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GROWTH DISTURBANCES IN TREES ON FERTILE MINERAL SOILS

**FINAL REPORT OF THE PROJECT “GROWTH DISTURBANCES IN BURNT-OVER NORWAY
SPRUCE STANDS”**

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Appendix: English translations for the figures and tables shown in the original report

Cover photo: A typical Norway spruce stand suffering from strong boron deficiency (needle boron concentration 1–2 mg/kg). Healthy-looking trees and trees with growth disturbances grow side-by-side in the same forest. Photographed by Erkki Oksanen.

Growth disturbances in trees on fertile mineral soils — Summary

Risto Rikala

Fig. 1. Schematic figure of the development of multiple-leader top of Norway spruce (*Picea abies*). Brown buds are dead and green buds are alive.

Fig. 2. Bush-like top of 34-year-old, ten meters high Norway spruce. Photographed by Risto Rikala.

Fig. 3. Severe growth disturbances, also dead trees, in a 30-year-old stand suffering from boron deficiency. Photographed by Risto Rikala.

Fig. 4. Dead tops of Norway spruce with foliar boron concentration of 3 mg/kg. Photographed by Risto Rikala.

Fig. 5. Over the years the tops of trees may exhibit cycles of growth disturbances and recovery and many forks of stems and ramicornes remind of earlier growth disturbances. Cross-section of the top of 34-year-old Norway spruce. Photographed by Erkki Oksanen.

Fig. 6. Growth disturbances caused by boron deficiency in Scots pine (*Pinus sylvestris*), Norway spruce and silver birch (*Betula pendula*) growing in mineral soil on abandoned agricultural field (mineral soil). Photographed by Risto Rikala.

Fig. 7. The top of a 20-year-old and three meter high Scots pine tree with severe growth disturbance. Foliar boron concentration 1.1 mg/kg, grown on a heaping area. Photographed by Risto Rikala.

Fig. 8. A 23-year-old black spruce (*Picea mariana*) stand with severe growth disturbance planted on abandoned agricultural field (mineral soil) which was previously used as pasture land. Foliar boron concentrations of trees varied between 1.0–3.0 mg/kg. Photographed by Erkki Oksanen.

Fig. 9. Originally strongly bush-formed 16-year-old Norway spruce three years after fertilization (2.4 kg boron/ha). Photographed by Risto Rikala.

Fig. 10. Multiple-leadered, young silver birch growing on former agricultural field. Forking of stem was caused by birch bell moth (*Epinotia tetraquetrana*). Photographed by Risto Rikala.

Fig. 11. Multiple-leadered Scots pine sapling. Growth disturbance in the top is caused by insects. Photographed by Risto Rikala.

RESEARCH ARTICLES

I Symptoms of growth disturbance at the cell-level and the development of the disturbance

Sirkka Sutinen, Risto Rikala and Tarja Lehto

Fig. 1. Needle boron concentration in three experimental stands in 1999 and 2000. H = a Norway spruce stand with severe growth disturbance, LH = a Norway spruce stand with mild growth disturbance and T = a healthy-looking Norway spruce stand. *y-axis*: Needle boron concentration, mg/kg and *x-axis*: Month.

Fig. 2a. Longitudinal section of a last year's healthy-looking bud tip of a tree with growth disturbance on 22nd May. The lateral meristem (Rm) can be seen in the apical dome. The earliest stages of bud scales as humps (asterisks) in the base of the apical dome and under that the primordial shoot (Av) can be seen. A vascular bundle (Jj) is developing up to the uppermost primary needle (An). A red line in the base of the apical dome shows the cross-section place of Fig. 2b. Bar = 200 μ m. Photographed by Sirkka Sutinen.

Fig. 2b. Cross-section of a healthy-looking bud of a tree with disturbance on 22nd May. The cross-section is cut from the bottom of the apical dome (see Fig. 2a). The early phases of bud scales (asterisks) are observable as humps in the lateral meristem (Rm). Dead and/or tannin (dark accumulated mass; arrows) containing cells can be seen both in the lateral meristem and in the developing primary needles (An). Bar = 200 μ m. Photographed by Sirkka Sutinen.

Fig. 3. Visually healthy-looking buds of Norway spruce seedlings at the end of the growth chamber experiment (experiment day 103) in the B1 treatment (B fertilization started at the beginning of the growing season; Fig. a) and in the B0 treatment (no B fertilization during the whole summer; Fig. b). In the B1 treatment (Fig. a) only a few cells contain tannin (seen as dark accumulations), while in the B0 treatment (Fig. b) tannin has accumulated in the large part of the cells of the primordial shoot (Av). In the figures also primary needles (An) and in the Fig. b the innermost bud scales (Ss) can be seen. Bar = 200 μ m. Photographed by Sirkka Sutinen.

Fig. 4. Apical buds of a healthy-looking Norway spruce (T-stand, Fig. a) and of Norway spruces with growth disturbance (H-stand; Figs. b and c) in November. a) Pith, primordial shoot and bud scales have developed normally. b) Bud that has a bottle-neck shaped pith and an underdeveloped primordial shoot and bud scales. c) Bud scales have accumulated a lot of resin and the pith is necrotic. The development of the bud has ceased before the formation of primordial shoot. In the figures the primordial shoot is marked with arrows, pith with asterisks and bud scales with Ss. Bars in all figures = 200 μ m. Photographed by Sirkka Sutinen.

Fig. 5. Cross-sections of central cylinder from needles of a healthy Norway spruce (T-stand; Fig. a) and of a Norway spruce with growth disturbance (H-stand; Fig. b). The needle from a healthy tree has characteristically many schlerenchyma cells (asterisks), while their number in a tree with growth disturbance is considerably decreased. On the other hand xylem tissue (Ps) has more tracheids in a tree with growth disturbance than in a healthy tree. Bar = 0.1 mm. Photographed by Sirkka Sutinen.

II Occurrence of growth disturbances and boron concentrations in soil and needles on fertile forested mineral soils in Southern Finland.

Pekka Tamminen and Anna Saarsalmi

Fig. 1. Norway spruce trees suffering from growth disturbances. Photographed by Erkki Oksanen.

Fig. 2. Growth disturbance class distribution in fertile Norway spruce stands on 102 sample plots of the 9th National Forest Inventory in southern Finland. Growth disturbance classes: Healthy (blue dots), slightly damaged (yellow dots), severely damaged (red dots). Forestry centres: 1 = Rannikko, 2 = Lounais-Suomi, 3 = Häme-Uusimaa, 4 = Kaakkois-Suomi, 5 = Pirkanmaa, 6 = Etelä-Savo, 7 = Etelä-Pohjanmaa, 8 = Keski-Suomi, 9 = Pohjois-Savo, 10 = Pohjois-Karjala.

Fig. 3. Boron concentrations in current needles on 102 sample plots of the 9th National Forest Inventory in southern Finland. See Fig. 2 for explanation of the Forestry centres.

Fig. 4. Hot water extractable boron concentrations in the organic layer. The connection between boron concentration in the organic layer and needles was as follows: 1.4 mg B/kg (organic layer) \Leftrightarrow 5 mg B/kg (needles), 1.7 mg B/kg (organic layer) \Leftrightarrow 10 mg B/kg (needles) and 4.53 mg B/kg (organic layer) \Leftrightarrow 20 mg/kg (needles). See Fig. 2 for explanation of the Forestry centres.

Fig. 5. Hot water extractable boron concentrations in the 0–10 cm mineral soil layer. The connection between boron concentration in the mineral soil and needles was as follows: 0.1 mg B/kg (soil) \Leftrightarrow 5 mg B/kg (needles), 0.17 mg B/kg (soil) \Leftrightarrow 10 mg B/kg (needles) and 1.12 mg B/kg (soil) \Leftrightarrow 20 mg/kg (needles). See Fig. 2 for explanation of the Forestry centres.

III Growth disturbances in Norway spruce stands in North Savo and their economic significance

Tenho Hynönen and Timo Makkonen

Fig. 1. Top and stem disturbances in Norway spruce stands in the 8th (dark green) and 9th (light green) National Forest Inventories in North Savo. *y-axis*: Disturbance, % and *x-axis*: Stand development classes: young seedling stand, mature seedling stand, young growing stand, mature growing stand, regeneration maturity stand, shelterwood stand, seed crop stand and mean.

Fig. 2. Height of Norway spruce at breast height diameter classes in different growth disturbance classes. *y-axis*: Height, dm and *x-axis*: Breast height diameter, cm. Normal looking trees in stand compartments with growth disturbance (blue), trees with growth disturbances in stand compartments with growth disturbances (red) and normal looking trees in stand compartments with no disturbance (green).

Fig. 3. The effect of the proportion of Norway spruce trees with growth disturbance calculated per basal area on the stem volume (blue line with open circles), log volume (green line with green squares), proportion of wastewood volume (red line with red triangles) and transfer of spruce pulpwood to pine pulpwood (blue line with blue squares) compared with the normally developed stand at the breast height. *y-axis*: Change, % and *x-axis*: Proportion of the spruce trees with growth disturbance, %.

Fig. 4. The occurrence of top and stem disturbances in Norway spruce classified by the proportion of the trees with growth disturbance weighted by the basal area (disturbance classes). Several disturbances can occur in the same tree. No disturbances means stand compartments that do not include trees with growth disturbance. *y-axis*: Proportion of the trees with growth disturbance, % and *x-axis*: Growth disturbance classes: no disturbance, disorder class 0–20, 20–40, 40–60, 60–80 and 80–100. Dense branchiness (dark green), vertical branch (light green) and multiple tops (yellow).

Table 1. The distribution of stands and sample trees in different site classes and development classes (T2 = mature seedling stand, mean height over 1.3 m and $d_{1.3} < 8$ cm, O2 = young growing stand, $8 \text{ cm} < d_{1.3} < 16$ cm, O3 = mature growing stand, $d_{1.3} > 16$ cm).

Site	Grove (OMaT: <i>Oxalis</i> – <i>Maianthemum</i> – type)		Grove-like upland forest (OMT: <i>Oxalis</i> – <i>Myrtillus</i> -type)				Moist upland forest (MT: <i>Myrtillus</i> -type)				Altogether	
	With disturbance		With disturbance		With no disturbance		With disturbance		With no disturbance		N	%
	n	%	n	%	N	%	n	%	n	%		
Number of stands	5	8	34	57	4	7	9	15	8	13	60	100
Number of sample trees (spruces)	197	7	1740	62	160	6	359	13	334	12	2790	100
Development class												
T2	2	15	6	46	2	15	8	22	3	23	13	100
O2	3	8	22	59	1	3	1	10	3	8	37	100
O3			6	60	1	10			2	20	10	100
Biological age, yr	26 ± 6		32 ± 19		38 ± 33		35 ± 17		52 ± 33		35 ± 22	

Table 2. The yield of Norway spruce stemwood at 80 yr rotation period, with three harvests in the grove-like upland forest.

Timber assortment	Vuokila & Väliaho (1980)	Spruces with growth disturbance, 20–40 % of the basal area	
		Yield, m ³ /ha	Yield, m ³ /ha
Spruce log	410	362	143
Spruce pulpwood	132	111	205
Pine pulpwood	0	21	31
Altogether	6	7	10
Altogether per year	548	501	390

Table 3. The yield of Norway spruce stand at 80 yr rotation period, with three harvests in the grove-like upland forest. When the earnings were calculated the mean stumpage price of the timber assortments in North-Savo in 2003 was used. The normal yield of Norway spruce stand was calculated according to Vuokila & Väliäho (1980).

	Normal looking spruce stand	Spruces with growth disturbance, 20–40 % of the basal area euros, ha	Spruces with growth disturbance, more than 80% of the basal area euros, ha
Spruce log	18850	16638	6591
Spruce pulpwood	2878	2415	4473
Pine pulpwood	0	274	410
Altogether	21728	19328	11475
Altogether per year	272	242	143

IV Fungal injuries in Norway spruce forests with growth disturbances

Martti Vuorinen

Fig. 1. Red spots in the leaves of birch cherry (*Prunus padus*) caused by *Pucciniastrum areolatum*. Photographed by Erkki Oksanen.

Fig. 2. Aecidia of *P. areolatum* on the conescales of Norway spruce. Photographed by Erkki Oksanen.

Fig. 3. Resin flow bending of Norway spruce shoots caused by *P. areolatum*. Photographed by Erkki Oksanen.

Fig. 4. *P. areolatum* causes the bending of the upper shoots of Norway spruce. Photographed by Risto Rikala.

VI The effect of boron deficiency on frost hardiness in Norway spruce

Mikko Räisänen, Tapani Repo and Tarja Lehto

Fig 1. Frost hardiness of stem of Norway spruce shoots in nitrogen and boron fertilized trees in the field experiment during autumn 2002. Frost hardiness values are assessed by laboratory freezing tests and measurements of ion leakage. Line shows daily minimum temperatures at the experimental site. Data points show mean of sampling weeks in each fertilization treatment 0: control, B, N and NB, and error bars show standard error of mean. *y-axis:* Frost hardiness and air temperature, °C and *x-axis:* Date: 1 August 2002, 1 September 2002, 1 October 2002, 1 November 2002 and 1 December 2002.

Fig 2. Frost hardiness of stem (brown) and bud (green) of Norway spruce seedlings with different boron status [0% (0B), 30% (30B) and 100% (100B)]. Frost hardiness values of stem are assessed by laboratory freezing tests and measuring an ion leakage from sample, while bud frost hardiness is measured by DTA. Mean \pm S.E. *Defining texts inside the figure:* Short-day period / low temperature period / mild freezing period. *y-axis:* Frost hardiness, °C and *x-axis:* Sampling time.

Fig. 3. Electrical resistance of extracellular space of stem in shoot Norway spruce seedlings with different boron status. Mean \pm S.E. *Defining texts inside the figure:* Short-day period / low temperature period / mild freezing period. *y-axis:* Extracellular resistance, Ω m and *x-axis:* Measuring time.

Fig. 4 A. Proportion of trees with growth disturbance in different fertilization treatments at each year. First inventory in 2000 has been done before fertilization. B. Proportion of trees with growth disturbance. The trees were classified according to needle boron concentration. Needle samples for boron analyses were collected in February 2003 (n=20, despite of at the highest boron concentration). A. *y-axis:* Percentage of trees with growth disturbance and *x-axis:* Year of inventory. B. *y-axis:* Percentage of trees with growth disturbance and *x-axis:* Boron concentration, mg/kg.

VII The significance of boron for fine roots and mycorrhizas of trees

Tarja Lehto, Marjoriitta Möttönen, Mikko Räisänen, Anu Lavola and Pedro Aphalo

Fig. 1. Number of root tips in Norway spruce seedlings grown at different levels of B supply [0% (B0), 30% (B30) and 100% (B100)] in the first seedling experiment between weeks 7 and 15 since germination. Root tips with *Cenococcum geophilum* mycorrhizas (green), root tips with other mycorrhizas with a mantle (yellow) and root tips without a mantle (brown). Means of 12 seedlings (two seedlings per block, altogether six blocks) and 95% confidence intervals for the total number of root tips. *y-axis*: Number of root tips per seedling and *x-axis*: Weeks since germination.

Fig. 2. Height on Day 9 of the drought treatment of well watered (light green) and drought-treated (dark green) Norway spruce seedlings grown at different B supply rates in the first seedling experiment. For levels of boron supply rates, see Fig. 1. Means of 12 seedlings (two seedlings per block, altogether six blocks) and 95% confidence intervals. *y-axis*: Height, mm and *x-axis*: Boron supply rate.

Fig. 3. Visible damage to the upper shoot of the Norway spruce seedlings expressed as percentages of the total number of seedlings (192 seedlings per treatment) in the second seedling experiment 19 weeks since germination. For levels of boron supply rates, see Fig. 1. Drought treatments: D0 (well-watered seedlings), D1 (one drought period of eight days) and D2 (two drought periods: the first drought period of six days, watered for two days and the second drought period of eight days). Mild visible symptoms of damage with some yellow or brown needles (solid light green), medium visible symptoms of damage with several yellow or brown needles (brown) and severe visible symptoms of damage with dead apical tips and abundant yellow or brown needles (black, see Fig. 6). *y-axis*: Proportion of the damaged seedlings, % and *x-axis*: Boron supply rate and the drought treatment.

Fig. 4. Fine root length in the humus layer of mature Norway spruce stands in Heinävesi and Kannonkoski experimental sites after nine years of B fertilization. Fine root length is expressed in different diameter classes (0–1 mm: light green and 1–2 mm: dark green). The bars represent means calculated for Heinävesi and Kannonkoski together and error bars represent standard errors of subsamples (n=16). *y-axis*: Fine root length, m/m² and *x-axis*: Treatment.

Fig. 5. The dry mass of fine roots in growth columns at different depths from the surface of the humus layer (cm) in the fertilization experiments of young Norway spruce stands situated in Pyhäselkä. The bars on the left represent live root mass and the bars on the right represent dead root mass. The columns were in the soil for two years. The bars represent the mean of the whole mass and the error bars represent standard error. *y-axis*: Root dry mass, g/m² and *x-axis*: Treatment.

Fig. 6. Severe visible growth damage in the top of the Norway spruce seedling. This kind of damage appeared in the seedlings that had low B supply rate and two drought treatments (see Fig. 3). Photographed by Pedro Aphalo.

Fig. 7. Experimental lay-out where the growth of roots of birch seedlings were limited to the upper part of the growth cassette. Only external hyphae of *Paxillus involutus* grown from the mycorrhizas of birch was allowed to grow in the lower part of the cassette. Photographed by Pedro Aphalo.

VIII Effect of boron fertilization on the nutrition and development of Norway spruce stand with growth disturbance

Anna Saarsalmi and Pekka Tamminen

Fig. 1. Boron concentrations in current needles of the trees representing different growth disturbance classes in the Kuopio, Tuusniemi and Kaavi experiments before fertilization. Growth disturbance classes: 1 = healthy (green), 2 = slightly damaged (brown), 3 = severely damaged (yellow). Mean values with the same letter do not differ significantly from each other. *y-axis*: Needle boron concentration, mg/kg and *x-axis*: Experiment.

Fig. 2. Boron concentrations in current needles in the Kuopio, Tuusniemi and Kaavi experiments before fertilization (in 1999) and one (in 2000), and three (in 2002) growing seasons after fertilization. Trees of all growth disturbance classes combined. Treatments: 0 = control, B = 2 kg B ha⁻¹ as borax, B+P = 2 kg B ha⁻¹ as borax and 40 kg P ha⁻¹ as superphosphate, N = 200 kg N ha⁻¹ as urea. Mean values with the same letter do not differ significantly from each other. *y-axis*: Needle boron concentration, mg/kg and *x-axis*: Treatment.

Fig. 3. Boron concentrations in needles of different ages three years after fertilization (in 2002) in the Kuopio experiment. Trees of all growth disturbance classes combined. See Fig. 2 for explanation of the treatments. Mean values with the same letter do not differ significantly from each other. *y-axis*: Needle boron concentration, mg/kg and *x-axis*: Treatment.

Fig. 4. Relative frequencies of the spruce trees in 2003 by growth disturbance class and treatment. All three experiments combined. Before fertilization all cell frequencies were 33.3 % (broken line) (n=10). See Fig. 1 for explanation of the growth disturbance classes, and Fig. 2 for explanation of the treatments. *y-axis*: Relative frequency, % and *x-axis*: Treatment.

Fig. 5. Average annual height growth (cm/yr) of spruce trees during four growing seasons after fertilization by growth disturbance class and treatment. All three experiments combined. See Fig. 1 for explanation of the growth disturbance classes, and Fig. 2 for explanation of the treatments. The difference in height growth between the treatments was statistically significant. *y-axis*: Mean height growth, cm/yr and *x-axis*: Treatment.

Table 1. Hot water extractable boron concentrations (mg/kg) on six control plots and on six boron fertilized plots in the Kaavi experiment in autumn 2002, i.e. three growing seasons after fertilization. The differences in boron concentrations between the treatments were statistically significant ($p < 0.001$) both in the organic layer and in the 0–10 cm mineral soil layer.

Soil layer	Boron fertilization			
	0 kg/ha		2 kg/ha	
	\bar{x}	Min–max	\bar{x}	min–max
Organic layer	1.05	0.94–1.22	2.26	1.47–2.85
0–10 cm	0.10	0.07–0.15	0.34	0.24–0.47

Table 2. Average nutrient concentrations in the needles before fertilization. Mean values with the same letter do not differ significantly from each other.

Experiment	Ca	K	Mg	N	P	B	Cu	Fe	Mn	Zn
	g/kg					mg/kg				
Kuopio	4.66a	6.15a	1.04b	14.4b	1.57a	2.5a	3.0b	25.9b	731b	37.0a
Tuusniemi	3.42c	5.22b	1.10a	14.3b	1.55a	1.7b	3.1b	27.7a	706b	26.5c
Kaavi	4.24b	5.52b	0.90c	15.6a	1.19b	1.5c	3.5a	24.8c	860a	32.0b

Table 3. Average nutrient concentrations in different tree compartments (mg/kg) on six control plots and on six boron fertilized plots in the Kaavi experiment in autumn 2002, i.e. three growing seasons after fertilization. The differences in boron concentrations between the treatments were statistically significant ($p < 0.001$) in all tree compartments excluding stemwood.

Tree Compartment	Boron fertilization			
	0 kg/ha		2 kg/ha	
	\bar{x}	min-max	\bar{x}	min-max
Needles 2000	2.0	1.2–2.9	18.9	7.1–29.2
Needles 2001	2.4	1.5–4.2	15.2	6.9–24.3
Needles 2002	2.8	1.3–6.1	14.9	9.5–20.7
Branches	3.8	3.1–5.2	6.8	4.5–9.97
Bark	7.9	5.6–11.9	12.2	7.4–17.2
Stemwood	1.5	0.9–2.4	1.9	1.3–3.8

IX Boron fertilizers and the recovery of young Norway spruce stands from the disturbance

Tenho Hynönen

Fig. 1. Needle boron concentrations in a planted Norway spruce seedling stand grown in the peatland formerly used for agriculture (experiment A) by fertilization treatments. The needle samples were collected annually between November and December. The stand was fertilized on 8th June, 2001. Control (black broken line), PK1 fertilizer for forested fields (green line), B fertilizer for forests (brown line) and NP2 for forests (yellow line). *y-axis*: Needle boron concentration, mg/kg and *x-axis*: Month/year.

Fig. 2. Needle boron (upper left), nitrogen (upper right), potassium (lower left) and phosphorus (lower right) concentrations in the late autumn between 2001–2003 by fertilization treatments and summarizing all experiments. The experiments were fertilized in June, 2001. Error bars represent standard error of the mean. *y-axis*: Nutrient concentration and *x-axis*: Treatment: control, PK1 fertilizer for forested fields, B fertilizer for forests and NP2 for forests.

Fig. 3. Height growth of the trees summarizing the height growth during years 2001–2003 in the fertilization experiments A–E (for explanations, see Table 1.) by fertilization treatments. Control (yellow), PK1 fertilizer for forested fields (brown), B fertilizer for forests (light green) and NP2 for forests (dark green). *y-axis*: Height growth, cm and *x-axis*: Fertilization experiment.

Fig. 4. The vitality of the tops in Norway spruce calculated as an average for the five experiments three growing seasons after fertilization (fertilized in June, 2001) in the late autumn 2003. Poor (yellow), satisfactory (brown), good (light green) and excellent (dark green). *y-axis*: Proportion, % and *x-axis*: Treatment: control, PK1 fertilizer for forested fields, B fertilizer for forests and NP2 for forests.

Table 1. The location of the experiments, site class, development class, age, mean height and growth disturbance class at the beginning of the experiment. T1 = young seedling stand, T2 = mature seedling stand, mean height over 1.3 m and $d_{1.3} < 8$ cm and 02 = young growing stand, $8 \text{ cm} < d_{1.3} < 16$ cm.

Experiment	Municipality	Site class	Development class	Age, yr	Height, m	Growth disturbance class
A	Kiuruvesi	Heathy peatland of <i>Myrtillus</i> -type ⁽¹⁾	T2	13	2.2	severe
B	Lapinlahti	Moist upland forest site (MT = <i>Myrtillus</i> -type)	T1	5	0.8	mild
C	Varpaisjärvi	Grove-like moist upland forest site (OMT = <i>Oxalis-Myrtillus</i> -type)	02	30	8.1	mild
D	Varpaisjärvi	MT= <i>Myrtillus</i> -type	T2	18	4.9	mild
E	Vehmersalmi	Grove-like moist upland forest site (OMT = <i>Oxalis-Myrtillus</i> -type)	T2	20	5.5	severe

⁽¹⁾ Forested peatland field

Table 2. Fertilizers and their nutrient concentrations and amount of fertilizer used in the experiment. N = nitrogen, P = phosphorus, K = potassium, Ca = calcium, Mg = magnesium, S = sulphur, B = boron, Cu = copper and Zn = zinc. The control plots (1) were not fertilized.

Fertilizer	N	P	K	Ca	Mg %	S	B	Ca	Zn	Amount kg/ha
2 PK1 for forested agricultural fields	0	6.0	10.8	12.5	4.0	3.0	0.60	0.5	0.5	400
3 B for forests	0	0	0	10.5	2.0	14.0	0.75	0	0	320
4 NP2 for forests	19.0	4.0	0	4.3	1.0	12.0	0.40	0	0.15	600

X Autumn boron fertilization in a Norway spruce stand

Risto Rikala and Martti Vuorinen

Fig. 1. The effect of timing of fertilization on boron concentration of Norway spruce current needles by sampling times (columns: control = no fertilization (brown), fertilized on 6th September, 2002 (green), fertilized on 3rd October, 2003 (light green), fertilized on 15th May, 2003 (yellow)). Error bars on the tops of columns show standard error of means (n = 6). *y-axis*: Needle boron concentration, mg/kg and *x-axis*: Sampling time: 5 September, 2002, 6 November, 2002 and 22 October, 2003.

XI Boron status and growth disturbances in silver birch stands

Risto Rikala and Martti Vuorinen

Fig. 1. Boron concentration in green (“B-vihreä”) and yellow (“B-Kelt.”) leaves of 19-year-old silver birch stand in August and September. *y-axis*: Boron concentration, mg/kg and *x-axis*: sampling time (7 August, 21 August, 3 September, 18 September and 3 October).

Fig. 2. Nitrogen concentration in green (“B-vihreä”) and yellow (“B-Kelt.”) leaves of 19-year-old silver birch stand in August and September. *y-axis*: Nitrogen concentration, g/kg and *x-axis*: sampling time (7 August, 21 August, 3 September, 18 September and 3 October).

Fig. 3. Classification of growth disturbances of silver birch stands used in this study. On the left: healthy-looking: straight stem, only slight curves, one top; in the middle: slight growth disturbance: little curvy stem, some forks or ramicorns, long branches, two- or multiple-leadered; and on the right: severe growth disturbance: strongly curvy stem, plenty of forks or ramicorns and branch rosettes, bush-like top. Photographed by Risto Rikala.

Fig. 4. Nitrogen (g/kg)(A), boron (mg/kg) (B) and manganese (mg/kg) (C) concentrations in birch leaves by disorder classes of stands. The stands were classified to afforested fields with mineral soil (green square), afforested fields with organic soil (originally peatland) (red diamond) and forest mineral soils (blue triangle). *y-axis*: Nutrient concentration and *x-axis*: Growth disturbance class: healthy-looking, with slight disturbance, with severe disturbance.

Fig. 5. The concentrations of total nitrogen (%) (A) and total phosphorus (mg/kg) (B) in soil (0-20 cm) by growth disturbance classes of stands. For stand classification, see Fig. 4. *y-axis*: Nutrient concentration and *x-axis*: Growth disturbance class: healthy-looking, with slight disturbance, with severe disturbance.