stem, branches and needles, and nutrient contents of tree components. Eriksson (1976) presented functions for biomass yield production in Norway spruce stands growing on forest land. Dry weight was estimated as the product of stem volume and basic density of the mean trees. Marklund (1987) developed functions for Norway spruce growing on forest land in Sweden, among other species. The functions were designed for single trees and consisted of six components: stem over bark, stem wood, stem bark, living branches, needles and dead branches. Most of the stands upon which functions were calculated are even-aged.

In Norway, Wilhelmsen and Vestjordet (1974) constructed preliminary tables for determining the dry weight of merchantable stems and stands of Norway spruce. The stands were naturally regenerated on forest land and uneven-aged. In Finland, Hakkila (1971,1972) developed functions for branches and stump root systems of Scots pine and Norway spruce. Inclusion of the crown ratio improved the branch biomass function. Mälkönen (1973) studied a 70-year-old spruce stand with 1800 stems per hectare in southern-middle Finland. Burger (1939) studied biomass and tree components of Norway spruce in northern Switzerland. In Japan Satoo (1971) made studies on biomass production.

Studies of basic density for Norway spruce growing on different sites have been made by several researchers. In a study by Hakkila (1979) the basic density for Norway spruces of different age classes was as follows: 371 kg m^{-3} (–25 years), 368 kg m^{-3} (26–50 years), 383 kg m^{-3} (51–100 years) and 401 kg m^{-3} (101– years), with an average of 380 kg m^{-3}. In a study by Oksbjerg (1971) in 33-year-old stands of Norway spruce, the basic density of Norway spruce was 450, 420 and 390 kg m^{-3} for stems with breast height diameters of 10, 15 and 20 cm respectively.

Few studies dealing with biomass yield from Norway spruce stands growing on farmland are published. Today the demand for increasing amount of biofuel increases. Most of the fast growing spruces planted on farmland area in 1960–70 must be thinned. The amount of yield is high but the basic density of fast growing spruces is lower than for spruces growing on medium fertile soils on forest land (Johansson and Karlsson 1988). The timber quality such as the stress of the wood of fast growing spruces is low. Further on spruce stands growing on farmland are infected by root rot after thinning. Mostly the infection is more common in pure stands than in a mixed stand.

These problems are not solved yet and there is a lack of practical experience how to manage these stands. Practical recommendations are sparsely. A scenario could be to clear cut the stand at 40–50 years of age. The harvested wood could be used for pulpwood and/or biofuel. Another scenario could be to thin the stand and use the removal as biofuel. These scenarios might be an interesting alternative both on farmland and on fertile forest lands.According to the above mentioned lack, more knowledge about biomass production of Norway spruces growing on farmland and fertile forest land is necessary.

The aim of present study was to construct dry weight equations for Norway spruce growing on abandoned farmland. Constructed functions were then used for calculating biomass production for even-aged plantations of Norway spruce growing on abandoned farmland. As an example of practical implication, the amounts of biomass removed in connection with the first and second thinning in Norway spruce stands growing on fertile forest land were calculated based on the presented biomass functions. Characteristics such as basic density, LAI, MAI and SLA for a single tree or a stand were estimated and calculated.

2 Material and Methods

2.1 Sampling Procedure for Construction of Biomass Equations

The study consists of 32 stands of Norway spruces growing on abandoned farmland in Sweden ranging in latitude from 58° to 63° N (Table 1). The total age of the stands varied from 17 to 54 years (Table 1). The plants were 3–4 years old at the time of planting, and in most cases bare-root seedlings were used. 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. Stands with large gaps were also rejected. All stands had an area of at least 1 ha. A 10-m-wide buffer strip was established along the border of each sampled stand in order to avoid the effects of wind, open areas, ditches and shading by adjacent stands, etc. 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 the groundwater level being at 30–50 cm depth.

The soil profile of each of the stands was analysed, and the soil type was recorded (Table 1). Soil was sampled (3–5 samples per stand) from ground level to below the former ploughing depth (20–30 cm). The average texture for 0–30 cm depth was determined. Soil type was classified in the field in accordance with the instructions provided by Atterberg (Ekström 1926), and the soils were classified as sediments, tills or organogenic types. Johansson (1999) presents detailed information about the technique for soil classification used for this type of object. Site index (H_{40}) was estimated for each stand using the measured height of the felled trees. Site index was calculated from site index curves for Norway spruces growing on abandoned farmland (Johansson 1996a), Table 1.

A modified "mean tree technique" method was used for biomass estimation. The five largest spruces in the stand (determined on the basis of diameter at breast height) were chosen for sampling. Then one of the tallest trees was chosen for biomass estimation. This technique makes it possible to use the site index estimate based on the top height tree, c.f. Johansson (1996b). On ten 100 m^2 circular subsample plots in a scatter of the stand, the number of trees and their diameter at breast height were registered (Table 1). The basal area weighted mean diameter was calculated for each of the ten sample plots. The means were almost equal and diameters from all measured trees in the stand were used to calculate the basal area weighted mean diameter for the stand.

Among the five largest spruces one tree was used as a sample tree if it had an undamaged, straight stem without double leaders, was free from root rot (*Heterobasidion annosum* (Fr.) Bref.) and was not growing in a large opening. After this tree had been felled, its height (m), diameter at breast height (dbh, mm) and bark thickness (mm) were measured (Table 2). Increment cores were taken at intervals corresponding to 1, 10, 20, 30, 50, 70 and 90 % of tree height. All cores extended to the pith. Total age was recorded (Table 2). All branches including the needles on the tree were then cut and weighed fresh in the field, and the fresh weight of the

Table 1. Main characteristics of Norway spruce localities and stands.

Locality no	Lat, N	Long, E	Alt, m	Age, years	Mean diam., mm (dbh) 1)	Basal area, $m^2\ ha^{-1}$	Number of stems ha^{-1}	Site index, H_{40}, m	Soil type
1	63°30'	16°42'	200	53	211	43.1	1 233	18	Fine sand
2	63°30'	16°42'	200	54	205	37.4	1 133	16	Silt
3	63°27'	16°45'	200	27	115	38.1	3 666	17	Fine sand
4	63°21'	19°12'	10	39	159	50.3	2 533	17	Silt
5	63°10'	17°00'	120	33	137	45.7	3 100	17	Light clay
6	60°33'	16°26'	95	43	139	28.5	1 933	17	Fine sand
7	60°32'	16°01'	105	17	54	17.4	7 600	22	Fine sand
8	60°23'	16°10'	120	43	186	30.8	1 133	20	Silty till
9	60°16'	15°50'	150	26	115	20.8	2 000	15	Light clay
10	60°18'	15°49'	155	25	130	27.9	2 100	19	Light clay
11	60°12'	16°00'	115	28	132	34.7	2 533	22	Silt
12	60°17'	15°51'	145	23	109	21.5	2 300	20	Light clay
13	60°20'	16°07'	110	21	83	11.5	2 133	16	Fine sand
14	60°13'	16°00'	130	27	138	26.4	1 767	17	Light clay
15	60°10'	18°15'	20	39	208	54.4	1 600	21	Medium clay
16	60°15'	17°25'	35	33	151	33.4	1 867	19	Medium clay
17	60°10'	18°25'	5	31	163	41.7	2 000	19	Coarse sand
18	58°15'	15°39'	90	32	118	25.9	2 367	15	Heavy clay
19	58°15'	15°39'	90	32	135	37.7	2 633	21	Heavy clay
20	58°15'	15°39'	90	37	137	42.7	2 900	21	Heavy clay
21	58°25'	13°40'	130	36	115	33.6	3 233	16	Moorland peat
22	58°25'	13°40'	130	37	172	62.0	2 667	18	Silty clay
23	58°25'	14°05'	150	37	160	51.6	2 567	22	Sandy till
24	57°58'	12°26'	70	25	145	31.4	1 900	22	Sand
25	57°58'	12°26'	70	28	124	31.4	2 600	20	Light clay till
26	57°57'	12°26'	70	40	212	53.2	1 507	20	Fine sand
27	57°59'	12°26'	65	18	56	7.1	2 867	19	Silty till
28	57°56'	12°26'	65	17	59	7.4	2 700	22	Light clay
29	57°56'	12°26'	70	17	32	2.4	2 967	13	Fine sand
30	58°01'	12°26'	85	22	136	32.4	2 233	23	Fine sand
31	57°59'	12°26'	15	25	143	33.2	2 067	24	Fine sand
32	57°56'	12°26'	20	18	69	7.0	1 867	20	Sand

1) Basal area weighted mean diameter

stem was measured. A 5- to 10-cm-thick stem disc was then removed at 3-m height. Discs were kept frozen prior to the measurement of basic density in the laboratory.

Since reports on needle characteristics, such as projected leaf area (PLA), leaf area index (LAI) and specific leaf area (SLA) for spruces growing on farmland are sparse, needle and canopy measurements were made. Needle characteristics, mainly LAI, are important structural parameters of forest ecosystems and have an important influence on the exchange of energy, gas and water (Bolstad and Gower 1990). On a 30 m × 30 m area in the stand, leaf area was estimated using a LAI-2000 plant canopy analyser (LI-COR, Inc, London, Nebraska). The initial measurement was taken outside the stand, whereupon another five measurements were made along a strip inside the stand. Five strips were measured, totally 25 estimations spread around the strip as measured points both were fixed under a spruce and within the row between two spruces. The final LAI-measurement was taken outside the stand to calibrate the LAI-light. The plant canopy analyser (LAI-2000) assumes random foliage positioning. However, the conifer

Table 2. Main characteristics of sample trees of Norway spruce.

Locality no	Age, years	Height, m	Diameter, mm , ob	Bark thickness, mm	Percentage dry matter by fresh weight, %			Basic density, kg m^{-3}
					Stem	Twigs	Needles	
1	53	23.4	290	17	40	62	50	320
2	54	19.5	298	17	45	53	53	320
3	27	10.8	164	9	43	45	52	280
4	39	16.9	206	11	41	60	51	290
5	33	13.8	203	8	51	47	51	290
6	43	18.4	245	10	41	67	57	330
7	17	7.3	100	8	39	73	43	360
8	43	18.8	248	12	45	59	48	320
9	26	9.5	167	9	34	43	42	310
10	25	11.5	200	9	36	59	52	300
11	28	14.9	184	9	34	60	46	320
12	23	9.8	160	9	33	53	47	300
13	21	7.0	124	5	33	38	53	320
14	27	10.9	175	12	38	55	50	370
15	39	20.7	328	17	42	65	49	290
16	33	13.7	214	15	42	62	46	340
17	31	14.6	280	11	33	43	44	300
18	32	12.0	199	9	33	60	46	310
19	32	16.1	196	11	37	61	55	350
20	37	18.7	226	12	41	61	55	380
21	36	14.8	194	12	36	61	45	360
22	37	17.0	264	13	41	42	43	280
23	37	20.4	256	11	37	53	47	360
24	25	12.9	221	9	39	55	54	290
25	28	13.8	213	8	40	53	46	360
26	40	20.3	330	12	49	57	48	340
27	18	6.0	97	6	44	64	46	410
28	17	6.8	94	5	40	44	53	330
29	17	4.1	49	4	42	42	56	360
30	22	11.8	189	9	34	48	64	280
31	25	13.9	219	12	35	61	49	280
32	18	7.3	103	7	39	59	58	340
Mean ± SE	31±2	13.7±0.9	201±12	10±1	39±1	55±2	50±1	314±11
Range	17–54	4.1–23.4	49–298	4–17	33–51	36–73	42–64	280–410

needles are not arranged randomly in space. Models based on the random-arrangement assumption way will underestimate the transmittance of a conifer canopy (Norman and Jarvis 1975; Oker-Blom and Kellomäki 1981). As a consequence, the plant canopy analyser will underestimate LAI in this type of canopy. Gower and Norman (1991) hypothesised that the analyser measures a shoot area index in conifer stands. They proposed correcting the predictions by multiplying the estimates by a factor R.

R = projected needle area / average projected shoot area

where

average projected shoot area
= average area of the shadow cast by a horizontally held shoot

projected needle area
= the sum of individual needle shadow areas measured after removing needles from the shoot.

The total dry weight of each sample tree was estimated in the laboratory. Needles were sampled from ten branches taken from throughout the crown. In each sample 100 needles were analysed. The ten samples were weighed fresh, whereupon the leaf area was determined with a leaf-area meter (LI-3000, LI-COR, Inc. Lincoln, Nebraska). Each of the ten samples were then dried at 105 °C in an oven for 24 h and weighed. All branches with needles were dried in an oven at 70 °C for 5 days. Needles and the branches were then weighed separately. Basic density was estimated according to the water-immersion method described by Andersson and Tuimala (1980). The disc was saturated in water for 24 h. The fresh weight (f.w.) was transformed to volume (v). The dry matter content of the barked disc was determined after drying at 105 °C. in an air-ventilated oven for 24 h. Dry weight (d.w) in g per unit fresh volume (cm^3) of the barked disc was then calculated as basic density (kg m^{-3}). Thereafter the percentage dry weight, %, was calculated as (d.w. / f.w.) × 100. Stem dry weight was calculated based on the percentage dry weight. The fresh weight of the total quantity of needles was calculated based on the percentage dry weight of the needles. The fresh weight of branches was obtained by subtracting the total fresh weight of branches and needles from the fresh weight of needles (Table 2).

The biomass production per tree in a stand was calculated on the basis of curves describing the correlation between diameter at breast height and biomass production (kg d.w. $tree^{-1}$). Dry weight for all 32 of the measured tree were used for the calculation.

Three functions were tested:

$$B = b_0 + b_1 \times D + b_2 \times D^2 \quad (1)$$

$$B = a \times D^{b0} \quad \text{(Power function) (2)}$$

$$B = b_0 \times (1 - \text{EXP} \times (-b_1 \times D))^{b2} \quad \text{(Richards 1959) (3)}$$

where
B = biomass production (kg d.w. $tree^{-1}$)
D = diameter at breast height (ob), mm
b_0, b_1, b_2 = parameters

When comparing the plotted values and the curves of the tested functions, function no. 3 fitted the material best for both thin and thick trees. This function has the highest determination coefficient (R^2) for functions for all frac-

Table 3. Estimated parameters of equation model nos. 1–3 for dry weight estimations of Norway spruce growing on abandoned farmland.

Components	Parameter	Equation no 1		Equation no 2		Equation no 3	
		Parameter estimates	R^2	Parameter estimates	R^2	Parameter estimates	R^2
Total	B_0	16.3690	0.923	0.0020	0.953	21 988.7574	0.975
	B_1	–0.3447		2.0816		0.0006	
	B_2	0.0044				2.4400	
Stem + twigs	B_0	21.7410	0.965	0.0003	0.924	1 910.3700	0.961
	B_1	–0.5241		2.3877		0.0029	
	B_2	0.0046				3.9846	
Stem	B_0	25.6640	0.946	0.0001	0.903	3 381.7292	0.972
	B_1	–0.5768		2.5680		0.0021	
	B_2	0.0040				3.2841	
Twigs	B_0	–3.9234	0.866	0.0007	0.920	348.6448	0.962
	B_1	0.0527		2.0149		0.0025	
	B_2	0.0006				2.6100	
Needles	B_0	–5.3718	0.656	0.0702	0.681	36.2826	0.955
	B_1	0.1795		1.0702		0.0080	
	B_2	–0.0002				2.1576	

tions. Further information about parameter estimates is given in Table 3. Function no. 1 rose steeply outside the plotted figures total fractions with increasing diameter > 300 mm. Function no. 2 overestimated values of needles and branches for thin trees. Total biomass above ground, stem + branch biomass, stem biomass, branch biomass, and needle biomass were all calculated. Based on a stand's basal area weighted mean diameter the actual biomass production of the stand was estimated for all 32 of the stands included in the study.

2.2 Biomass Levels from Thinning Removals in Long-Term Thinning Experiments

Based on the results from long-term thinning trials the removals from thinning of spruce stands were estimated using the constructed biomass functions. Biomass yields in stands thinned in different ways were compared. Long-term thinning experiments were carried out by the Department of Forest Yield Research during 1960–1980 throughout much of Sweden with the aim to investigate the effects of thinning and fertilisation. The experiments were designed as randomised blocks, with 8–12 replications in each experiment (Johansson 1986). Depending on the thinning programme, the thinning cycle varied between 5 and 15 years. In each experiment routine measurements were made at intervals of 5–7 years. All experimental plots were 0.1 ha with a 10-m-wide border. Naturally thinned (unthinned control) stands were compared with stands thinned from below. Removal in thinnings of trees was converted into biomass units by using the mean basal area weighted diameter for the removed trees and biomass estimated from functions constructed in the present study. Then the number of stems removed was multiplied by the tree weight for the mean tree in the stand. The mean annual increment and the current periodic annual increment of the total aboveground biomass for the different treatments were estimated. Mostly the stands included in the experimental plots were examined each five years. The mean basal area weighted diameter was calculated for five-year periods. Then the current periodic annual increment by five years could be estimated.

3 Results

3.1 Sample Trees

Curves relating the dry weights of the total biomass above stump level, stem + branches, stem, branches and needles per tree to dbh are presented in Fig. 1. With increasing dbh the needle dry weight increased slowly, whereas the fresh weight of needles increased rapidly (Fig. 3).

The percentage of the total dry weight accounted for by the dry weight of stem, branches and needles was 56 ± 13 %, 24 ± 5 % and 20 ± 10 % respectively. The thicker the stem the higher was the stem proportion of the total dry weight and the lower was the needle proportion (Fig. 2).

Basic densities of the 32 Norway spruces varied between 280 and 410 kg m^{-3} with a mean of 314 ± 61 kg m^{-3} (Table 2). The mean percentage

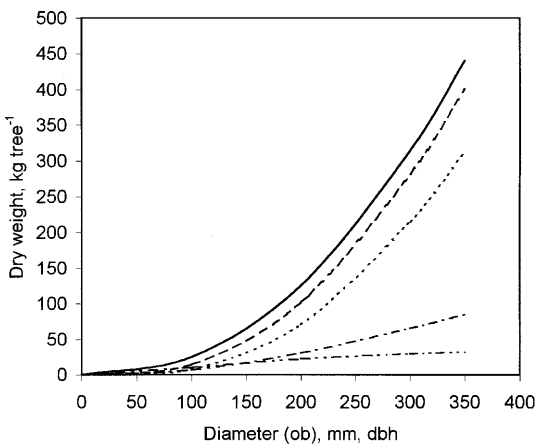

Fig. 1. Biomass production, kg d.w. $tree^{-1}$ by diameter (ob), mm (dbh) of total (—), stem + branches (– –), stem (·····), branches (– · –) and needles (– ·· –) for Norway spruce growing on abandoned farmland.

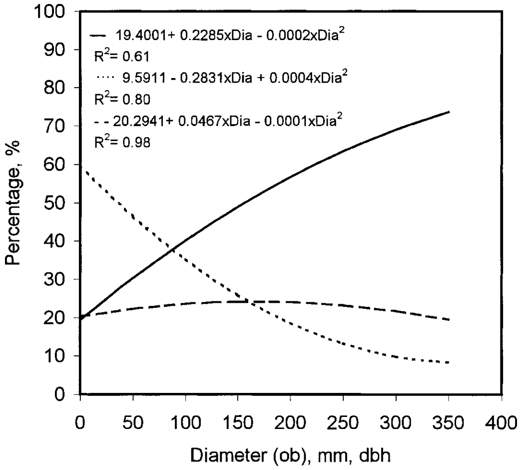

Fig. 2. Percentages of total tree dry weight accounted for by stem (—), branches (– –) and needles (·····) in relation to diameter (ob) at breast height (mm) for sample trees of Norway spruce growing on abandoned farmland.

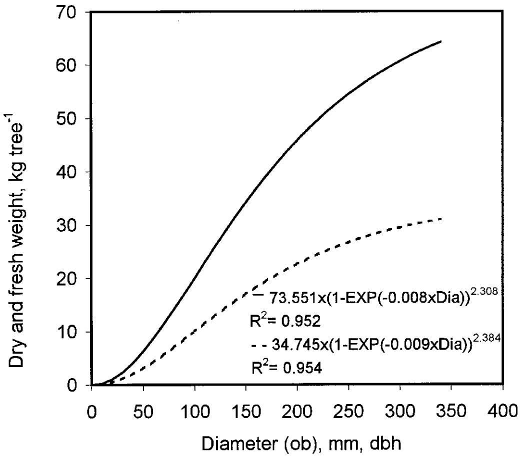

Fig. 3. Fresh (—) and dry (- - -) weights of needles, kg tree^{-1} in relation to diameter (ob) at breast height (mm) for sample trees of Norway spruce growing on abandoned farmland.

SD dry matter of fresh weight (range within parentheses) for stem, branches and needles was 39 ± 5 % (33–51), 55 ± 9 % (38–73) and 50 ± 5 % (42–64) respectively.

Fresh and dry weights for the 32 sampled spruces are presented in Table 4. These individual weights are needed for calculating some leaf characteristics. Among the youngest trees, nos. 28 and 29 (17 years old) and nos. 27 and 32 (18 years old), the dry weight of needles exceeded the dry weight of the stem. Spruce no. 13 (17 years old) did not follow the above-mentioned pattern.

The mean weight per needle was 9.3 ± 1.8 mg (Table 5). The number of needles per tree was then calculated by dividing the total dry weight of needles per tree by the weight of a single needle (Table 5). Generally the total number of needles per tree increased with the dbh. The average number of needles per tree was 2.4 ± 0.2 mill. and measured as kg d.w. of needles tree^{-1} was 21.5 ± 1.5.

The mean projected leaf area (PLA) was 20.3 ± 0.7 mm^2, and the mean surface leaf area per needle was 52.0 ± 1.8 mm^2. The mean specific total leaf area per tree (SLA) was 5.9 ± 0.2 m^2 kg^{-1} (Table 5). The thicker the tree the higher was its surface leaf area.

3.2 Stands

Leaf area index (LAI) varied between 5.30 and 10.34 in the study (Table 5). Based on the mean basal area weighted diameter, dry weight per hectare was calculated for the studied stands by using data from the curves presented in Fig. 1, Table 6. The mean total dry weight above stump level was 116.3 ± 60.8 ton d.w. ha^{-1} with a range of 6.0 to 237.4 ton d.w. ha^{-1}. The mean annual increment for each stand was also calculated. The youngest stands (nos. 7, 13, 28, 29 and 32) had the lowest increment (Table 6). The same pattern was found when mean annual increment was correlated with the dbh (Fig. 4). The thicker the tree, the greater was the increment. In Fig. 5, the regression between total biomass production above stump level, including biomass removed in previous thinnings, and diameter is presented.

Table 4. Fresh and dry weight (kg tree^{-1}) of within-tree distribution of biomass for sample trees of Norway spruce.

Locality no	Fresh weight				Dry weight			
	Total	Stem	Twigs	Needles	Total	Stem	Twigs	Needles
1	745.8	589.0	106.1	50.7	327.1	235.6	66.2	25.3
2	567.9	432.0	88.5	47.4	269.8	194.4	50.2	25.2
3	126.6	85.5	30.3	10.8	56.0	36.8	13.6	5.6
4	286.1	220.0	32.3	33.8	127.0	90.2	19.4	17.4
5	224.0	145.5	48.3	30.2	112.4	74.2	22.7	15.5
6	499.0	380.0	70.2	48.8	202.7	155.8	46.9	27.7
7	43.4	25.0	5.9	12.5	19.5	9.8	4.3	5.4
8	475.7	356.5	70.5	48.7	225.0	160.4	41.4	23.2
9	194.8	92.0	47.7	55.1	75.1	31.2	20.5	23.4
10	251.4	137.5	66.7	47.2	113.6	49.5	39.6	24.5
11	259.9	193.4	30.8	35.7	100.7	65.8	18.6	16.3
12	148.5	71.5	37.4	39.6	62.0	23.6	19.9	18.5
13	132.8	86.6	23.8	22.4	49.5	28.6	9.0	11.9
14	232.5	138.1	40.2	54.2	101.7	52.5	22.1	27.1
15	772.7	597.5	110.6	64.8	354.5	251.0	71.9	31.6
16	314.0	196.5	64.1	53.4	146.7	82.5	39.8	24.4
17	519.7	337.5	129.4	52.8	189.9	111.4	55.1	23.4
18	301.7	183.5	64.2	54.0	124.2	60.6	38.6	25.0
19	327.0	226.0	57.3	43.7	142.7	83.6	35.1	24.0
20	467.4	364.9	60.3	42.2	209.4	149.6	36.6	23.2
21	317.6	193.0	62.8	61.8	132.9	64.5	40.5	27.9
22	466.6	314.0	99.0	53.6	192.6	128.7	41.1	22.8
23	704.2	488.5	132.1	83.6	289.6	180.7	70.0	38.9
24	342.3	201.0	86.9	54.4	155.8	78.4	48.2	29.2
25	323.5	206.0	68.6	48.9	141.2	82.4	36.1	22.7
26	831.9	601.5	156.5	73.9	418.3	294.3	88.5	35.5
27	54.6	23.5	10.9	20.2	26.5	10.3	7.0	9.2
28	73.6	22.1	23.2	28.3	34.0	8.8	10.3	14.9
29	18.6	6.6	4.3	7.7	8.9	2.8	1.8	4.3
30	225.8	140.2	42.8	42.8	95.7	47.7	20.7	27.5
31	296.5	190.2	50.2	56.1	124.8	66.6	30.7	27.5
32	59.5	28.5	13.5	17.5	29.3	11.1	8.0	10.2
Mean±SE	309.7±37.1	227.3±30.6	60.5±6.7	43.6±3.1	145.6±17.9	91.4±13.4	33.6±3.8	21.5±1.5
Range	18.6–831.9	6.6–601.5	4.3–156.5	7.7–83.6	8.9–418.3	2.8–294.3	1.8–88.5	4.3–38.9

Table 5. Weight of needles (mg), number of needles tree^{-1}, and weight (kg^{-1} d.w.) of needles tree^{-1}, projected leaf area (mm^2), total surface area (mm^2) per needle, specific total leaf area (m^2 kg^{-1}) on sample trees, and leaf area index in stands of Norway spruce.

Locality no	Weight needle^{-1} mg	No tree^{-1} (million)	Weight tree^{-1} kg^{-1} d.w.	PLA [1] mm^2	Total surface area, mm^2	SLA [2] m^2 kg^{-1} d.w.	LAI [3] measured	LAI [3] corrected [4]
1	6.1	4.1	25.3	20.4	52.4	8.5	5.28	8.45
2	7.5	3.4	25.2	16.8	43.2	5.8	5.19	8.31
3	7.4	0.8	5.6	14.0	36.1	5.2	4.89	7.82
4	9.0	1.9	17.4	18.5	47.5	5.2	5.19	8.30
5	9.9	1.7	15.5	18.4	47.2	5.2	5.03	8.05
6	7.6	3.6	27.7	19.3	49.7	6.5	4.76	7.61
7	8.9	0.6	5.4	19.5	50.1	5.6	4.47	7.15
8	9.7	2.4	23.2	22.3	57.3	5.9	3.59	5.74
9	10.9	2.1	23.4	22.9	58.9	5.3	5.50	8.80
10	11.6	2.1	24.5	23.9	61.3	5.3	5.32	8.51
11	9.2	1.8	16.3	19.9	51.1	5.6	5.19	8.30
12	6.3	2.9	18.5	14.6	37.5	5.9	3.71	5.94
13	9.3	2.4	11.9	14.0	36.0	7.3	3.31	5.30
14	9.1	3.0	27.1	19.4	49.9	5.5	4.14	6.62
15	9.1	3.5	31.6	19.3	49.7	5.5	5.44	8.70
16	10.1	2.4	24.4	22.1	56.8	5.6	4.97	7.95
17	9.7	2.4	23.4	22.2	57.1	5.9	5.09	8.15
18	11.6	2.2	25.0	26.6	68.4	6.0	5.09	8.14
19	10.6	2.3	24.0	19.8	61.0	5.8	5.38	8.60
20	9.9	2.3	23.2	10.4	26.6	2.6	5.36	8.58
21	8.9	3.2	27.9	21.3	54.7	6.3	4.89	7.82
22	12.6	1.8	22.8	24.8	63.7	5.0	5.04	8.07
23	9.8	4.0	38.9	22.3	57.4	5.9	4.57	7.31
24	6.4	4.6	29.2	17.2	44.1	6.9	4.81	7.70
25	9.5	2.4	22.7	25.1	64.4	6.8	5.79	9.26
26	11.0	3.2	35.5	22.5	57.7	5.2	5.08	8.13
27	7.7	1.2	9.2	17.2	44.3	5.8	4.68	7.49
28	10.3	1.4	14.9	23.7	60.8	5.7	4.92	7.87
29	12.2	0.4	4.3	26.5	68.2	6.3	3.04	4.86
30	12.2	2.3	27.5	23.6	60.7	5.1	5.75	9.20
31	7.4	3.7	27.5	20.8	53.5	7.2	6.46	10.34
32	7.5	1.4	10.2	21.4	55.0	7.5	3.80	6.08
Mean±SE	9.3±1.8	2.4±0.2	21.5±1.5	20.3±0.7	52.0±1.8	5.9±0.2	4.9±0.1	7.8±0.2
Range	6.1–12.6	0.4–4.6	4.3–38.9	14.0–26.6	26.6–68.4	2.6–8.5	3.31–6.46	5.30–10.34

1) PLA = Projected leaf area
2) SLA = Specific total leaf area, needles
3) LAI = Leaf area index
4) Corrected = 1.6 × $LAI_{measured}$

Table 6. Dry weight production (ton ha^{-1}) and mean annual increment (MAI) (ton ha^{-1} year^{-1}) of Norway spruce stands and total biomass production above stump level (ton ha^{-1}) including previous thinning removals.

Locality no	Dry weight, ton ha^{-1} Total	Stem	Twigs	Needles	MAI, ton ha^{-1} yrs^{-1}	Production, ton ha^{-1} Thinnings	Total 1)
1	175.5	102.6	41.9	28.8	4.6	65.7	241.2
2	150.9	88.6	36.5	25.8	3.6	43.1	194.0
3	127.6	45.1	34.1	44.4	4.7	0	127.6
4	187.9	94.5	48.1	45.3	4.8	0	187.9
5	162.8	73.0	42.8	46.8	4.9	0	162.8
6	105.0	47.8	27.4	29.8	3.3	37.4	142.4
7	47.2	6.1	12.2	28.9	2.8	0	47.2
8	120.8	67.2	27.4	23.7	3.6	34.5	155.3
9	69.6	26.8	18.6	24.2	2.7	0	69.6
10	97.4	41.8	25.8	29.8	3.9	0	97.4
11	121.8	52.9	32.2	36.7	5.1	20.0	141.8
12	70.6	25.5	19.1	26.0	3.1	0	70.6
13	34.3	8.7	9.4	16.2	1.6	0	34.3
14	94.4	42.8	24.7	26.9	3.5	0	94.4
15	220.3	130.3	53.0	37.0	5.9	10.9	231.2
16	122.8	59.5	31.7	31.6	3.7	0	122.8
17	157.2	80.6	40.0	36.6	6.6	47.4	204.6
18	87.6	34.4	23.4	29.8	2.7	0	87.6
19	133.5	59.2	35.3	39.0	4.2	0	133.5
20	152.3	68.5	40.0	43.8	4.1	0	152.3
21	112.5	43.3	30.1	39.1	3.1	0	112.5
22	237.4	126.0	59.7	51.7	6.4	0	237.4
23	193.3	97.6	49.5	46.2	6.4	44.5	237.8
24	113.8	53.6	29.6	30.6	4.6	0	113.8
25	108.2	44.5	28.9	34.8	3.9	0	108.2
26	216.7	129.6	51.7	35.4	6.6	46.1	262.8
27	19.3	2.9	4.9	11.5	1.1	0	19.3
28	20.5	3.2	5.4	11.9	1.2	0	20.5
29	6.0	0.3	1.2	4.5	0.4	0	6.0
30	115.2	51.3	30.4	33.5	5.2	0	115.2
31	119.9	55.8	31.2	32.9	4.8	0	119.9
32	19.7	3.9	5.2	10.6	1.1	0	19.7
Mean±SE	116.3±10.7	55.3±6.5	29.7±2.7	31.1±2.0	3.9±0.3		
Range	6.0–237.4	0.3–130.3	1.2–59.7	4.5–51.7	0.4–6.6		

1) Thinning removal included.

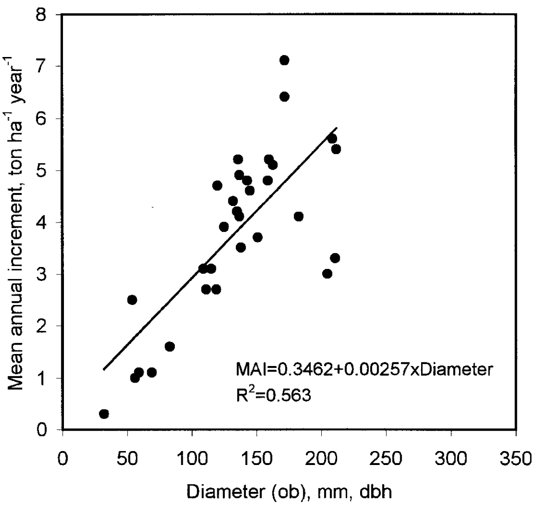

Fig. 4. Mean annual increment (ton ha^{-1} $year^{-1}$) in relation to diameter (ob) at breast height (mm) for sample trees of Norway spruce growing on abandoned farmland. Individual sample values are represented by dots.

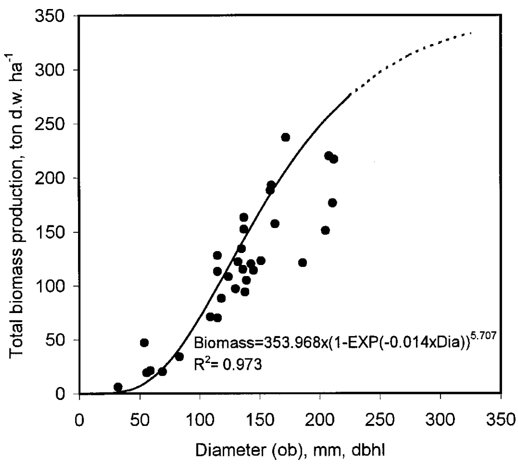

Fig. 5. Total biomass production above stump level (ton d.w. ha^{-1}) in relation to diameter (ob) at breast height (mm) for Norway spruce stands growing on abandoned farmland. Individual sample values are represented by dots.

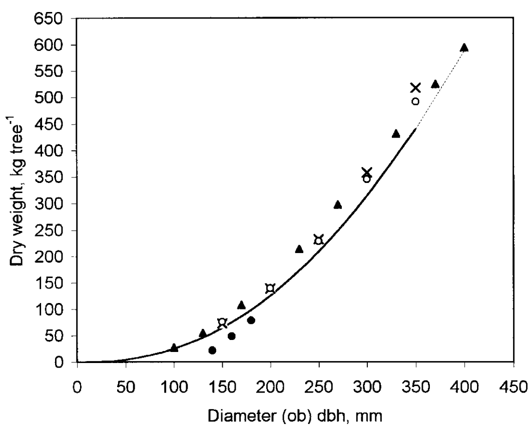

Fig. 6. Dry weight per tree (kg $tree^{-1}$) for Norway spruce by diameter (dbh) growing on abandoned farmland. Comparison between data from the present study and (●) Wilhelmsen and Vestjordet (1974), (x) Jokela et al. (1986), (o) Nihlgård (1972) and (▲) Marklund (1987).

3.3 Biomass Supplied through Thinning

The above-ground biomass obtained by thinning from below (heavy thinning) four to five times, starting at 23–37 years of age and with the final thinning at 51–64 years of age, was 179–288 ton per hectare (Table 7). Stands thinned from above produced 217–301 ton per hectare. Unthinned stands produced yields between 163 and 312 ton ha^{-1}. As shown in Table 7, the biomass supplied by the first thinning was 17–38 ton d.w. ha^{-1} for stands thinned from below and 17–43 ton d.w. ha^{-1} for stands thinned from above. Even though thinning from above resulted in a higher yield than thinning from below (Fig. 7) the patterns of regrowth after thinning were similar, with the curves running parallel to each other.

In the unthinned treatment in four of the six trials (nos. 2,3,4 and 6) the current periodic annual increment (CAI) calculated as the difference in biomass between the two most recent measurements, 5–10 years was higher than mean annual increment (MAI). For stands thinned from above the MAI was lower than the CAI except in trial nos. 3 and 4 (cf. Table 7). The same pattern

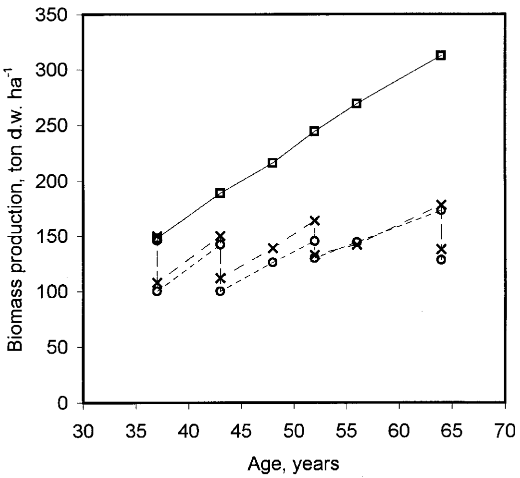

Fig. 7. Biomass production (ton d.w. ha^{-1}) for unthinned (□), heavy thinned (○) and thinned from above (x) stands of Norway spruce in a long-term experimental trial. Trial no. 3 (cf. Table 7).

was generally found for stands thinned from below except in trial no. 1. Mean percentage dry weight above stump level by volume production above stump level for 15 stands in the six trials was 38 ± 3 % (33–43 %), (Table 7).

4 Discussion

4.1 Biomass Production

Generally the annual production of foliage has been estimated from either standing biomass or from litter-fall. In the present study the estimate of total biomass was based on felled trees. According to Madgewick (1970) this method assumes that annual biomass production is equal to the biomass of one-year-old leaves on the trees at the end of the growing season. However, on conifer species such as Norway spruces, which has needles of different ages (1–5 years), this problem is of less importance. Moreover the dry

Table 7. Total biomass production above ground (ton ha^{-1}), mean annual and current periodic annual increment (ton ha^{-1} year^{-1}) and percentage biomass by volume (%) for unthinned and thinned Norway spruce stands growing on longterm experimental plots.

Trial no	Site index H_{40} m	Age of the stand 1)	Thinning method 2)	No. of thinnings	Biomass production ton ha^{-1} Total	Thinnings Total	Thinnings First	(Year)	Increment 3) ton , ha^{-1} yr^{-1}		Percentage dry matter by volume, % 4)
1	20	23–52	0	0	167	0	0		3.21	2.50	39
	20	23–52	A	4	179	81	20	(30)	3.44	3.00	42
2	23	26–51	0	0	225	0	0		4.41	5.62	34
	23	26–51	B	5	264	160	17	(27)	5.18	6.25	42
3	22	37–64	0	0	312	0			4.88	5.38	34
	22	37–64	A	4	268	161	38	(37)	4.19	5.25	33
	22	37–64	B	4	301	160	43	(37)	4.70	4.50	38
4	22	30–56	0	0	287	0	0		5.12	5.43	37
	22	30–56	A	5	288	120	17	(30)	5.14	5.57	38
	22	30–56	B	5	266	133	31	(30)	4.75	4.57	40
5	19	34–60	0	0	163	0	0		2.72	2.00	38
	19	34–60	B	3	227	148	19	(34)	3.78	4.71	43
6	20	31–58	0	0	247	0	0		4.26	5.56	36
	20	31–58	A	5	235	112	20	(36)	4.05	5.33	38
	20	31–58	B	6	217	105	11	(31)	3.74	4.33	41

1) Age of the stand: The period during the rotation period when the thinning operations were made.
2) Thinning method: 0 = No thinning A = Thinning from below (heavy thinning: 3–6 thinnings) B = Thinning from above (3–6 thinnings).
3) Increment: Mean annual increment (Left), Current periodic annual radial increment for the period between the two latest examinations (Right).
4) Percentage dry weight above stump level (ton ha^{-1}) by volume production above stump level (m^3 ha^{-1}).

weight of needles varies over the year, e.g. from 33.7–46.6 % for the first-year needles (Horntvedt 1983). Air pollution also influences needle biomass to various extents depending on geographical location, stand age and abiotic factors such as soil type and soil nutrient status.

Madgewick (1973) concluded that a highly satisfactory result could be obtained using the tree of mean basal area. In the present study the dominant tree was used. When calculating the biomass for the present stands the basal area weighted mean diameter was used. The resulting curves describing total biomass production above stump level for stem + branches, stem, branches and needles (Fig. 1) are in accordance with the findings of other studies cf. Table 8. Estimating biomass by sampling the dominant trees in the stand has some advantages. The procedure for estimating site index is based on measurements of the dominant tree(s) in a stand (Johansson 1996a). A simple test was made in five stands. Fresh weights of stems and branches + needles was made on both the dominant tree and the mean tree. The relation between fractions and total weight was the same for the two sampled trees. Generally, the dominant tree is the least disturbed tree in a stand. On the other hand, this tree does not represent a "true mean tree" for the stand. But in a homogenous stand such as a plantation on farmland, the distribution is narrow. In practise, this is a simple meth-

Table 8. Reported above-ground biomass production for Norway spruce stands.

Reference	Stand age (years)	Treatment No stem ha^{-1}	Total production (tonnes ha^{-1})	MAI (tonnes ha^{-1} year^{-1})	Basic density (kg m^{-3})	Remarks
Brække (1986)	31	2 969	97.2	3.1		Norway (56°16' N 10°49' E)
		3 203	104.4	3.4		
		5 126	88.2	2.9		
		5 208	109.2	3.5		
Klem (1952)	44	816	166.0	3.8	416	Norway
		1111	218.0	5.0	426	
		2500	218.0	5.0	430	
		4330	240.0	5.5	425	
		5715	261.0	5.9	422	
von Droste (1969)	79	800	306.3	3.9		Bavaria (48°04' N)
Gower et al. (1993)	28	2 500	128.0	6.0		Wisconsin (43°52' N 91°51' W)
Kestemont (1975)	55		201.1	3.7		Belgium (50°03' N)
Nihlgård (1972)	55	880	308.0	5.6	380	Sweden (55°59' N 13°10' E)
Johansson and Karlsson (1988)	30–35	2 195–4 286	92–226	3.7–7.4	284–346	Sweden (57°–60° N)
						Sweden
Tamm (1969)	59	Thinned	115.0	2.0		(59° N)
	53	Thinned	138.0	2.6		(57° N)
	50	Thinned	191.0	3.8		(55° N)
	50	Unthinned	283.0	5.7		(55° N)
	85	Thinned	214.0	2.5		(55° N)
	85	Unthinned	382.0	4.5		(55° N)
	65	Thinned	178.0	2.7		(60° N)

od for estimating biomass and constructing local biomass functions.

There have been published several studies dealing with the deviation between estimation methods. Attiwill and Ovington (1968) determined forest biomass according to reports by Baskerville (1965) and Ovington and Madgwick (1959). In their report they concluded that the degree of deviation between estimation methods tends to be much greater for individual tree components than for the tree as a whole. Estimations of standing foliage biomass are mostly based on a mean tree, i.e. “the mean-average-diameter-tree or “the basal-area-diameter-tree”. In the present study the largest- diameter tree was used, which provides the best conditions for foliage growth among trees in the stand. Nevertheless, the foliage biomass can be affected by factors other than tree height and diameter, (cf. Madgewick 1970 for an overview).

4.2 Biomass Distribution

Some of the stands in the present stands are thinned earlier. This is important to keep in mind when comparing the total biomass production above stump level estimated in the present study with estimates made in previous studies. Measured values presented in Table 6 represent actual biomass production. A more relevant comparison is the relation between dbh and single-tree biomass values on both a whole-tree and tree-component basis. However an attempt to include biomass removed in previous thinnings was made for thinned stands. Diameters of stumps remaining after thinning operations were registered. The relation between diameter at stump level and at breast height was used for calculating breast height diameters for the thinned stems. The forest owner provided information about the period of thinning. In Table 6, total biomass production, including previous thinning removals, is presented in order to be able to compare the present results with those of other studies at the stand level.

In Fig. 5, the relation between breast height diameter and total biomass production is presented. The correlation ($R^2 = 0.97$) between diameter and total biomass production is high. Compared with findings by other studies, the results from the present study are on the same level (Table 8). A comparison between dry weight for single trees estimated in the present study and reported by other studies (dots) is presented in Fig. 6. Tree weights for the present study are 10–17 % lower than for corresponding diameters from other studies. These differences might, among other things, depend on lower basic density for spruces growing on abandoned farmland compared with the other studies where the spruces were growing on forest land.

In the previous study, the stands are growing on fertile farmland areas and the plantations have succeeded. All stands were established by planting at spacings of 1.8 × 1.8 m, and the needle biomass of young trees was able to expand rapidly on fertile soils before the stands closed later on. However the findings in the previous study are in congruence with results presented in other studies which are discussed below. The percentage of the total dry weight above stump level accounted for by stem for the sampled spruces in the present study are the same as those reported by Tamm (1969), Hakkila (1971), Nihlgård (1972), Brække (1986) and Marklund (1987), Fig. 2. In the present study the twig proportion of the biomass was about 20 % throughout the diameter range (Fig. 2). The mean stem percentage of the above-ground biomass (dry weight) was 56 % in the present study. Eriksson (1976) reported a value of 60 % for stems based on several studies by other researchers. The spruce stands in Tamm’s study were older (50–85 years) than those in the present study. The stem percentage of the total above-ground biomass in his study was 76–86 %, and corresponding values were 8–15 % for branches and 6–10 % for needles. The stem percentage was highest, 68–86 %, for the oldest stands (85 years) which were unthinned. In Hakkila’s study the needle and branch proportions of the total biomass decreased with increasing diameter: 50 % for 100 mm; 41 % for 110–150 mm; 34 % for 160–200 mm and 32 % for 200+ mm. In accordance with Tamm, Nihlgård (1972) reported stem, twig and needle proportions of 85 %, 9 %, and 6 % for a 55-year-old spruce stand. Brække (1986) studied 31-year-old Norway spruce stands planted on fertilized peat-soil sites in southern. Figures from his study are similar to those obtained in the present one (Fig. 2). The stem, twig and needle proportion of the biomass in his study was 61, 21 and 18 % respectively. Seven years earlier (24 years old) the corresponding values were 48, 24 and 28 % respectively. In Marklund's study the twig percentage decreased with increasing diameter, being 50 % at 50 mm dbh, 35 % at 200 and 25 % at 400 mm. In a study by Jokela et al. (1986) on nine 47–52-year-old Norway spruce stands growing in central New York the percentage stem, branches and needles was 64, 25 and 11 %.

4.3 Basic Density of Wood

Generally, the basic density of Norway spruce is lower on fertile sites, such as farmland and some forest areas, than on nutrient poor forest sites (Olesen 1973; Madsen et al. 1978; Harvald 1989). Madsen et al. (1978) found a significant correlation between the clay content of the soil and basic density. The basic density was negatively correlated with the water amount available to the spruces. High clay content decreases water available. Hakkila (1966) distinguished four site types in a study of Norway spruces growing on forest land in Finland. He reported a mean difference in basic density of 20 kg m^{-3} between sites with the most fertile site having the lowest values. In the present study the level of basic density was 314 kg m^{-3} (280–410) (Table 2). The highest basic densities were found in stands with a high site index and/or in very young stands (17–20 years old), Table 1. Hakkila and Uusvaara (1968) also reported that Norway spruce had a lower density in plantations than in naturally regenerated stands. The difference was 6.2 % at 25 years of age and 4.2 % at 70 years. Norén (1996) studied six young (25–34 years of age) Norway spruce stands growing on abandoned farmland and fertile forest land in southern and middle Sweden (Lat. 58–60° N). The site indexes for the stands were H_{100} = 27 and 35 m (H_{40} = 17 and 23 m) on forest land and 29, 34, 35 and 38 m (19, 22, 23 and 26 m) on farmland. Norén reported small differences in basic density between different types of sites. Johansson (1993) reported basic densities of 375–390 kg m^{-3} in 30-year-old Norway spruce stands growing in southern Sweden. There were no statistically significant differences in basic densities between initial spacing of 1.5 and 2.5 m.

4.4 Foliage Characteristics

Needle biomass characteristics are given in Table 5. In a study of 55-year-old Norway spruces growing in southern Sweden, Nihlgård (1972) estimated a projected needle area of 25 mm^2, whereas it was 20.3 mm^2 in the present study. The mean surface area per needle was 52 ± 1.8 mm^2 in the present study. In a study on 35-year-old Norway spruces growing in northern Switzerland, Burger (1939) reported a surface leaf area of 47.9 mm^2. The stand in his study had 2924 stems per hectare and a basal area of 34 m^2. Needle size and volume influence needle area indices, photosynthesis, gas exchange and transpiration, among other things (Riederer et al. 1988). The authors presented functions for surface area (4.440 × needle length – 24.8) and needle volume ($0.208 \times PLA^{1.353}$). They studied 48 Norway spruces trees, which were 5, 30 and 130 years old and growing in northeastern Bavaria. The needle length and volume for needles in the present study were calculated using the formulas mentioned above. The mean needle length is 17.5 mm (11.6–21.0) and the mean needle volume 12.2 mm^3 (4.9–17.6). Kerner et al. (1977) stated that for a given needle length of Norway spruce, the total surface area on one needle could range from 40 to 65 mm^2 depending on the origin of the needle in the crown. For a given needle length, sun-type needles had a greater total surface area than shade-type needles. In a study by Kerner et al. (1977) on 80-year-old Norway spruces a correlation between needle length and total surface area was calculated. When using a mean value of calculated needle length of 17.5 mm, as mentioned above, the total surface area for the present study calculated using the formula given by Kerner et al. will be 58 mm^2 (measured 52 mm^2). The specific leaf area (SLA) varies greatly among species and is influenced by environmental conditions. In addition, SLA is an important leaf characteristic since it is positively related to net assimilation rate (Korner 1991). The SLA for the present study was 5.8 ± 1.1 m^2 kg^{-1} d.w. compared with 12.4 m^2 kg^{-1} in Burger's study. Hager and Sterba (1985) reported a SLA-value of 5.0 ± 1.7 m^2 kg^{-1} for 17-year-old Norway spruces growing in Austria (Lat. 48°20' N, Long. 15°20' E). Spruces at the same age in the present study (stands nos. 7, 27, 28, 29 and 32) had a SLA of 6.0 ± 0.7 (5.6–7.5). Gower et al. (1993) reported a SLA of 3.3 m^2 kg^{-1} d.w. for 28-year-old Norway spruces growing in southwestern Wisconsin. The mean number of needles per kg d.w. of needles was 114 024 ± 27 727 in the present study compared with 290 000 in a study by Burger (1941). These differences stated among others that, on average, the mean dry weight of a needle is lower in stands studied by Burger (3.4 mg) than in the stands that we studied (9.3 ± 1.6 mg). Nihlgård (1972) reported a needle weight of 4.5 mg per needle. In Table 5, LAI-values for the estimated stands are given.

Gower and Norman (1991) reported an R-value of 1.60 for Norway spruce in order to get a reliable value of measured LAI with the plant canopy analyser. In Table 5 the Lai (LAI_{corr}) corrected in accordance with the above discussion is given. Nihlgård (1972) reported a LAI-value of 11.5 in a 55-year-old plantation of Norway spruce plantation in southern Sweden. In study of young Norway spruce stands growing at different spacing Johansson (1990) reported LAI-values of 2 to 8 for 3-m high trees. Gower et al. (1993) reported a LAI-value of 10.2 ± 1.8 for 28-year-old Norway spruces growing in southwestern Wisconsin. The plantation consisted of 1930 stems per hectare, and the basal area was 54 m^2 ha^{-1}. In the present study, stands 9, 14, 24 and 31 have about the same characteristics except for basal area which was much lower, being 20.8, 26.4, 31.4 and 33.2 m^2 ha^{-1}. The LAI for those stands was 8.80, 6.62, 7.70 and 10.34 respectively. In another study on a young Norway spruce stand growing in southwestern Wisconsin Gower and Norman (1991) presented a LAI of 10.4. This stand had 1725 stems per hectare, an average diameter at breast height of 151 mm and a basal area of 37.1 m^2.

4.5 Thinning Regime and Biomass Production

Stand biomass production was affected by the type of thinning regime used (Table 7). The thinning yield in stands thinned from below was similar to that of stands thinned from above. Stands growing on lower quality sites produced less biomass than stands on better sites (Table 7). For unthinned stands the mean annual increment was generally higher than the current periodic annual increment. There was no difference in thinning yield between stands thinned from below and stands thinned from above in any of the trials. However, Madsen et al. (1978), who studied a 32-year-old Norway spruce stand in Denmark (Lat. 54°45', Long. 11°30' E), found that dry matter production decreased with increasing thinning intensity. In the present study the mean percentage dry weight of tree production by volume production was 38 ± 3 %, with the value being lower for unthinned stands (36 ± 2 %) and higher for stands thinned from below (38 ± 4 %) and stands thinned from above (41 ± 2 %).

4.6 Implications for Harvesting Strategies

Results from the present results imply that when managing Norway spruce plantations on abandoned farmland, rather high biomass production is found. As the risk for root rot (*Heterobasidion annnosum* (Fr.) Bref.) is high especially on abandoned farmland after thinning other "products" than timber and pulpwood might be interesting. A clear cut of the stand, after a rotation period of 30–40 years could be an alternative. Lower silvicultural costs than for conventional forest will be a result of this operation. Further on, if the stand is fresh without root rot, a second plantation of spruces is possible. At the end of the second rotation period, two harvests have been made during one rotation period of a conventional management of a Norway stand.

Another practical implication of the present results concerns the utilisation of spruces growing on forest land which are harvested after first thinning. The total biomass harvested in the first thinning of Norway spruce stands in the long-term experiments was 18–38 ton ha^{-1} for heavily thinned stands and 10–42 ton ha^{-1} for stands thinned from the above. As the stands are growing on fertile soils, most of the stands were even aged and most sites have been pasture land, biomass yields are equal to those harvested on farmland. However, advances of practical value have been made with regard to thinning in spruce stands. A high thinning grade, e.g. a level of thinning removal results in a lower MAI than a moderate thinning grade does.

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