

Chapter 3

Soil Properties

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3.1 Introduction

The soils at the three beech forest sites, Göttinger Wald, Zierenberg, and Solling, are derived from different bedrocks and cover the whole acidity range ($\text{pH}(\text{H}_2\text{O})$ 3–7) of German soils (Wolff and Riek 1997). The bedrock of the Göttinger Wald soil is limestone. Its carbonate buffer is responsible for the high soil $\text{pH}(\text{H}_2\text{O})$ between 5.7 and 6.9 in the surface 10 cm of the mineral soil. According to Wolff and Riek (1997), only 9% of the German forest soils have soil $\text{pH}(\text{H}_2\text{O}) > 6.2$ and are buffered by carbonate. Of German forest soils, 59% have a $\text{pH}(\text{H}_2\text{O}) < 4.2$, and 32% a $\text{pH}(\text{H}_2\text{O})$ between 4.2 and 6.2. A representative soil of the lower pH range is the Solling soil, derived from loess, with a $\text{pH}(\text{H}_2\text{O})$ of 3.4–3.8 and a very high content of aluminum and protons. Representative of the third group is the soil at the Zierenberg site on basaltic rock which is free of carbonate, has a slightly lower $\text{pH}(\text{H}_2\text{O})$ than Göttinger Wald soil (5.2–5.7) but is very rich in Mg and P, two of the most important plant nutrients in forest ecosystems. The soil properties of the three sites will be described in detail regarding the parent material, the mineral content of the soils, soil texture, the chemical status, the prevailing systems for buffering of produced and deposited acidity, the nutrient status and the organic layer types of the soils.

3.2 Parent Material, Mineral Composition, Soil Texture

The study sites were not covered by glaciers during the Pleistocene, but were influenced by peri-glacial processes such as cryoturbation, solifluction, erosion and loess deposition. The soils have developed during the last 10,000 years (Holocene) and are thus relatively young.

The minerals of the soil forming Triassic limestone at *Göttinger Wald* are calcite (CaCO_3 , 940 g kg^{-1}), dolomite (Ca, MgCO_3 , 2 g kg^{-1}), and siderite (FeCO_3 , 4 g kg^{-1}) (Thöle and Meyer 1979). The horizontally bedded rock consists of

Table 3.1 Soil texture and gravel content of the soils at Göttinger Wald (Brumme 1986), Zierenberg, and Solling (Beese 1986) sites

	Depth cm	Soil texture ^a			Gravel %
		Clay %	Silt %	Sand %	
Göttinger Wald	0–5	36	61	3	21
	5–10	41	57	2	12
	10–20	39	59	2	23
	20–30	54	45	1	39
	30–60	30	53	17	40
	60–90	23	61	16	57
Zierenberg	0–5	13	79	8	5
	5–10	12	78	10	15
	10–20	14	74	12	20
	20–40	14	76	10	25
	40–80	9	77	14	30
Solling	0–10	17	57	26	15
	10–20	18	55	27	9
	20–30	17	55	28	9
	30–40	19	51	30	10
	40–50	16	53	31	10

^aAs fraction of fine earth, clay (<2 μm), silt (2–60 μm), sand (60 μm –2 mm), gravel (>2 mm) (British Standards Institution)

solid plates of a few centimetres thickness, which are separated by thin silty layers of a few millimetres thickness, and are vertically broken by endogenic processes below 100 cm depth. In the upper 100 cm, the nearly horizontal stratification of the limestone is completely disturbed by cryoturbation. Dissolved limestone leached out as $\text{Ca}(\text{HCO}_3)_2$. Only 5% of the limestone remained as non-calcareous residue and formed the soil at Göttinger Wald. The predominant particle size of the non-calcareous residue (analyzed after dissolving the rock with HCl) consists of clay (58%), silt (41%), and of quartz (310 g kg^{-1}), illite (200 g kg^{-1}), montmorillonite (150 g kg^{-1}), mica (140 g kg^{-1}), feldspar (100 g kg^{-1}), chlorite (50 g kg^{-1}), and vermiculite (40 g kg^{-1}) (Thöle and Meyer 1979).

The skeleton content decreases from the subsoil upward, the clay content of the soil reaches its maximum between 20 and 30 cm (Table 3.1). The decrease of gravel content in the surface soil (<20 cm) indicates an admixture of loess which is reflected also in the higher content of quartz in the fine soil (Table 3.2). Within the upper 20 cm, the calcite content is negligible, but calcite is the most abundant mineral below 20 cm depth.

The parent material at *Zierenberg* is tertiary basaltic debris overlying Triassic limestone with a thickness of the basalt decreasing downslope from 100 cm to around 10 cm (Jochheim 1992). The main research area is located on the upper midslope. Its soil is moderately gravelly and dominated by silt (70–80%) which is partly derived from basalt weathering but also from loess deposits. This is indicated by the high quartz content but of the illite/muscovite components (Table 3.3). Of basaltic origin are the Mg-bearing minerals pyroxene, hornblende, olivine and

Table 3.2 Mineral composition of the soils (g kg^{-1}) (fine earth <2 mm) at different depths (cm) at the Göttinger Wald site

	0–5	5–10	10–20	20–30	30–40
Quartz	300	300	200	220	120
K-Feldspar	20	20	10	30	30
Albite	20	20	10	10	10
Calcite	0	10	20	390	500
Fe Minerals	10	10	10	10	10
Anatas	4	4	4	4	4
Kaolinite	71	64	67	20	13
Mg Chlorite	0	0	7	4	0
Illite	260	230	200	140	230
Vermiculite	170	170	230	140	78
Al Vermiculite	140	170	240	30	7

Table 3.3 Mineral composition of the soils (g kg^{-1}) (fine earth <2 mm) at different depths (cm) at the Zierenberg site (Butz-Braun, personal communication)

	0–5	5–10	10–20	20–40	40–80
Quartz	260	260	270	270	200
Feldspar	90	90	130	100	100
Hornblende	10	10	20	20	20
Pyroxene	100	100	100	80	80
Olivine	10	20	40	20	0
Kaolinite	60	40	50	60	30
Chlorite	0	10	10	20	0
Vermiculite	0	50	90	40	40
Illite/Muscovite	300	340	190	260	170
Smectite	170	80	140	130	360

smectite. The high content of Mg-rich minerals marks an important difference to the soil at the Göttinger Wald site. Moreover, basalt is known to contain between 7 and 30 g kg^{-1} of the phosphorus mineral apatite (Wedepohl 1968).

The bedrock at *Solling* is Triassic sandstone (>140 cm depth) which is covered with loess. The gravel content of the loess is low in the upper 60 cm (Table 3.1) and steadily increases between 60 and 140 cm depth indicating an admixture with weathered sandstone fragments by solifluction (Benecke 1984). The predominant minerals of the Triassic sandstone are quartz ($450\text{--}680$ g kg^{-1}), illite and mica ($100\text{--}250$ g kg^{-1}) and K-feldspar ($80\text{--}200$ g kg^{-1}) (Deutschmann 1994). The sandstone layer below the solifluction layer has higher contents of illite and mica ($660\text{--}740$ g kg^{-1}) and a lower content of quartz ($170\text{--}260$ g kg^{-1}). Therefore, the mineral composition of the soil shows an increasing illite content with depth from about $60\text{--}90$ g kg^{-1} in the surface 30 cm to about 284 g kg^{-1} between 150 and 200 cm depth (Table 3.4). The quartz content decreases in the same direction from about 740 to 470 g kg^{-1} .

Table 3.4 Mineral composition of the soils (g kg^{-1}) (fine earth <2 mm) at different depths (cm) at the Solling site

	0–5	5–10	10–20	20–30	40–50	80–100	150–200
Quartz	740	720	700	690	680	640	470
K-Feldspar	80	120	130	130	120	120	160
Albite	20	20	15	15	15	0	0
Fe Minerals	13	15	17	17	17	17	30
Anatas	5	5	5	5	5	5	5
Kaolinite	33	26	27	25	34	65	34
Mg Chlorite	0	0	1	1	2	0	0
Mixed layer Chlorite/Vermiculite	0	0	0	0	0	0	10
Illite	81	62	69	89	109	147	284
Mixed layer Illite/Vermiculite	5	6	8	4	5	0	0
Vermiculite	6	10	11	3	0	0	0
Al Vermiculite	0	5	6	21	13	03	0
Vermiculite de-Al	17	11	11	0	0	0	0
Smectite	0	0	0	0	0	3	7

3.3 Soil Types, Soil pH, and Buffer Systems of Soils

The study sites differ with respect to the buffer systems indicated by the pH of the soils. The pH increases with depth and shows marked differences among the sites (Fig. 3.1). At the *Göttinger Wald* site, the relatively high pH of the soil is stabilized by a high buffer capacity and a high buffer rate (carbonate buffer range, $\text{pH}(\text{H}_2\text{O}) > 6.2$, Ulrich 1981, 1987), except of the carbonate free parts of the topsoil and at some places at deeper soil depths where admixture with loess material occurs. About 26% of the soils at the *Göttinger Wald* research site are shallow (Ah–Cv soils, soil depth <20 cm) and are classified as *Rendzic Leptosols* according to the FAO/UNESCO classification, or as *Rendzina* in the German classification (Meiwes and Beese 1988). They are still rich in carbonate in the Ah-horizon and have high soil $\text{pH}(\text{CaCl}_2)$ values (6.1–7.0). The dominant soils at the *Göttinger Wald* research site are up to or >30 cm deep and have a Ah–Bv–Cv profile (*Calcaric Cambisol*, FAO/UNESCO classification, or *Terra fusca – Rendzina*, German classification). Occasional pockets of soils with a thicker loess deposit occur. The *Calcaric Cambisols* are often free of carbonate in the topsoil so that the $\text{pH}(\text{CaCl}_2)$ may drop down to 4.7. The prevailing buffer material in carbonate free soil layers are silicates (silicate buffer range, $\text{pH}(\text{H}_2\text{O})$ 5–6.2). The dominant soil type *Terra fusca–Rendzina* has a $\text{pH}(\text{H}_2\text{O})$ between 5.5 (min) and 6.9 (max) in the 0–10 cm depth depending on the content of carbonate (Table 3.5). This soil type is located between the carbonate and silicate buffer range. With increasing depth, soil $\text{pH}(\text{H}_2\text{O})$ may increase up to 8 indicating that the deeper soil is buffered by carbonate.

The soil at *Zierenberg* is carbonate free except in the 80–100 cm depth where some admixture from the underlying limestone was found (Jochheim 1992). Soil $\text{pH}(\text{H}_2\text{O})$ increased from 5.3 in the 0–20 cm depth to 6 in the 40–80 cm depth

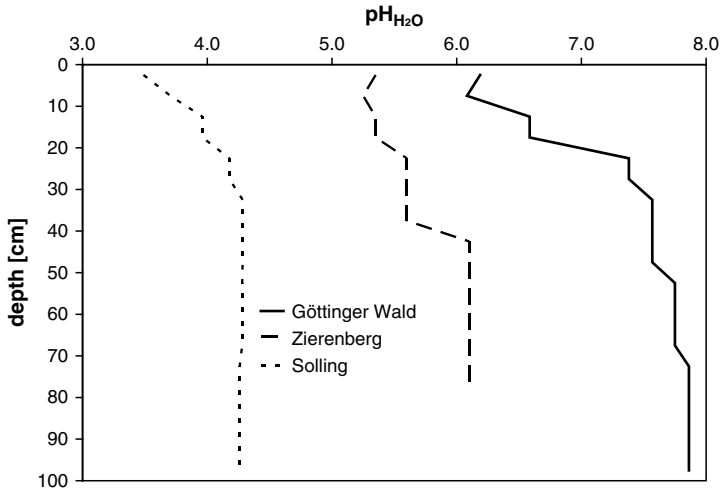


Fig 3.1 Depth functions of pH (H₂O) for Göttinger Wald, Zierenberg, and Solling

(Table 3.5). These values are thus lower than those found in the Göttinger Wald soil, and the soils are primarily assigned to the silicate buffer range. Because of high acidity in stemflow fluxes (Chap. 15, this volume), the soils in the vicinity of stems have been more acidified than those in the inter-stem areas. At the Zierenberg site, the soil pH(H₂O) is 1.2 units lower near the stems (20 cm distance) than within the stems in the 0–10 cm depth, and by 0.4 units in the 40–60 cm depth (Jochheim 1991). The soil type is classified as *Eutric Cambisol* (FAO/UNESCO classification) (*Braunerde*, *Ranker-Braunerde*, German classification).

The mineral soil at the *Solling* site is free of carbonates and has low pH (pH(H₂O)) which slightly increased with depth from 3.4 to 4.3 (Table 3.5). The low pH is primarily related to low amounts of fast weathering minerals. The relatively high silicate content consists mainly of resistant phyllosilicates (mica, illite) and K-feldspar (Table 3.4). A low buffer rate and high acid load has resulted in a soil pH of the aluminum buffer range within the top 30 cm (Al-buffer range, pH(H₂O) < 4.2). Slightly higher soil pH(H₂O) exists below 30 cm depth (exchange buffer range, pH(H₂O) 5–4.2). Values below pH(CaCl₂) 4.0 were found down to a depth of 6 m (Meiwes et al. 1994). The soil is classified as *Dystric Cambisol* (FAO/UNESCO classification) and *podsolige Braunerde* (German classification).

3.4 Cation Exchange Capacity, and Exchangeable Cations

The composition of a cation exchange complex is an expression of the acid–base status of a soil. The three study sites show big differences in their cation exchange composition (Table 3.6). At the *Göttinger Wald* site, more than 95% of the

Table 3.5 Soil chemical characteristics (mean and standard deviation (in brackets)) except for pH (min and max values are given) of the soils at Göttinger Wald (soil inventory in 1995), Zierenberg (soil inventory in 1996), and Solling (soil inventory in 1993), (Göttinger Wald and Solling: $n = 6$, each is a mixture of four samples) (Zierenberg: $n = 4$)

	Depth cm	BD g cm^{-3}	pH _{H₂O}	pH _{KCl}	CaCO ₃ g kg^{-1}	C _{org} g kg^{-1}	N g kg^{-1}	P $\mu\text{g g}^{-1}$	C/N g g^{-1}	C/P g g^{-1}
Göttinger Wald	L/F	-	5.52 (5.33–5.73)	5.16 (4.94–5.44)	0	445 (14)	13 (1)	527 (54)	34.5 (2.3)	854 (13.8)
	0–5	0.94	6.19 (5.66–6.76)	5.57 (4.99–6.22)	23.9 (44.5)	81.7 (8.7)	6.1 (0.6)	696 (110)	13.3 (0.3)	118 (9.3)
	5–10	0.96	6.08 (5.47–6.91)	5.19 (4.49–6.48)	5.4 (2.5)	56.9 (10.0)	4.9 (0.8)	637 (126)	11.7 (0.5)	89.7 (6.4)
	10–20	1.06	6.59 (6.12–7.35)	5.86 (5.27–6.96)	85.3 (88.4)	42.9 (8.2)	3.7 (0.7)	554 (95)	11.6 (0.4)	77.4 (6.6)
	20–30	1.27	7.38 (7.13–7.59)	6.77 (6.38–7.22)	127 (77.1)	29.6 (4.7)	2.6 (0.3)	462 (45)	11.4 (0.4)	63.8 (5.2)
	30–40	1.33	7.57 (7.31–7.72)	7.07 (6.75–7.59)	255 (98.4)	17.4 (3.0)	1.6 (0.4)	340 (66)	11.0 (1.7)	52.5 (14.4)
	40–50	1.33	7.75 (7.58–7.86)	7.11 (6.79–7.65)	283 (98.4)	16.7 (3.0)	1.4 (0.4)	349 (66)	12.1 (1.7)	46.4 (14.4)
	50–70	1.84	7.86 (7.69–7.97)	7.29 (6.97–7.66)	343 (90)	9.9 (1.6)	0.7 (0.3)	269 (72)	17.3 (7.0)	37.5 (6.1)
	70–80	1.82	7.81 (7.78–7.84)	7.31 (7.25–7.38)	186 (10.7)	11.3 (1.0)	1.1 (0.1)	439 (23)	10.8 (0.6)	25.8 (3.6)
	Zierenberg	F	-	5.40 (4.60–5.80)	4.95 (4.10–5.30)	0	397 (16)	20.0 (1.3)	1145 (161)	20.0 (1.0)
Solling	0–5	1.10	5.43 (5.3–5.7)	4.8 (4.7–5.0)	0	48.0 (3.2)	4.1 (0.4)	1218 (185)	11.9 (1.0)	40.1 (6.1)
	5–10	1.20	5.28 (5.2–5.4)	4.58 (4.5–4.7)	0	35.8 (3.3)	3.1 (0.4)	1178 (192)	11.7 (0.7)	30.8 (4.0)
	10–20	1.30	5.38 (5.3–5.5)	4.68 (4.6–4.8)	0	27.0 (1.4)	2.5 (0.2)	1156 (206)	11.1 (0.8)	23.9 (4.5)
	20–40	1.40	5.63 (5.5–5.8)	4.83 (4.7–5.0)	0	15.3 (3.4)	1.4 (0.3)	1100 (194)	10.9 (1.1)	14.3 (4.6)
	40–80	1.45	6.1 (6.0–6.2)	5.3 (5.2–5.4)	0	5.3 (1.3)	0.6 (0.1)	1275 (288)	8.7 (0.9)	4.3 (1.5)
	L	-	4.75 (4.44–4.90)	3.91 (3.57–4.05)	0	494 (13)	25 (1)	1238 (76)	19.6 (0.6)	400 (22.4)
	F	-	3.85 (3.69–3.98)	2.87 (2.83–2.92)	0	444 (12)	23 (1)	979 (30)	19.5 (0.4)	454 (20.4)
	H	-	3.48 (3.35–3.62)	2.76 (2.68–2.88)	0	285 (65)	15 (3)	964 (98)	18.8 (0.8)	298 (67.8)
	0–5	1.04	3.49 (3.44–3.55)	2.84 (2.76–2.89)	0	61.5 (19.4)	3.2 (0.9)	505 (19)	18.8 (1.8)	120.9 (34.5)
	5–10	1.23	3.70 (3.60–3.76)	3.12 (2.99–3.28)	0	36.0 (15.0)	1.9 (0.6)	475 (16)	18.7 (2.5)	80.6 (35.8)
10–20	1.19	3.96 (3.90–4.04)	3.46 (3.32–3.62)	0	24.8 (3.7)	1.5 (0.2)	370 (25)	17.0 (1.2)	67.0 (8.5)	
20–30	1.30	4.18 (4.14–4.22)	3.80 (3.68–3.92)	0	17.5 (1.6)	1.2 (0.1)	345 (14)	15.2 (0.8)	50.8 (3.1)	
30–50	1.48	4.28 (4.24–4.48)	4.03 (3.94–4.13)	0	10.8 (0.5)	0.8 (0.1)	299 (26)	12.9 (0.5)	36.2 (3.0)	
50–70	1.55	4.28 (4.23–4.42)	3.98 (3.93–4.07)	0	4.0 (1.8)	0.4 (0.1)	234 (32)	11.0 (4.6)	16.9 (7.0)	
70–100	1.55	4.26 (4.17–4.37)	3.83 (3.77–3.90)	0	2.2 (0.8)	0.3 (0.0)	253 (52)	7.0 (2.6)	9.1 (4.1)	

Table 3.6 Exchangeable cations, cation exchange capacity (CEC, NH_4Cl extraction for Solling and Zierenberg, BaCl_2 extraction for Göttinger Wald), and base saturation (BS) (mean and standard deviation (in brackets)) of the soils at Göttinger Wald (soil inventory 1995), Zierenberg (mineral soil inventory in 1996) and Solling (soil inventory 1993) (Göttinger Wald and Solling: $n = 6$, each is a mixture of four samples) (Zierenberg: $n = 4$)

Depth cm	CEC $\text{mmol}_c \text{kg}^{-1}$	Ca %	Mg %	K %	Na %	Mn %	Al %	Fe %	H %	BS %
Göttinger Wald										
0–5	480 (114)	95 (1.2)	3.1 (0.7)	1.6 (0.5)	0.2 (0.1)	–	–	–	–	–
5–10	435 (142)	96 (1.2)	2.4 (0.6)	1.4 (0.5)	0.3 (0.1)	–	–	–	–	–
10–20	439 (113)	97 (0.6)	1.8 (0.3)	1.1 (0.2)	0.3 (0.1)	–	–	–	–	–
20–30	406 (38.6)	97 (0.3)	1.3 (0.2)	1.0 (0.2)	0.2 (0.1)	–	–	–	–	–
30–40	310 (68.8)	97 (0.2)	1.2 (0.2)	1.2 (0.1)	0.2 (0.1)	–	–	–	–	–
40–50	295 (54.3)	97 (0.2)	1.2 (0.2)	1.3 (0.2)	0.2 (0.0)	–	–	–	–	–
50–70	130 (142)	97 (0.4)	1.1 (0.3)	1.6 (0.2)	0.3 (0.1)	–	–	–	–	–
70–80	334 (27.9)	97 (0.1)	1.2 (0.2)	1.4 (0.0)	0.3 (0.0)	–	–	–	–	–
Zierenberg										
0–5	154 (10)	64 (4)	29 (4)	3.9 (0.6)	0.2 (0.1)	1.6 (0.4)	1.2 (0.3)	0.1 (0.0)	0	97 (1)
5–10	124 (18)	60 (4)	30 (6)	4.4 (0.7)	0.2 (0.1)	1.4 (0.3)	4.7 (2.7)	0.2 (0.0)	0.02 (0.05)	94 (3)
10–20	111 (8)	58 (4)	31 (6)	3.7 (2.3)	0.3 (0.1)	1.2 (0.3)	5.2 (1.8)	0.2 (0.0)	0	93 (2)
20–40	104 (18)	60 (3)	35 (5)	2.1 (1.9)	0.4 (0.1)	0.6 (0.2)	1.7 (1.0)	0.2 (0.0)	0	98 (1)
40–80	146 (12)	59 (6)	38 (6)	1.0 (0.3)	0.6 (0.1)	0.1 (0.1)	0.3 (0.0)	0.2 (0.0)	0	99 (0)
Solling										
0–5	120 (33.0)	3.4 (0.8)	1.4 (0.2)	1.5 (0.1)	0.5 (0.2)	0.4 (0.1)	64.5 (3.5)	8.7 (0.8)	19.7 (4.2)	6.8 (1.1)
5–10	110 (20.2)	1.8 (0.3)	0.9 (0.1)	1.1 (0.2)	0.5 (0.1)	1.5 (0.6)	79.2 (3.5)	4.7 (1.5)	10.4 (2.3)	4.2 (0.4)
10–20	86.7 (11.9)	1.5 (0.1)	1.0 (0.4)	1.2 (0.1)	0.7 (0.3)	2.1 (0.4)	89.4 (2.1)	1.3 (0.8)	2.9 (1.9)	4.3 (0.8)
20–30	60.6 (11.6)	2.4 (3.0)	1.1 (0.9)	1.3 (0.1)	0.8 (0.5)	1.3 (0.6)	83.8 (25.7)	1.7 (3.4)	7.6 (18.4)	5.6 (4.4)
30–50	45.7 (5.1)	1.3 (0.3)	0.9 (0.3)	1.7 (0.2)	0.7 (0.1)	1.2 (0.2)	94.0 (0.6)	0.1 (0.1)	0.0 (0.0)	4.7 (0.7)
50–70	49.7 (4.2)	1.4 (0.5)	0.8 (0.2)	2.1 (0.1)	0.8 (0.4)	1.0 (0.3)	93.9 (0.9)	0.1 (0.1)	0.0 (0.0)	5.1 (0.6)
70–100	56.0 (15.2)	0.9 (0.2)	1.0 (0.5)	2.4 (0.2)	0.6 (0.2)	0.9 (0.5)	94.2 (0.7)	0.1 (0.0)	0.0 (0.0)	4.8 (0.4)

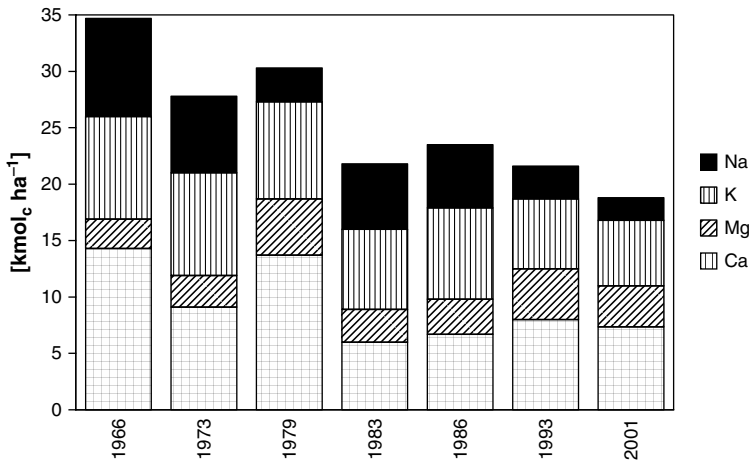


Fig. 3.2 Pools of exchangeable base cations in the mineral soil (0–50 cm) at the Solling site between 1966 and 2001 (for the calculation, an average bulk density was used which did not change significantly over the period) (Meessenburg et al. 1999)

exchange sites of the *Terra fusca – Rendzina* are occupied by Ca. Base saturation is mostly 100% for the whole soil profile. However, where loess has accumulated, pH values may be lower and exchangeable Al may appear in low concentrations in the 5–10 cm depth indicating the occurrence of silicate weathering. The cation exchange capacity (CEC) is about 3–4 times higher at this site than at the Solling and Zierenberg sites. At the *Zierenberg* site, the composition of the cation exchange complex is more balanced. About 60% of the exchange sites are occupied by Ca and 29–38% by Mg. Base saturation is less than 100% due to the presence of acid cations. At *Solling*, the base saturation is <7% in the upper 100 cm soil. Al is the dominating ion at the exchange sites with proportions up to 94%. Fe and H⁺ account for 9–20% of exchange sites in the top soil, respectively, indicating a very strong acidification. Analysis of a soil core down to 30 m depth revealed a base saturation below 25% within the upper 6 m depth and 25–80% between 6 and 8 m depth (Meiwes et al. 1994). Below 8 m depth, base saturation is above 80%. Soil inventories conducted 7 times between 1966 and 2001 indicated that base cation pools in the Solling soil was decreasing during this period (Fig. 3.2). Nevertheless, a trend towards some re-translocation of base cations from the mineral soil into the organic layer was apparent at the Solling site, as was indicated by an increase in thickness of the organic layer during the last 30 years (Meiwes et al. Chap. 4, this volume).

3.5 Nutrient Status of Soils and Organic Layer Types

Soils are sources of nutrients for the plants as a result of processes such as mineral weathering, cation exchange and mineralization of organic matter. Exchangeable nutrients are highly available and Table 3.7 show large differences between the

Table 3.7 Total contents of exchangeable nutrients (kg ha^{-1}) in the mineral soil (0–100 cm depth) of Göttinger Wald, Zierenberg, and Solling sites

Site	K_{ex}	Ca_{ex}	Mg_{ex}
Göttinger Wald	1,100	49,400	430
Zierenberg	1,300	16,400	7,400
Solling	520	230	83

sites. Exchangeable K content decreases in the order Zierenberg, Göttinger Wald, Solling soils. Exchangeable Mg follows the same order among sites but the soils had much higher differences. Exchangeable Ca is about 3 times higher at Göttinger Wald than at Zierenberg, whereas it is very low at Solling. This indicates that the nutrient status at Zierenberg site is well balanced with respect to cations when compared to the Göttinger Wald site where the very high values of exchangeable Ca may result in an insufficient uptake of K and Mg by plants. The Solling site is very poor in exchangeable Ca and Mg which may induce deficiency of these elements in plants.

The organic layer at the base-rich Göttinger Wald and Zierenberg sites consists of unaltered dead remains of plants and animals (L or Oi layer) and a layer with fragmented, partly decomposed but still recognizable material underneath the L layer (F or Oe layer). The L/F mull humus indicates a rapid decomposition and disappearance of plant residues from the soil surface by earthworm activity and has resulted in relatively low nutrient pools in the organic layer (Table 3.8).

The organic layer of the acid Solling soil consists of L, F, and H layers and is classified as moder humus. The H layer (or Oa layer) consists of well-decomposed, amorphous organic matter with a thickness of 1.5 cm. The moder humus accumulate considerable amounts of nutrients of which Ca and Mg equal to about 90% and 100%, respectively, of the exchangeable pools within the upper 100 cm depth of the mineral soil. Heavy metal and Al content typically increased from L to F and then to H layers (Table 3.9) indicating increased enrichment of these elements during organic matter decomposition.

Mineral weathering of nutrients such as K, Ca, Mg, or P is a slow process and less important for plant nutrition in the short-term. In the long-term, it is the most important source for nutrients in terrestrial ecosystems except that of nitrogen. The juvenile soils at the study sites are relatively rich in primary silicates (see Sect. 3.2) which ensures a continuous release of base cations depending on mineral composition and content.

3.6 Additional Study Plots at the Solling Site

At the Solling site, additional plots were installed in 1982 adjacent to the permanent observation plot to study the effects of various treatments involving application of high doses of alkaline (liming, BK plot) or acidifying (ammonium sulphate, BN

Table 3.8 Thickness and contents of nutrients (mean and standard deviation (in brackets)) of the organic layer at Göttinger Wald, Zierenberg, and Solling (P, S, K, Ca, and Mg were estimated after HNO₃ pressure digestion (aqua regia extraction at Zierenberg) by ICP, N by combustion technique) (Göttinger Wald, soil inventory 1995; Zierenberg, soil inventory 1996; Solling, soil inventory 1993)

	Thickness (cm)	Amount							kg ha ⁻¹	
		C	N	P	S	K	Na	Ca		Mg
		Mg ha ⁻¹	Mg ha ⁻¹	Mg ha ⁻¹	Mg ha ⁻¹	Mg ha ⁻¹	Mg ha ⁻¹	Mg ha ⁻¹	Mg ha ⁻¹	Mg ha ⁻¹
Göttinger Wald	L/F	17.7 (9.0)	200 (100)	9.5 (5.3)	19.4 (9.6)	71.2 (54.6)	2.6 (1.8)	369 (199)	35.6 (24.9)	
Zierenberg	F	11.2 (-)	223 (15)	12.8 (1.8)	-	15.1 (0.8)	-	161 (72)	31.7 (16.2)	
Solling	L	17.8 (2.2)	450 (60)	22.0 (2.7)	38.8 (4.9)	28.3 (3.7)	2.6 (0.4)	92.6 (15.2)	13.3 (1.9)	
	F	36.0 (9.0)	820 (200)	35.1 (8.4)	91.4 (21.5)	75.1 (26.3)	5.9 (1.7)	81.2 (23.5)	25.4 (9.0)	
	H	39.0 (8.2)	580 (130)	37.3 (7.4)	73.2 (13.5)	184 (84.1)	10.2 (3.4)	36.3 (7.6)	49.9 (20.3)	

Table 3.9 Element concentration of the organic layer at Solling, Göttinger Wald, and Zierenberg (Jochheim 1992) (HNO₃ pressure digestion at Solling and Göttinger Wald, aqua regia extraction at Zierenberg)

		Al	Fe	Mn	Zn	Cu	Cr	Ni	Cd	Pb
		mg kg ⁻¹								
Göttinger Wald	L/F	12,523	5,893	481	69	9.4	14.3	7.9	0.30	28
		(2,967)	(1,594)	(70)	(9)	(0.9)	(3.7)	(1.6)	(0.09)	(6)
Zierenberg	F	1,880	3,200	1,030	86	15	–	0.65	25	
		(460)	(1,250)	(1,220)	(19)	(1.5)			(0.23)	(11)
Solling	L	2,051	1,959	1,868	95	19.1	–	–	0.63	66
		(799)	(636)	(385)	(6)	(2.9)			(0.05)	(20)
	F	7,581	6,096	371	115	31.3	–	–	0.62	284
		(814)	(600)	(37)	(8)	(3.8)			(0.14)	(41)
	H	19,356	12,107	148	87	30.8	–	–	0.28	367
		(5,667)	(2,465)	(45)	(14)	(6.3)			(0.08)	(54)

plot) substances. Parent material and physical soil characteristics are similar at the treated and untreated plots. Also the structure of the forest stands and silvicultural treatment are comparable with the main Solling plot since all plots belong to the same forest management unit. Tree cuttings were performed only for safety reasons, and the timber was retained on the plot.

At the BK plot, dolomitic lime was applied in 1982 with a dose of 30 Mg ha⁻¹ (Beese and Stickan 1989). The BN plot was treated for 11 years between 1983 and 1993 with a dose of 1,000 mmol m⁻² per year (NH₄)₂SO₄ (140 kg ha⁻¹ per year N, 160 kg ha⁻¹ per year S, Meesenburg et al. 2004).

Chemical characteristics of the soil solid phase at the BN plot showed only small differences compared to the untreated plot when measured 10 years after the start of the treatment, whereas the liming of the BK plot altered soil characteristics especially of the topsoil (Tables 3.10 and 3.11). Distributions of organic C within the soil profile as well as C pools are similar at the treated and untreated plots. N contents are enhanced over the whole profile at the BN plot resulting in an N pool (organic layer and mineral soil 0–100 cm) of 13.3 Mg ha⁻¹, which is 1.5 Mg ha⁻¹ higher than the N pool of the untreated plot. 1.4 Mg ha⁻¹ N was applied additionally at the BN plot between 1983 and 1992, but N output with soil solution was higher by 0.5 Mg ha⁻¹ N during this period than from the untreated plot (Meesenburg et al. 2004). N pools at the limed plot (BK) are not different from the untreated plot.

The acid–base status of the soils at the BK plot has been markedly altered by liming. Contents of exchangeable Ca and Mg have increased manifold in the 0–20 cm soil, but also their concentrations in the subsoil have been raised significantly. Nevertheless, base saturation was above 10% in the 0–20 cm depth at the limed plot (Table 3.11). At the limed plot, pH(CaCl₂) was higher than at the untreated plot in the soil to 100 cm depth. At the BN plot, base saturation is lower than in the untreated plot below 5 cm depth due to the application of acidity. A decrease of pH was not observed at the BN plot.

Table 3.10 Soil chemical characteristics (mean and standard deviation (in brackets)) except for pH (min and max values are given) of the limed (BK) and fertilized plot (BN) at the Solling site (soil inventory in 1993), (bulk density, *BD*) ($n = 5$, each is a mixture of four samples)

Depth cm	BD g cm ⁻³	pHCaCl ₂	Corg g kg ⁻¹	N g kg ⁻¹	P µg g ⁻¹	C/N	C/P
BK							
L	-	4.95 (4.84-5.08)	469 (20.5)	23.7 (0.9)	1256 (91)	19.8 (0.5)	375 (19.3)
F	-	6.02 (5.65-6.21)	319 (20.6)	17.3 (1.0)	856 (45)	18.5 (0.5)	373 (18.1)
H	-	5.14 (4.83-5.37)	339 (19.1)	19.1 (1.8)	1038 (39)	17.8 (0.6)	327 (32.6)
0-2	1.05	4.61 (4.11-5.25)	82.2 (12.6)	4.5 (0.4)	587 (13)	18.1 (1.2)	140 (18.7)
2-5	1.04	4.20 (4.09-4.37)	39.6 (06.4)	2.2 (0.3)	472 (20)	17.8 (0.6)	83.7 (10.1)
5-10	1.23	3.95 (3.89-4.07)	27.0 (2.4)	1.5 (0.1)	409 (22)	17.5 (0.9)	66.1 (4.8)
10-20	1.19	4.06 (3.96-4.36)	23.4 (3.4)	1.4 (0.2)	389 (23)	16.6 (0.8)	60.0 (6.8)
20-30	1.30	4.14 (4.08-4.32)	16.0 (0.7)	1.1 (0.1)	362 (19)	14.9 (0.8)	44.3 (1.7)
30-50	1.48	4.20 (4.16-4.24)	9.1 (0.5)	0.7 (0.1)	321 (35)	13.0 (1.3)	28.6 (1.7)
50-70	1.55	4.14 (4.06-4.22)	3.6 (1.0)	0.3 (0.0)	268(21)	11.5 (3.2)	13.3 (3.3)
70-100	1.55	4.07 (4.03-4.12)	1.9 (0.0)	0.3 (0.0)	282 (9)	6.0 (0.0)	6.7 (0.2)
BN							
L	-	3.21 (2.75-3.74)	508 (20.5)	25.4 (1.0)	1043 (68)	20.0 (0.1)	488 (29.8)
F	-	3.22 (2.84-3.75)	468 (25.5)	23.4 (1.5)	865 (62)	20.0 (0.6)	544 (45.3)
H	-	2.82 (2.77-2.89)	352 (35.7)	19.2 (2.0)	1183 (76)	18.4 (0.3)	297 (24.9)
0-2	1.05	3.21 (3.17-3.31)	101 (13.1)	6.1 (0.8)	708 (48)	16.5 (0.5)	142 (10.4)
2-5	1.04	3.31 (3.25-3.44)	42.2 (8.3)	2.8 (0.5)	503 (48)	15.0 (1.5)	83.4 (11.6)
5-10	1.23	3.45 (3.36-3.54)	28.5 (4.7)	2.0 (0.3)	410 (37)	14.6 (1.4)	69.4 (7.3)
10-20	1.19	3.69 (3.61-3.78)	23.2 (3.2)	1.8 (0.2)	402 (32)	13.2 (1.3)	57.5 (5.8)
20-30	1.30	3.94 (3.86-4.06)	15.3 (2.0)	1.4 (0.2)	371 (28)	11.3 (0.5)	41.4 (4.3)
30-50	1.48	4.07 (3.99-4.21)	9.2 (2.0)	0.9 (0.1)	315 (30)	9.7 (1.1)	29.2 (5.3)
50-70	1.55	4.02 (3.90-4.16)	7.1 (0.8)	0.8 (0.1)	324 (64)	9.2 (1.0)	22.6 (5.5)
70-100	1.55	4.00 (3.94-4.06)	2.7 (1.8)	0.4 (0.2)	321 (55)	6.5 (1.1)	8.5 (5.5)

Table 3.11 Exchangeable cations, cation exchange capacity (CEC, NH_4Cl extraction), and base saturation (BS) (mean and standard deviation (in brackets)) of the limed (BK) and fertilized (BN) plots at the Solling site (soil inventory 1993) ($n = 5$, each is a mixture of four samples)

Depth cm	CEC $\text{mmol}_c \text{kg}^{-1}$	Ca %	Mg %	K %	Na %	Mn %	Al %	Fe %	H %	BS %
BK										
0-2	165 (33)	45 (16)	37 (11)	1.3 (0.4)	0.4 (0.1)	0.6 (0.2)	13 (23)	1.5 (1.4)	1.0 (2.0)	84 (26)
2-5	129 (8.6)	24 (6.3)	23 (3.8)	1.5 (0.3)	0.4 (0.0)	0.4 (0.0)	42 (9.5)	4.2 (1.1)	4.8 (0.8)	49 (10)
5-10	119 (8.0)	9.1 (2.1)	11 (1.2)	1.1 (0.1)	0.4 (0.0)	1.3 (0.4)	71 (3.5)	1.8 (0.7)	5.0 (0.6)	21 (3.1)
10-20	100 (6.4)	8.1 (4.4)	8.6 (3.9)	1.2 (0.1)	0.4 (0.0)	2.0 (0.3)	78 (8.4)	0.6 (0.1)	1.5 (0.4)	18 (8.4)
20-30	75 (3.4)	3.7 (1.2)	5.0 (1.3)	1.4 (0.2)	0.5 (0.1)	1.4 (0.2)	88 (2.3)	0.3 (0.0)	0.0 (0.0)	11 (2.5)
30-50	58 (4.2)	2.1 (0.3)	3.5 (0.6)	1.9 (0.2)	0.6 (0.1)	1.0 (0.4)	91 (0.9)	0.1 (0.1)	0.0 (0.0)	8.1 (0.8)
50-70	60 (4.0)	2.6 (1.2)	3.6 (0.8)	2.3 (0.2)	1.0 (0.6)	0.8 (0.5)	90 (2.3)	0.0 (0.0)	0.0 (0.0)	9.6 (2.1)
70-100	60 (4.2)	1.3 (0.2)	2.1 (0.2)	2.9 (0.3)	0.8 (0.2)	0.9 (0.3)	92 (0.4)	0.0 (0.0)	0.0 (0.0)	7.1 (0.4)
BN										
0-2	117 (56)	4.1 (0.4)	2.0 (0.1)	2.5 (0.3)	0.4 (0.1)	0.8 (0.2)	57 (4.9)	7.9 (1.2)	26 (5.6)	8.9 (0.3)
2-5	123 (13)	1.8 (0.3)	1.2 (0.2)	1.9 (0.2)	0.4 (0.2)	0.9 (0.4)	70 (6.9)	7.6 (1.0)	16 (7.1)	5.3 (0.6)
5-10	122 (7.7)	1.2 (0.2)	0.7 (0.1)	1.6 (0.2)	0.3 (0.1)	2.2 (1.0)	81 (3.3)	1.8 (0.9)	11.4 (3.4)	3.8 (0.3)
10-20	130 (46)	1.1 (0.2)	0.7 (0.1)	1.5 (0.2)	0.4 (0.1)	2.8 (0.8)	89 (2.9)	0.5 (0.1)	3.7 (2.4)	3.7 (0.3)
20-30	99 (39)	1.0 (0.1)	0.6 (0.1)	1.5 (0.2)	0.4 (0.1)	2.1 (0.4)	94 (0.3)	0.2 (0.1)	0.2 (0.3)	3.5 (0.3)
30-50	63 (4.9)	0.9 (0.1)	0.6 (0.0)	1.7 (0.1)	0.5 (0.1)	1.3 (0.4)	95 (0.6)	0.1 (0.1)	0.0 (0.0)	3.6 (0.3)
50-70	66 (2.6)	0.9 (0.2)	0.7 (0.1)	2.2 (0.3)	0.5 (0.1)	1.2 (0.3)	94 (0.7)	0.1 (0.1)	0.0 (0.0)	4.2 (0.5)
70-100	67 (17)	0.7 (0.2)	0.6 (0.2)	2.3 (0.6)	0.5 (0.1)	1.2 (0.6)	87 (16)	0.1 (0.1)	7.7 (17)	4.2 (1.0)

3.7 Conclusions

- The soils at the three beech forest sites, Göttinger Wald, Zierenberg, and Solling, are derived from different parent material (limestone, basalt, loess over sandstone, respectively) and cover a wide range of soil types, buffer ranges and nutrient contents.
- The Göttinger Wald and Zierenberg sites show indications of soil acidification in the uppermost soil layers, whereas the soil at Solling is highly acid in the whole rooting zone.
- The base saturation of soils has values higher than 90% at the Göttinger Wald and Zierenberg sites. At the Solling site, exchangeable base cations in the mineral soil have decreased during 1966–2001 resulting in base saturation of less than 7%.
- The nutrient status of the sites differs considerably with the Solling site having lowest nutrient pools. Calcium dominates the exchange sites at the Göttinger Wald and Zierenberg sites while aluminium is the predominant cation at the Solling site. The Zierenberg site has the most balanced composition of exchangeable cations owing to a high content of exchangeable magnesium and potassium.
- Mineral soils of the additional study sites at Solling which were used for manipulation experiments, showed only small differences in soil properties after treatment with heavy doses of ammonium sulphate, but on liming the soil showed markedly altered acid–base status of the top 20 cm depth.

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