1. Phosphorus Concentrations in Environmental Samples

1.6 Soils

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Total Phosphorus (TP) concentration in soils especially depends on parent material and time for soil development. Additionally, soil development is affected by landform configuration (e.g. position at the slope), water regime (e.g. groundwater level) and dry and wet deposition. Within a soil profile, site-typical soil genetic processes such as podzolization and subsequent differentiation of soil horizons can cause differences in TP concentrations among separate soil horizons. TP concentrations are further impacted by vegetation (e.g. deciduous/coniferous forest), anthropogenic type of usage (e.g. arable or pastureland) and type of cultivation (e.g. plaggic Anthrosols).

In mineral soils, the effect of **parent material** on TP concentrations is particularly obvious. For example, TP concentrations of Cambisols (German classification: Braunerde) of basalt are relatively high but that of Pleistocene glaciofluvial sand are low (Werner et al. 2016, Tab. 1.6-1).

Landform configuration and thereby affected soil genesis can cause strong differences in TP concentrations in soils at a relative small scale. For example, if nutrient- and therefore TP-rich material is transported downhill and accumulated in depressions by water erosion TP concentrations can differ substantially.

Within a **soil profile**, TP concentrations can vary substantially in different soil horizons. Soil horizons are soil layers, which can be differentiated mostly visually and can differ substantially in their properties such as particle size distribution, soil organic matter (SOM) concentration, processes of leaching and accumulation of elements or in water dynamics (Fig. 1.6.-1). During podzolization SOM complexed Al- and Fe(hydr)oxides and their sorbed P are transported downward from the A horizon and accumulated in deeper horizons (Bh, Bs). This causes low TP concentrations in the Ae horizon and higher TP concentrations in the B-horizons. For example, in the illuvial Bh horizon of a Podzol under spruce the TP concentration was 10 times higher than in the eluvial Ae horizon (Leinweber & Ahl 2013, Tab. 1.6-2). Plagging of nutrient rich material for decades or centuries caused considerably higher TP concentration in the E-horizon of plaggic

Anthrosols (German classification: Plaggenesch) compared to the original nutrient poor parent material.

Figure 1.6-1 a Cambisol on a esker at Neuburg (Normbraunerde auf Os bei Neuburg)

Figure 1.6-1 b Luvic Stagnosol near Nienhagen (Fahlerde Pseudogley im Gespensterwald bei Nienhagen)

Figure 1.6-1 c Eutri-Ombric Histosol near Warnow (Humusnassgley über Erdniedermoor bei Warnow)

Long-lasting excess of **water** in soil causes development of peat and resulting moors (Succow & Jeschke 1986). The anaerobic conditions inhibit degradation of SOM and cause an SOM accumulation of > 30 %. Upland moors are relatively nutrient poor, because they are only driven by rainwater, whereas lowland fens are affected by groundwater and/or flowing water. P concentrations in lowland fens therefore depend on P concentrations of the flowing water, which causes mostly much higher P concentrations than in upland moors (Tab. 1.6-1). SOM concentrations significantly affect density of the soil, which significantly influence P concentrations (up to 41000 mg TP kg^{-1}, Tab. 1.6-1). For this reason, density of soils with high SOM concentration (such as peat soils) should be determined and TP concentration should additionally be related to sample density (mg cm^{-3}) or –area (mg cm^{-2}) instead only to sample mass (mg kg^{-1}).

Additionally, **anthropogenic usage** can alter TP concentrations in soils significantly, thus arable field have higher TP concentrations than comparable forest soils due to fertilization (Tab. 1.6-1). TP concentrations of grassland soils differ also due to their origin (e.g. mineral grassland soils or grassland on lowland fens). Their TP concentrations are additionally affected by usage intensity (fertilization/grazing/mowing frequency).

Table 1.6-1 TP concentrations (mg kg^{-1} dry $matter^{-1}$) in mineral soils (< 2 mm) and in moors

Soil	Horizon	depends on	TP (mg kg^{-1} dry $matter^{-1}$)	Reference
Cambisol from basalt[1]	Ah	Parent material	2080	Werner et al. (2016), Prietzel et al. (2016)
Cambisol from glacio-fluviatile sand[2]			60	
Stagnic Cambisol (Pseudogley-Braunerde) from sand above till[3]			190	Leinweber & Ahl (2013)
Luvisol (Parabraunerde) in upper slope[4]	Ap	Landform configuration (position at slope)	652-992	Heilmann et al. (2005)
Gleysol in lower slope[4]	Ah/p		521-1020	
Humic Podzol (Humuspodsol)[5]	Ah	Horizon	180	Leinweber & Ahl (2013)
	Ae		14	
	Bh		140	
	IIBh		68	
	elCv		79	
Plaggic Anthrosol (Plaggenesch)[6,7]	E		713-1412	Hubbe et al. (2007)
	Ae		124-387	
	E		1631-2924	Schnepel et al. (2014)
	C		1060-1748	
Upland moor (Hochmoor)[8]	0-5 cm	Water regime	400	Keller et al. (2006)
Histosol (Erdniedermoor)[9]			750	
Histosol (Erdniedermoor-Mulmniedermoor)[10]	nHw		40795	Leinweber & Ahl (2013)
Arable field[11]	Ap	Usage	500-3500	Leinweber et al. (1994)
Forest[12]	Ah		163-843	Alt et al. (2011)
Grassland[12] (mineral soil)			460-1422	
Grassland[13] (lowland fen)	nHw		2900-3800	Leinweber & Ahl (2013)

In soil science, the litter layer such as in the forest is analysed separate to the mineral soil (< 2 mm). According to their composition (depending on vegetation), TP concentrations can vary between 47 und 5100 mg kg^{-1} (Tab. 1.6-2). The material of the litter layer is handled such as peat or plant material due to the high concentrations of organic matter.

Table 1.6-2 TP Concentrations in organic litter layer in L/Of/Oh-Horizons

Vegetation	Soil Type	TP (mg kg^{-1} dry matter^{-1})	Reference
Pine	Regosol (Pararend-zina)[14]	47	Leinweber & Ahl (2013)
	Podzol (Eisenpodsol)[15]	440	
Spruce	Podzol (Humuspod-sol)[15]	130	Leinweber & Ahl (2013)
	Cambisol, Luisol, Regosol, Stagnosol (Braunerde, Parabraun-erde, Rendzina, Pseudo-gley)[16]	790-950	Taubert (2015)
Beech	Luvic Stagnosol, (Fahlerde-Pseudogley)[17]	5100	Leinweber & Ahl (2013)
	Cambisol, Luvisol, Regosol, Stagnosol (Braunerde, Parabraun-erde, Rendzina, Pseudo-gley)[16]	730-760	Taubert (2015)
Beech/Oak	Stagnic Cambisol (Pseudogley-Braun-erde)[18]	1800	Leinweber & Ahl (2013)

[1] Bad Brückenau (Bavaria)
[2] Lüß (Lüneburg Heath, Lower Saxony)
[3] Gespensterwald near Nienhagen (district Rostock, Mecklenburg-Western Pomerania (MWP), p. 86 ff.)
[4] Schäfertal near Quedlinburg (Saxony-Anhalt), parent material: Loess
[5] Ribnitzer Stadtforst (district Western-Pomerania-Rügen, MWP, p. 71 ff.), Spruce, parent material: sand
[6] Surrounding area of Arkhangelsk (European North-Russia), parent material: silty Sand glacial sediments
[7] Jæren (South Sweden), parent material: glacial sediment
[8] Gogebic County (Michigan, USA), rain water driven, no anthropogenic usage, Vegetation: sphagnum moss, woody Ericaceae
[9] Gogebic County (Michigan, USA), no anthropogenic usage, Vegetation: small reed, sedges, willows
[10] percolation moor in Trebeltal (District Western-Pomerania-Rügen, MWP, p. 61 ff.), high ground water level, Grassland, Vegetation: rushes

[11] Surrounding area of Vechta, Quakenbrücker Becken, Bakumer Geest (districts Vechta und Cloppenburg, Lower Saxony), soil type/parent material: Luvisol, Cambisol, Stagnosol, plaggic Anthrosol, Gleysol ((Para)Braunerde, Pseudogley, Plaggenesch, Gley) from sand and silty sand, incl. arable fields with speciality crop or high stocking density
[12] Biodiversitätsexploratorien Schorfheide-Corin (Brandenburg), Hainich-Dün (Thuringia), Schwäbische Alb (Baden-Wuerttemberg)
[13] Lowland fen near Warnow (district Rostock, MWP, p. 92 ff.), hay meadow
[14] former areas of gravel mining near Neukloster/Perniek (district Nordwestmecklenburg, p. 86 ff.), parent material: sandur gravel
[15] Ribnitzer Stadtforest (district Western-Pomerania-Rügen, p. 71 ff.), parent material: sand
[16] Biodiversitätsexploratorien Hainich, Schwäbische Alb (Thuringia, Baden-Wuerttemberg)
[17] Beech forest near Züsow (district Nordwestmecklenburg, p. 86 ff.), parent material: loam sand above till
[18] Gespensterwald near Nienhagen (district Rostock, p. 86 ff.), parent material: sand above till

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