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Soil characteristics under selected broadleaved tree species in East Norway

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ABSTRACT: Comprehensive analyses of soil properties of sites of native Scandinavian broadleaved tree species were performed in 36 habitats in East Norway. The material consisted of stands of silver birch (*Betula pendula* Roth.), white birch (*Betula pubescens* Ehrh.), black alder (*Alnus glutinosa* Gaertn.), speckled alder (*Alnus incana* Moench.), European ash (*Fraxinus excelsior* L.), pedunculate oak (*Quercus robur* L.) and sessile oak (*Quercus petraea* [Matt.] Liebl.). The main objective was to describe the vertical characteristics and variations in some selected soil variables of the soil profiles. Particular soil horizons of 15 Brunisolic soils, 11 Regosolic soils, 6 Gleysolic and 4 Podzolic were sampled and analyzed for soil texture, bulk density, specific density, porosity, oxidizable carbon, total nitrogen content, pH in water, exchangeable acidity, exchangeable cations and anions (Mg, Ca, Mn, Al, S, Fe, B, P and K), cation exchange capacity and base saturation. No regular patterns were found in selected soil properties when tested between various soil units in silver birch stands. Furthermore, silver birch stands were found on sites, which topsoil (*i*) significantly differed in their cation exchange capacities, (*ii*) did not differ significantly in their pH values, and (*iii*) mostly differed in their clay contents and (*iv*) mostly did not differ in BS. Differences among the Humic Regosols, Luvic Gleysols, Sombric Brunisols, Eutric Brunisols and Humo-Ferric Podzols for silver birch stands in their topmost horizons of humified organic matter intimately mixed with the mineral fraction horizons and differences among particular soil horizons for the main soil properties under all the selected broadleaved tree species stands are discussed.

Keywords: broadleaved forest stands; forest soils; soil chemistry; soil classification; soil properties

The vegetation cover interacts with a wide range of soil properties and feedback mechanisms are found (Brais et al. 1995; Binkley, Giardina 1998). The effect of particular soil properties on tree species has been recognized for a long time (Shear, Steward 1934; Binkley et al. 1992) and stands of conifers and broadleaved trees are found to influence mineral soil properties and/or forest floor characteristics differently (Brais et al. 1995; Vesterdal, Raulund-Rasmussen 1998). Forest trees also modify the stand climate. Moreover, forests are often characterized by well-developed O horizons, high water use and net primary production along with, in non-tropical areas, large allocation of C to the soil (Lynch, Whipps 1990). Even though tree species may grow and survive in a wide range of soils and climates strong relationships are normally found between species composition and site class.

Although some Norwegian forest site evaluations have been performed (Tveite 1977; Tomter 1999),

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these studies have not had special emphasis on soil characteristics *per se* in broadleaved stands. To our knowledge, such in-depth studies of Norwegian deciduous forest types are lacking. This study was designed to investigate not only the properties of soils under broadleaved tree species but also to refer to the likely patterns in selected soil properties among different soil units in silver birch (*Betula pubescens* Ehrh.) stands. In addition to the purely descriptive potential, such data is also thought to be important in a wider perspective, e.g. for studies focusing on mineral status and decomposition dynamics of organic matter in forest soils (Christensen et al. 2005; Davi et al. 2005), and interrelationships between trees and soils (Vesterdal, Raulund-Rasmussen 1998). In this study detailed information of physical and chemical soil properties, their vertical characteristics and quantitative variations, are presented for 36 broadleaved stands in East Norway.

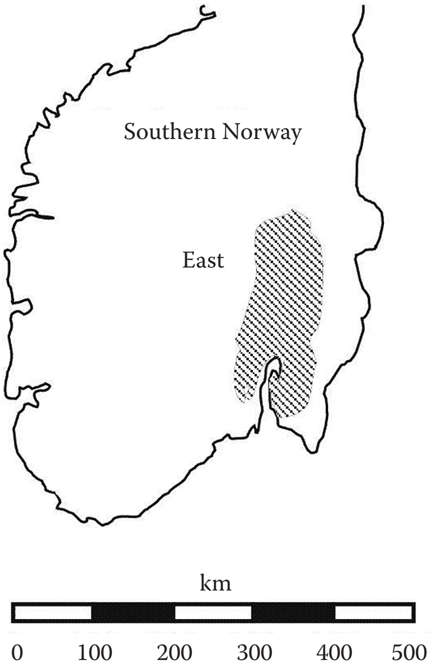

Fig. 1. Location of the study area in East Norway

MATERIALS AND METHODS

The study was focused on six broadleaved tree species: silver birch (*Betula pendula* Roth.), white birch (*Betula pubescens* Ehrh.), black alder (*Alnus glutinosa* Gaertn.), smeckled alder (*Alnus incana* Moench.), European ash (*Fraxinus excelsior* L.) and pedunculate oak (*Quercus robur* L.). In total, 74 experimental sites of naturally occurring pure stands of native Scandinavian deciduous tree species were studied. However, only sites having minimally three of the same soil units (*N* = 36) could be treated statistically and chosen to be reported here. The study area was located in East Norway (Fig. 1).

The soil classification was performed according to the Canadian System of Soil Classification (1998). Soils were classified in great soil groups where up to ten different horizons were described. Different tree species tended to some extent to occupy habitats with different soil types (Table 1). To reflect spatial variation in the soil a design-based sampling was used. An extensive pooling of the soil samples, both from the different walls in the profile together with the same horizons from the sub-pits. The subsoil was sampled from one deep soil pit, whereas the topsoil was sampled from the central soil pit and four shallow sub-pits. Thus, three individual soil samples for particular subsoil horizons and seven individual soil samples for particular topsoil horizons were taken at each study plot.

Twenty basic soil properties were determined in each soil sample and analyzed according to Ogner et al. (1991). Soil physics and chemistry were described

Table 1. Number of study plots of different tree species and soil groups

Soil great group	Tree species						
	Bpe	Bpu	Agl	Ain	Fex	Qro	Sum
Humic Regosol	3		1		6	1	11
Luvic Gleysol	2		3	1			6
Sombric Brunisol	4	1	1				6
Melanic Brunisol	3						3
Eutric Brunisol	6						6
Humo-Ferric Podzol	4						4
Sum	22	1	5	1	6	1	36

Bpe –*Betula pendula*; Bpu – *Betula pubescens*; Agl – *Alnus glutinosa*; Ain – *Alnus incana*; Fex – *Fraxinus excelsior*; Qro – *Quercus robur* by particle size analyses (clay < 0.002 mm; silt 0.002 to 0.06 mm; sand 0.06 to 2.0 mm; gravel > 2.0 mm), bulk density, specific density, porosity, C_{ox} and N_t, C:N ratio, active soil reaction (pH/H_20), exchangeable acidity in the 1M NH_4NO_3 extract, exchangeable cations and anions (Mg, Ca, Mn, Al, S, Fe, B, P and K) by the ICP techniques in the same extract, cation exchange capacity (CEC) and base saturation (BS). All analyses were performed for each particular soil horizon: the main horizons to focus on were selected in the compliance with the stratigraphy of particular soil units.

The data were statistically treated by Shapiro-Wilk test of normality and analysis of variance. Confidence intervals for *t*-scores means and medians were computed by multisample data using the binomial distribution. The comparison of soil characteristics between two horizons were carried out by separate variance *t*- and *F*-tests. The comparisons among more horizons were performed by homogeneity of variance tests, ANOVA and Tukey-HSD multiple comparisons (Jongman et al. 1987; Webster 2001). Using 0.05% as the limit of significance, significantly different pairs and homogeneous subsets were targeted. Non-parametric Cochran test for analyzing randomized complete block designs with the response variable as binary variable (Kendall, Stuart 1979), were commonly used in the statistical treatment. Cochran's test for homogeneity of variances for equal or unequal sample sizes is based on Cochran's cumulative distribution function (cochcdf) and expressed by Cochran's C significance. Estimating differences within the selected soil properties, the initial data from nineteen soil profiles in silver birch stands were used for multiple comparisons of A/A2. Differences in selected soil variables were tested using great soil groups ($N = 5$) as independent variables and soil variables ($N = 7$) in particular soil horizons as dependent variables. The minimum number of study plots for particular great soil group tested was four ($N > 4$). Where only two sets of data were available, the soil properties selected were treated on the level of *t*- and *F*-tests. Where three or more set of data were available, 2-Tail Probability (P(2-tail)), Right-Tail Probability (PNorm) and Cochran's C significance were given.

RESULTS AND DISCUSSION

Results of soil physical and chemical properties from 11 Humic Regosols (Table 2; RN according to Němeček et al. 2001), 6 Luvic Gleysols (Table 2; PG according to Němeček et al. 2001), 15 Brunisols (Tables 2 and 3; KA according to Němeček et al. 2001) and 4 Podzols (Table 3; PZ according to Němeček et al. 2001) under selected broadleaved tree species in East Norway are reported.

Humic Regosol

H horizons

With respect to soil reaction, Humic Regosols showed moderately acid surface organic Layer with pH 5.94. The amount of nitrogen in these soils displayed high share, equally with high contents of phosphorus (244.9 $mmol \cdot kg^{-1}$), sulphur (2.24 $mmol \cdot kg^{-1}$) and very high C:N ratio (~30). On the contrary, there were low amounts of potassium, calcium and magnesium. The mean nitrogen content reached 1.62%, the mean C:N 30 where the SD value of nitrogen is 1.7 and SD of C:N is 3.6. Comparing the findings with an evaluation of organic surface layer on shallow silicate soils (White 2005) and an evaluation of highly productive forest ecosystems developed on pure skeletal detritus (Reintam et al. 2002), the results indicate favourable growth conditions for deciduous tree species. This suggests that there is a high rate of dead organic matter mineralization.

A horizons

Sandy particles showed a high share of the various particle size classes (58.9%). The concentration of potassium was very high, the concentrations of calcium and magnesium low. Both the cation exchange capacity and the C:N ratio were high.

C horizons

An evaluation of physical and chemical properties is of limited value due to the likely very different origin and characteristics of the pedogenetic substrates of the soils even though physical characteristics of C horizon are important for the water supply and chemical ones for nutrient supply. However, low amounts of clay, favourable porosity and the moderately acid conditions showing high BS (71.04 $mmol \cdot kg^{-1}$) were found.

Generally, Humic Regosols showed prominent signs of an intensive humification on weathered rock. This is in contrast to findings by Saarijärvi et al. (2004) performed in medium textured Dystric Regosol at North Savo Research Station (63°10'N, 27°18'E), Finland even when such study plots were situated in much colder climate.

Luvic Gleysol

O horizons

Very high nitrogen (2.26%), phosphorus (235.5 $mmol \cdot kg^{-1}$) and sulphur (1.44 $mmol \cdot kg^{-1}$) contents were found compared to findings of Kőlli

Table 2. Physical and chemical characteristics of Humic Regosols, Luvic Gleysols and Melanic Brunisol, East Norway

(A) Soil physics

Horizon (cm)	< 0.002	0.002–0.06	0.06–2.0	> 2.0	Porosity	Bulk density ($g \cdot cm^{-3}$)
	(%)					
Humic Regosols (N = 11)						
A (6–30)	6.3 ± 3.7	35 ± 8.4	59 ± 14	16 ± 8.0	58 ± 5.3	1.1 ± 0.1
C (30 →)	8.6 ± 7.3	40 ± 17	52 ± 24	30 ± 26	49 ± 4.3	1.4 ± 0.1
Luvic Gleysols (N = 6)						
A2 (18–42)	5.9 ± 2.3	30 ± 20	64 ± 21	8.4 ± 5.7	59 ± 5.8	1.0 ± 0.0
B (42–90)	11 ± 3.4	36 ± 25	54 ± 28	11 ± 9.7	45 ± 6.6	1.4 ± 0.1
C (90 →)	11 ± 8.2	37 ± 18	52 ± 27	13 ± 10	42 ± 6.7	1.5 ± 0.1
Melanic Brunisol (N = 3)						
A (2–19)	5.2 ± 2.6	30 ± 13	65 ± 16	22 ± 9.9	65 ± 0.5	0.9 ± 0.0
B (19–49)	5.4 ± 1.9	27 ± 18	58 ± 22	33 ± 6.1	47 ± 3.7	1.3 ± 0.1
BC (49–75)	5.4 ± 2.1	25 ± 15	70 ± 20	23 ± 8.2	48 ± 9.1	1.4 ± 0.1
C (75 →)	6.2 ± 2.8	40 ± 20	54 ± 15	29 ± 25	44 ± 2.4	1.4 ± 0.1

(B) Soil chemistry

Horizon (cm)	pH	C:N	CEC	exchangeable acidity	BS	N_t	Ca	P	K	Mg	S
			($mmol \cdot kg^{-1}$)		(%)		($mmol \cdot kg^{-1}$)				
Humic Regosols (N = 11)											
H (3–6)	6.0 ± 0.6	30 ± 3.6	143 ± 65	17 ± 7.5	88 ± 3.1	1.6 ± 1.7	89 ± 33	245 ± 128	22 ± 25	15 ± 9.6	2.2 ± 2.7
A (6–30)	5.0 ± 0.7	22 ± 5.6	114 ± 69	15 ± 6.2	87 ± 14	1.1 ± 0.7	82 ± 54	59 ± 47	6.8 ± 4.4	11 ± 7.9	1.0 ± 0.5
C (30 →)	5.5 ± 0.7	21 ± 16	62 ± 62	18 ± 4.6	71 ± 29	0.1 ± 0.1	41 ± 58	2.3 ± 4.8	1.2 ± 1.0	6.7 ± 7.4	0.3 ± 0.5
Luvic Gleysols (N = 6)											
O (0–1)	5.6 ± 0.3	22 ± 4.9	147 ± 72	24 ± 12	83 ± 1.1	2.3 ± 0.8	79 ± 35	236 ± 67	27 ± 28	14 ± 7.7	1.4 ± 0.6
A1 (1–18)	4.5 ± 0.5	18 ± 4.6	51 ± 20	13 ± 6.1	74 ± 16	0.7 ± 0.7	26 ± 15	35 ± 55	5.7 ± 1.9	5.3 ± 3.8	1.0 ± 0.4
A2 (18–42)	5.2 ± 0.2	14 ± 3.0	34 ± 17	13 ± 5.4	63 ± 22	0.1 ± 0.1	15 ± 11	1.7 ± 1.7	3.7 ± 1.6	2.3 ± 1.5	0.4 ± 0.3
B (42–90)	5.4 ± 0.6	19 ± 5.7	47 ± 41	13 ± 2.1	73 ± 28	0.0 ± 0.0	31 ± 31	2.0 ± 1.2	3.6 ± 1.4	8.7 ± 9.7	0.2 ± 0.3
C (90 →)	5.6 ± 0.5	54 ± 34	46 ± 44	14 ± 1.7	71 ± 8.7	0.0 ± 0.0	31 ± 34	2.5 ± 1.6	3.8 ± 2.2	6.7 ± 6.9	0.3 ± 0.3
Melanic Brunisol (N = 3)											
A (2–19)	4.9 ± 0.4	15 ± 2.4	56 ± 22	6.5 ± 3.1	88 ± 31	0.3 ± 0.0	32 ± 46	6.2 ± 1.0	3.6 ± 0.9	12 ± 8.7	1.1 ± 1.1
B (19–49)	4.9 ± 0.2	15 ± 3.3	12 ± 7.6	2.2 ± 0.9	82 ± 25	0.1 ± 0.0	3.6 ± 6.1	1.3 ± 1.0	1.1 ± 0.2	4.5 ± 4.2	0.8 ± 0.8
BC (49–75)	4.7 ± 0.6	17 ± 8.7	24 ± 0.5	8.9 ± 4.0	63 ± 15	0.0 ± 0.1	5.0 ± 7.1	0.6 ± 0.6	1.2 ± 0.1	8.6 ± 11	0.9 ± 1.1
C (75 →)	5.3 ± 0.7	26 ± 20	34 ± 26	7.7 ± 3.1	77 ± 39	0.0 ± 0.0	3.0 ± 5.1	1.7 ± 0.9	1.6 ± 1.3	21 ± 33.5	1.0 ± 1.0

(2002), who stated that the pools of organic matter in Estonian Gleysols did not show a notably positive correlation with soil productivity.

A horizons

Within the topmost horizons, Luvic Gleysols were characterized as sandy (63.7% of sandy particles) and further by average levels of porosity, bulk density, contents of nitrogen, phosphorus, sulphur and potassium. The pH (4.51) and C:N ratio (17.6, resp. 14.4) was lower than what could be expected (VIOLANTE et al. 2002).

B horizons

In general, they were more silty and clayey than A horizons, having medium porosities, high bulk

Table 3. Physical and chemical characteristic of Eutric Brunisol, Sombric Brunisol and Humo-Ferric Podzols, East Norway

(A) Soil physics

Horizon (cm)	< 0.002	0.002–0.06	0.06–2.0	> 2.0	Porosity	Bulk density
	(%)					(g·cm^{-3})
Eutric Brunisol (N = 6)						
A (3–9)	2.3 ± 1.5	22 ± 14.7	76 ± 16.3	24 ± 20.2	58 ± 8.6	1.0 ± 0.2
B (9–45)	1.8 ± 1.4	16 ± 18.8	83 ± 19.4	39 ± 24.1	51 ± 5.0	1.4 ± 0.1
C (45 →)	2.5 ± 1.5	19 ± 16.1	79 ± 17.0	56 ± 28.0	48 ± 4.1	1.4 ± 0.1
Sombric Brunisol (N = 6)						
A (4–17)	2.9 ± 4.6	16 ± 22	81 ± 26	16 ± 13	64 ± 7.9	0.9 ± 0.2
B (17–40)	4.6 ± 3.6	25 ± 16	70 ± 16	34 ± 17	51 ± 5.2	1.3 ± 0.0
BC (40–5)	6.6 ± 3.1	35 ± 5.9	59 ± 21	21 ± 9.3	52 ± 3.8	1.3 ± 0.2
C (55 →)	4.9 ± 3.9	34 ± 14	71 ± 1.9	43 ± 9.1	46 ± 4.4	1.4 ± 0.0
Humo-Ferric Podzols (N = 4)						
A (9–11)	3.8 ± 3.0	41 ± 4.4	55 ± 1.5	21 ± 8.4	51 ± 1.5	1.1 ± 0.2
B1 (11–20)	4.9 ± 2.1	29 ± 9.6	67 ± 4.9	17 ± 5.1	53 ± 5.9	1.2 ± 2.5
B2 (20–36)	2.3 ± 1.9	19 ± 11	79 ± 13	48 ± 19	48 ± 3.7	1.3 ± 0.1
BC (36–50)	2.8 ± 0.9	20 ± 3.2	77 ± 8.1	53 ± 9.2	47 ± 8.9	1.4 ± 0.4
C (50 →)	2.9 ± 1.3	34 ± 28	64 ± 29	53 ± 18	49 ± 5.2	1.4 ± 0.1

(B) Soil chemistry

Horizon (cm)	pH	C:N	CEC	exchangeable acidity	BS	N_t	Ca	P	K	Mg	S
			(mmol·kg^{-1})		(%)		(mmol·kg^{-1})				
Eutric Brunisol (N = 6)											
A (3–9)	5.1 ± 0.4	20 ± 4.3	67 ± 18.4	17 ± 7.3	75 ± 10.0	0.3 ± 0.1	41 ± 18.6	17 ± 16.2	4.1 ± 0.9	4.1 ± 1.6	1.4 ± 0.4
B (9–45)	5.2 ± 0.2	18 ± 5.3	41 ± 20.2	21 ± 9.1	48 ± 16.7	0.1 ± 0.0	16 ± 14.2	5.3 ± 6.1	1.4 ± 0.8	2.0 ± 2.0	1.0 ± 0.4
C (45 →)	5.3 ± 0.5	22 ± 4.0	33 ± 19.0	17 ± 7.9	49 ± 25.0	0.0 ± 0.0	13 ± 12.4	7.2 ± 12.7	1.1 ± 0.5	1.1 ± 1.1	1.0 ± 0.6
Sombric Brunisol (N = 6)											
A (2–4)	5.1 ± 0.7	25 ± 7.1	120 ± 61	24 ± 11	80 ± 1.8	1.8 ± 0.5	76 ± 54	153 ± 88	8.2 ± 2.6	11 ± 7.3	1.3 ± 1.0
B (4–17)	4.6 ± 0.3	18 ± 3.9	130 ± 82	59 ± 30	55 ± 23	0.9 ± 0.6	61 ± 56	40 ± 69	4.5 ± 2.1	4.6 ± 3.1	1.2 ± 0.5
BC (17–40)	5.0 ± 0.4	16 ± 3.4	56 ± 34	29 ± 13	49 ± 32	0.1 ± 0.1	23 ± 16	2.6 ± 1.8	1.4 ± 0.6	1.5 ± 1.8	0.8 ± 0.5
C (40–50)	5.4 ± 0.5	18 ± 0.4	59 ± 36	27 ± 11	55 ± 42	0.0 ± 0.0	28 ± 26	2.5 ± 3.2	1.6 ± 0.9	1.6 ± 2.0	0.7 ± 0.4
Humo-Ferric Podzols (N = 4)											
H (7–9)	4.5 ± 0.7	24 ± 3.4	127 ± 19	16 ± 7.1	88 ± 6.2	1.6 ± 0.4	90 ± 21	97 ± 14	9.6 ± 2.4	10 ± 4.9	1.7 ± 0.6
A (9–11)	4.5 ± 0.5	22 ± 2.4	44 ± 12	17 ± 7.2	62 ± 25	0.1 ± 0.1	21 ± 14	16 ± 12	1.9 ± 0.7	3.8 ± 3.8	0.7 ± 0.5
B1 (11–20)	5.1 ± 0.5	15 ± 4.8	38 ± 5.2	12 ± 3.3	67 ± 8.2	0.1 ± 0.1	21 ± 8.3	24 ± 6.9	1.2 ± 0.3	2.1 ± 0.8	0.9 ± 0.2
B2 (20–36)	4.9 ± 0.8	25 ± 0.2	25 ± 14	17 ± 8.3	32 ± 19	0.0 ± 0.0	5.3 ± 4.4	7.9 ± 6.3	1.2 ± 0.3	0.8 ± 0.7	0.6 ± 0.8
BC (36–50)	5.0 ± 0.5	26 ± 3.2	20 ± 6.3	13 ± 5.7	33 ± 21	0.0 ± 0.0	3.0 ± 1.3	6.7 ± 6.5	1.6 ± 0.4	1.0 ± 1.0	0.9 ± 1.1
C (50 →)	4.9 ± 0.2	34 ± 9.3	29 ± 12	18 ± 6.7	38 ± 5	0.0 ± 0.0	6.9 ± 5.2	5.6 ± 7.0	0.9 ± 0.3	2.6 ± 2.7	0.2 ± 0.0

densities (1.43 g·cm^{-3}), showing mild soil reactions and low exchangeable acidity, relatively higher both CEC, BS and calcium content.

C horizons

The moderately acid horizons (pH 5.59) showed low exchangeable acidities (13.52 mmol·kg^{-1}) and average BS. Luvic Gleysols stocked by alders and silver birch seemed to be relatively fertile soils creating favourable conditions for these tree species. The results presented are in compliance with comprehensive studies about Gleysols in forests done by Mohn et al. (2000) and Hagedorn et al. (2001).

Brunisolic soils

H horizons

Surface organic material from four stands growing on Sombric Brunisols was analyzed. These samples showed high C:N ratios (25.4) and high levels of phosphorus (152.87 mmol·kg^{-1}) and sulphur (1.29 mmol·kg^{-1}), together with relatively high calcium content (76.30 mmol·kg^{-1}), CEC (120.43 mmol·kg^{-1}) and BS (80.5%). Intermediate contents of nitrogen and potassium were found. Differences in chemical parameters of overlying organic layers in Sombric Brunisols is assumed to be due to variation in the decomposition and humification of dead organic matter between the localities (Van der Putten 1997).

A horizons

The levels of porosities, bulk densities, C:N ratios and the amounts of potassium were noticeably similar seen in the light of the very diverse content of phosphorus and levels of exchangeable acidities. Dealing with the particle-size classes, the level of clay and silt contents are more diverse than the gravel content nevertheless the very high level of SD did not allow to draw strong conclusions. However, pH, levels of calcium, magnesium, CEC and BS were found to distinguish the different soils within this great group and also between different soil orders (The Canadian System of Soil Classification 1998).

B horizons

A low variability was found in all physical characteristics whereas the chemical characteristics – especially soil reaction, BS and contents of phosphorus, calcium, and magnesium showed a large variability. C:N ratios and contents of nitrogen and potassium were comparable between the different localities. Large differences were found in pH, contents of sulphur, phosphorus, calcium and magnesium, exchangeable acidities and CEC, while signs of a generally expected natural acidification in B horizons (Bredemeier et al. 1990; Lükewille et al. 1993) have not been found.

C horizons

Considering the characteristics of brunification products (Sumner 2000), a similar nature in the soil physics was confirmed in terms of (*i*) a sandy nature of the parent material (e.g., 78.8% in Eutric Brunisols) and (*ii*) very similar values of porosities and bulk densities. Large variability in soil chemistry was found, e.g. the exchangeable acidity reached 31.82 mmol·kg^{-1} in Sombric Brunisols and only 7.72 mol·kg^{-1} in Melanic Brunisols.

Podzolic order

H horizons

These horizons were strongly acid and, with respect to silver birch litter, the levels of CEC, BS, C:N ratios and exchangeable acidities were at levels found by Anderson et al. (1982) and Pohlman and McColl (1988). Looking at the SD values for sulphur, phosphorus and calcium, they are smaller than we find in most other tables: such nutrient concentrations did not showed a great variability.

A horizons

In contrast to Anderson et al. (1982) and Boyle, Powers (2001), similar contents of silt and sand (41% and 55.1%, respectively) were measured in surface organomineral horizons. In these horizons, low values of soil reaction and high values of C:N ratios were found. The level of both CEC and BS were also found by Giesler et al. (2000).

Upper B horizons

These horizons were characterized by low values of CEC and BS, less acid with equally lower exchangeable acidities compared to other horizons and high contents of sand. Contrasting to the usually high porosity negatively correlated to bulk density, the data showed high porosity together with bulk density: in Table 3, B1 horizon has a porosity 53 and bulk density 1.2, where SD for both characteristics is high (bulk density of 2.5). In addition, there were markedly high concentrations of phosphorus (7.86 mmol·kg^{-1}) and potassium (1.24 mmol·kg^{-1}).

C horizons

C horizons are characterized by relatively high content of sandy particles and high acidity (pH 4.91) combined with much phosphorus (5.55 mmol·kg^{-1}).

Table 4. Multiple comparisons of vertical characteristics for Humic Regosols between soil horizons and selected soil properties

Soil horizons	pH	CEC	Ca
H–A	< 0.001	0.010	0.989
H–C	< 0.001	< 0.001	0.003
A–C	< 0.001	< 0.001	0.004

Values in bold are statistically different ($P < 0.05$)

The concentration of sulphur (0.18 mmol·kg^{-1}) is low compared to other soil orders. Related to massive translocations in the topsoils (Lundström et al. 2000), the other soil parameters ranged within values which are expected.

Effect of tree species on selected soil properties

Comparing the values of C:N and CEC in different soil horizons of Humic Regosol and Luvic Gleysol in plots with silver birch and black alder, no significant differences were found. Similarly to the study of Zerbe (2002) from Central Europe and Reimann et al. (2001) from Northern Europe, the particular chemical parameters of soils in our study sites were not influenced by the presence of the tree species. Our results are in agreement with studies (e.g. Dolman et al. 2001), indicating that other factors, as the chemical composition of the parent material and the soil texture, can discriminate the influence of tree species on soil properties. Equally to results from the study of 104 forest tree species stands by Johansson (2006) at latitude 56–63°N in Sweden focused on site index conversion equations, an important role of soil inorganic stores ought to be taken into mind discussing the interrelationships between the soil properties and the tree species.

Differences among particular soil horizons

The results of the testing for differences in selected soil variables are shown in Tables 4–8. Humic Regosols were tested for differences in physical properties in A and C horizons and for chemical properties in H, A, and C horizons (Table 4). The contents of clay (standard errors, SE: A – 0.29; C – 0.66) and skeletal (SE: A – 1.17; C – 2.46) particles, and porosity (SE: A – 1.31; C – 1.07) were treated on the level of *t*- and *F*-tests. Highly significant differences within the profiles were found for the content of clay (P(2-tail) = 0.04; PNorm = 0.0071), porosity (P(2-tail) = 0.000; PNorm = 0.263), gravel (P(2-tail) = 0.001; PNorm = 0.014). Both pH (Cochran's C significance: 0.76; $P = 0.001$) and CEC (Cochran's C significance: 0.47; $P = 0.001$) showed highly significant differences within the entire depth. For calcium content (Cochran's C significance: 0.14, $P = 0.001$), there are significant differences between

Table 5. Multiple comparisons of vertical soil characteristics for Luvic Gleysols – *P*-values of differences between soil horizons and soil properties

Soil horizons	Clay	Porosity	pH
O–A1			**< 0.001**
O–A2			0.207
O–B			0.106
O–C			0.962
A1–A2			**0.002**
A1–B			**0.002**
A1–C			**< 0.001**
A2–B	**< 0.001**	**< 0.001**	0.999
A2–C	**< 0.001**	**< 0.001**	0.056
B–C	0.179	0.112	**0.046**

Values in bold are statistically different ($P < 0.05$)

Table 6. Multiple comparisons of vertical soil characteristics of Eutric Brunisols – *P*-values of differences between soil horizons and soil properties

Soil horizons	Clay	Gravel	Porosity	pH	CEC
H–A				**0.028**	< **0.001**
H–B				0.350	< **0.001**
H–C				0.925	< **0.001**
A–B	**0.029**	0.237	< **0.001**	0.527	**0.003**
A–C	0.907	**0.018**	< **0.001**	0.098	< **0.001**
B–C	**0.013**	0.348	0.402	0.705	0.482

Values in bold are statistically different ($P < 0.05$)

H–C and A–C, but not between H–A. The values of BS showed non-homogenous variances and could therefore not be analyzed.

Luvic Gleysols (Table 5) were tested for their physical properties in A2, B and C horizons and their chemical properties in O, A1 (upper part), A2 (lower part), B and C horizons. The initial data from six soil profiles were treated. For most horizons, no significant differences were found in the vertical characteristics of the physical properties. The content of clay (Cochran's C significance: 0.29; $P = 0.001$) and porosity (Cochran's C significance: 1.0; $P = 0.001$) were significantly different between organo-mineral topmost and subsurface mineral horizons, but not within subsurface mineral horizons. The pH (Cochran's C significance: 0.07; $P = 0.001$) was significantly different between A1 horizon and all the other horizons, and between B and C horizons. Other than for the A1 horizon, no significant differences were found in soil reaction between the A2 horizon and the other horizons; the same was valid for O horizon, except for a comparison with the A1 horizon (see above). No significant differences in the content of gravel ($P = 0.1544$) were found. Nevertheless, it can be expected that the gravel content affects the quality of these horizons to a great extent making essential differences within the soil depth (Hölscher et al. 2002). Validity of statistical testing for the calcium content was rejected by non-homogenous variances (Cochran's C significance: 0.0048), CEC (Cochran's C significance: 0.0168) and BS (Cochran's C significance: 0.0019) values, which underlined the heterogeneity of such soil units.

Eutric Brunisols (Table 6) were tested for their physical properties in A, B and C horizons and for chemical properties in H, A, B and C horizons. For the clay content, statistical differences were only found between B and both other horizons (Cochran's C significance: 0.29; $P = 0.01$), and for the percentage of porosity, only between A, and both other horizons

Table 7. Multiple comparisons of vertical soil characteristics for Sombric Brunisols – *P*-values of differences between soil horizons and soil properties

Soil horizons	Gravel	Porosity	CEC	BS	Ca
H–A			0.348	**0.011**	0.661
H–B			< **0.001**	**0.001**	**0.002**
H–BC			< **0.001**	0.053	**0.001**
H–C			**0.009**	0.407	0.668
A–B	**0.007**	< **0.001**	**0.007**	0.854	**0.047**
A–BC	0.591	< **0.001**	< **0.001**	0.958	**0.027**
A–C	< **0.001**	< **0.001**	< **0.001**	0.390	0.999
B–BC	0.103	0.167	0.995	0.463	0.999
B–C	0.132	0.090	< **0.001**	0.066	**0.045**
BC–C	**0.001**	**0.001**	< **0.001**	0.790	**0.026**

Values in bold are statistically different ($P < 0.05$)

Table 8. Multiple comparisons of vertical soil characteristics for Humo-Ferric Podzoils – *P*-values of differences between soil horizons and soil properties

Soil horizons	Clay	Gravel	pH	CEC	BS
H–A			0.999	**< 0.001**	**0.001**
H–B1			0.092	**< 0.001**	**0.004**
H–B2			0.328	**< 0.001**	**< 0.001**
H–BC			**0.036**	**< 0.001**	**< 0.001**
H–C			0.159	**< 0.001**	**< 0.001**
A–B1	0.570	0.721	0.054	0.945	0.981
A–B2	0.280	**< 0.001**	0.213	**0.043**	**0.001**
A–BC	0.424	**< 0.001**	**0.020**	**0.004**	**< 0.001**
A–C	0.471	**< 0.001**	0.096	0.062	**0.002**
B1–B2	**0.019**	**< 0.001**	0.971	0.219	**< 0.001**
B1–BC	**0.035**	**< 0.001**	0.996	**0.028**	**< 0.001**
B1–C	**0.041**	**< 0.001**	0.999	0.292	**0.001**
B2–BC	0.998	0.993	0.813	0.875	0.971
B2–C	0.995	0.969	0.997	0.999	0.965
BC–C	0.999	0.999	0.967	0.790	0.636

Values in bold are statistically different ($P < 0.05$)

(Cochran's C significance: 0.06; $P = 0.0$). The gravel content (Cochran's C significance: 0.06; $P = 0.02$) was only found to be statistically different between A and C horizons, i.e. any content of gravel in B horizon had no relation to contents in other horizons. Non-homogenous variances were found among all BS (Cochran's C significance: 0.019) and calcium (Cochran's C significance: 0.0065) data. Almost all horizons, except for the comparison between B and C horizons, were statistically highly different between each other for CEC (Cochran's C significance: 0.74; $P = 0.0$). Significant differences in pH were only found between H and A horizons (Cochran's C significance: 0.56; $P = 0.03$). The results confirmed the similar pattern of brunification in different ecological circumstances where the time of weathering and content of primary iron compounds form taxonomically related soil units (Nielsen, Jørgensen 2003).

Sombric Brunisols (Table 7) were tested for their physical properties in A, B, BC and C horizons, and for their chemical properties in H, A, B, BC and C horizons. The clay content and the pH were not statistically treatable due to non-homogenous variances. Generally, the other selected soil properties showed a bit larger variability in the Sombric Brunisols than in the Eutric Brunisols. Most horizons showed significant differences among each other for gravel content (Cochran's C significance: 0.07; $P = 0.0$), porosity (Cochran's C significance: 0.8; $P = 0.0$), calcium content (Cochran's C significance: 0.02; $P = 0.0002$) and CEC (Cochran's C significance: 0.69; $P = 0.0$). On the contrary, the Table 7 does not show significant differences between A and B horizons for BS and not among H horizons and all others.

Humo-Ferric Podzols (Table 8) were tested for their physical properties in A, B1, B2, BC and C horizons, and for their chemical properties in H, A, B1, B2, BC and C horizons. Significant differences were detected between most horizons in contents of gravel ($P < 0.001$), CEC ($P < 0.001$) and BS ($P < 0.001$). Clay contents ($P = 0.012$) and pH ($P = 0.006$) only showed significant differences among a few horizons. No significant differences were found in porosity or calcium contents between soils in this great soil group.

Evaluation of soil properties of particular soil units in silver birch stands

Multiple comparisons of the various soil properties in the A and A2 horizons were tested in five soil units found in the silver birch stand (Table 9), derived from three profiles of Humic Regosols, two profiles of Luvic Gleysols, six profiles of Eutric Brunisols, four profiles of Sombric Brunisols and four profiles

Table 9. Multiple comparisons of A/A2 horizon for particular soil units in silver birch stands – *P*-values of differences between soil units and soil properties

Soil units	Clay	Porosity	pH	CEC	BS	Ca
Eutric Brunisol – Regosol	< **0.001**	0.971	0.895	**0.004**	0.108	0.098
Eutric Brunisol – Gleysol	**0.003**	0.969	0.899	**0.006**	0.736	0.540
Eutric Brunisol –Podzol	0.174	< **0.001**	0.080	**0.020**	0.491	0.477
Eutric Brunisol – Sombric Brunisol	0.734	0.507	0.243	< **0.001**	0.394	0.194
Sombric Brunisol – Regosol	**0.002**	0.344	0.845	< **0.001**	**0.009**	0.977
Sombric Brunisol – Gleysol	**0.027**	0.412	0.158	< **0.001**	0.999	**0.042**
Sombric Brunisol – Podzol	0.823	< **0.001**	0.970	< **0.001**	0.999	**0.019**
Regosol – Gleysol	0.910	0.999	0.590	< **0.001**	**0.045**	**0.024**
Regosol – Podzol	**0.010**	**0.001**	0.529	< **0.001**	**0.012**	**0.011**
Gleysol – Podzol	0.125	**0.004**	0.066	0.665	0.999	0.999

Values in bold are statistically different ($P < 0.05$)

of Humo-Ferric Podzols. Detecting no regular patterns between the soil units compared were given. Silver birch stands were found on sites which topsoil (*i*) significantly differed in their cation exchange capacities, and (*ii*) did not differ significantly in their pH and BS. The calcium contents (Cochran's C significance: 0.0506; $P = 0.003$) and porosities (Cochran's C significance: 0.07; $P = 0.0$) of the topsoils did not show any straightforward tendencies. Nevertheless, the results indicate an uncertainty how to evaluate the relationship between pH, BS and silver birch: silver birch stands were found on soils where mean pH varies between 4.5 and 5.1 with SD values up to 0.5. Furthermore, the results indicate that values of BS (Cochran's C significance: 0.99; $P = 0.008$) of the topsoil in the studied silver birch stands play an important role for an occurrence of this species irrespectively of the particular soil units. Further, both CEC (Cochran's C significance: 1.0; $P = 0.0$) and clay contents (Cochran's C significance: 0.1932; $P = 0.0001$) were specifically related just to their soil units and not to the presence of silver birch. Nevertheless, a large spatial variation was expected. Hölscher et al. (2001) showed similar variation in an evaluation of the nutrient pools of organic layers and the mineral soil in forest stands dominated by silver birch.

CONCLUSIONS

Referring to properties of soils under broadleaved tree species, Humic Regosols in East Norway showed prominent signs of an intensive humification on weathered rock. Luvic Gleysols displayed values of fertile soils. Brunisols manifested a similar nature in the soil physical properties and very varying soil chemistry. In Podzols, particular horizons showed particular patterns: (*i*) H horizons were strongly acid with a great variability in nutrient contents, (*ii*) A horizons showed similar contents of silt and sand, low values of soil reaction and high values of C:N ratios, (*iii*) upper B horizons were characterized by low CEC and BS values, and less acidity than other horizons with equally low exchangeable acidities, and (*iv*) C horizons were characterized by relatively high content of sandy particles, low soil reaction and sulphur content, and very high phosphorus content.

There were no significant differences in values of C:N and CEC in different soil horizons of Humic Regosol and Luvic Gleysol on plots with silver birch and black alder, i.e. the levels of C:N and CEC were not influenced by the presence of those tree species in our study sites.

Dealing with differences among particular soil horizons, Humic Regosols showed highly significant differences within the entire depth for the contents of clayey and gravel particles, porosity, pH and CEC. In the Luvic Gleysols, nearly no significant differences in the vertical characteristics were found. Almost all horizons of Eutric Brunisols were highly statistically different for CEC. The multiple comparisons of properties in horizons of Sombric Brunisols showed more different values within their vertical distribution than in Eutric Brunisols, which showed most significant relationships. Here, most horizons showed significant differences among each other for gravel content, porosity, calcium content and CEC. In terms of Humo-Ferric Podzols, there were found significant differences in the gravel content and BS among most horizons.

No regular patterns were found in selected soil properties when tested between various soil units in silver birch stands. Furthermore, silver birch stands were found on sites which topsoil (*i*) significantly differed in their cation exchange capacities, (*ii*) did not differ significantly in their pH values, and (*iii*) mostly differed in their clay contents, and (*iv*) mostly did not differ in BS. The results indicate that values of BS in the topsoil play an important role for occurrence of silver birch stands irrespectively of the particular soil units. In contrast, both pH, CEC and clay contents were specifically related just to their soil units and not to the presence of silver birch.

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