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Indicatory Properties of Soil Solutions in the Characteristics of Forest Site Quality

G. Porębska*, J. Sienkiewicz, A. Ostrowska

Institute of Environmental Protection, Krucza St. 5/11, 00-548 Warsaw, Poland

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Abstract

We have compared the mean contents of Al, combined Ca + Mg as well as of the total content of elements Σ (Ca, Mg, K, Na, Al, Fe, Mn, NH_4, Cl, SO_4 and NO_3) in solutions obtained for the Ofh, AE and Bv soil horizons. Soils were sampled in dry coniferous (Bs), fresh coniferous (Bsw) and mixed deciduous-coniferous (BMsw) forest sites. Higher values of combined Ca and Mg content and of total element content were found in the soil solution of all horizons in BMsw sites than in those in Bs and Bsw sites. The amount of Al migrating to aqueous solution is lower in Ofh horizons of BMsw sites than in Bs and Bsw sites. The soil sorption complex of BMsw sites, likewise respective soil solutions, is more abundant in combined bivalent basic cations than that of Bs and Bsw sites. Exchangeable Al content in the Ofh horizon is lowest in BMsw site, and highest in Bsw site. No direct effect was found on the forest floor vegetation on the concentration of soil solutions (expressed as element sum) or on the ionic composition of these solutions taking into account the elements analyzed.

Keywords: soil solution, plant communities, sites

Introduction

The composition of soil solution has been the subject of numerous studies, while methods for obtaining soil solution vary between authors. In the ion flux study in the system: inflow-accumulation-outflow, waters sampled *in situ* with the use of tension or gravitation lysimeters are considered as soil solutions [1, 2, 3, 4, 5]. The soil solution is also understood as a liquid phase separated from the solid phase of soil, i.e. the solution obtained by centrifuging, squeezing, sucking up or extraction of a fresh soil [2, 6, 7]. Water extracts of soils are also called soil solutions [8, 9, 10, 11].

The chemical composition of soil solution reflects soil quality as regards both the quantity of elements released from the solid phase to water and the influx of elements from anthropogenic sources (deposition, fertilisers, wastewater, etc.). There is a close relationship between the quality of soil solution and the growth of plant roots. Both solution concentration and composition with respect to proportions between individual ions exert a direct effect on plant roots since the soil solution is a source of both nutrients and toxic elements (heavy metals, aluminium). Plants affect the quality of soil solution as regards its ionic composition, reaction and content of soluble organic compounds as they take up individual elements depending upon their nutrition demand, i.e. selectively to some extent. They also secrete various ions and substances to the rhizosphere, where such changes are particularly evident. This effect probably depends on the properties of a given plant species.

The forest floor vegetation may have a special role in contributing to the quality of soil solution in the topsoil (Ofh, A and AE horizons). It seems that the analysis of indicative value of the soil solution properties used to assess the quality of forest sites should address both the quality of soils and species composition of the forest vegetation. The literature on the subject has not yet provided evidence of such a relationship.

*Corresponding author

In this paper, an attempt was made to determine whether and to what extent the ion composition of soil solution reflects the quality of a forest site defined with the use of floristic criteria and indicators. The concentration of soil solution, combined amount of calcium and magnesium and content of aluminium have been assumed to be indicative of the soil solution quality.

Experimental Procedures

The study was carried out on study plots in 15 forest tracts in various regions of the country. The plots were situated in the dominant site types, mainly in pine stands. The sites were characterized with respect to plant sociology as well as the stand and soil properties. In the soils, the sorption properties and content of organic matter were determined along with the concentration and composition of soil solution.

Vegetation

Plant sociological inventory was made in conformity with the standard Braun-Blanquet method [12]. Forest communities were identified according to the adopted guidelines [13]. The sites under study were classified as dry coniferous (Bs), fresh coniferous (Bsw), mixed deciduous-coniferous (BMsw) and fresh mixed deciduous (LMsw) forest site types.

The dry coniferous (Bs) sites were identified in the following forest inspectorates: Tuchola, Przymuszewo, Brzózka and Gubin (9 study plots). Fresh coniferous (Bsw) sites were in Tuchola, Ruszów, Spychowo, Garwolin, Janów Lubelski, Szklarnia, Ośno Lubuskie, Brzózka and Gubin (39 study plots). The BMsw sites were identified in forest inspectorates of Przymuszewo, Twardogóra, Jastrowie and Szczecinek (22 study plots). LMsw sites were in inspectorates Miłomłyn and Puszcza Borecka (3 study plots).

Local vegetation tables characterizing individual forest tracts were combined to produce synoptic tables representing the typological gradient of vegetation from dry coniferous wood to fresh mixed deciduous forest for the entire area under study. Synthetic indices were calculated, i.e. species constancy (S) or the index showing the probability of finding a species in a given community type (based on the species frequency in all releves in percent). Species showing III, IV and V constancy class may be considered as typical of given study conditions since they best reflect the average features of the communities identified. The quantitative share of a species in a community was calculated as the species coverage index (P). P index or species percent surface share was calculated for species with III, IV and V constancy class in the herbaceous and moss layers (C and D) in the communities examined. These layers are of basic significance for phytoindication. The use of P index or a summary P index enables an assessment of the quantitative role of a species or a whole vegetation layer in the community structure.

Soils

Soils and soil solutions of the BMsw and LMsw sites were considered as one group. At each plot the average mixed soil samples were taken according to methods described by Ostrowska et al. [14]. The samples were taken separately from three genetic horizons, i.e. O, A and B (mainly from Ofh, AE and Bv horizons), from soil microprofiles dug to a depth of about 40 cm. At each plot, samples of separate horizons at 5-10 spots were taken to small pails and thoroughly mixed. After mixing, the samples of separate genetic horizons represented the soil at a given plot. The soil material thus obtained was used to determine sorption properties, organic matter content as well as the average soil abundance in elements that migrate to soil solutions. Altogether, 214 soil samples and solutions have been analyzed.

The soil solutions were prepared in the laboratory by treating the samples with deionised water (ratio 1:3) and incubating them over 10 days at 25°C. In this way the so-called simulated soil solutions achieved stability with respect to ion concentration and composition [8]. In the filtrates obtained after centrifuging, i.e. in soil water extracts, the contents of Ca, Mg, K, Na, Al, Fe and Mn were determined by the AAS method, NH_4 – by colorimetric method, and Cl, SO_4 and NO_3 by capillary electrophoresis. In this paper only selected parameters of soil solutions have been discussed, such as the combined content of calcium and magnesium, content of aluminium and the total content of all elements determined. The results are expressed in $mmol_c$/kg. For comparison, the contents of exchangeable Al and exchangeable Ca+Mg in examined soils are given.

The forest soils are markedly more differentiated vertically (i.e. between individual genetic horizons of soils at a given plot) than horizontally (i.e. between the same horizons in soils of various study plots) [8]. Therefore, the element contents in soil solutions were considered as mean values for individual genetic horizons, i.e. organic (Ofh), humic (A, AE, ABv) and the horizons where weathering or illuvial enrichment (Bv, BvBbr, Bfe) take place. Mean values are given for individual soil horizons at various plots for the forest site types and the values of variation coefficients. The study plots were characterized in detail by Ostrowska et al. [15].

Discussion of Results

The study plots were established in pine monocultures from 50 to 120 years old. The most frequent site type is Bsw with BMsw and Bs having a much lesser share. The Bs sites occur on very poor soils classified as rusty podsolized with loose sand texture. Bsw sites have developed on rusty podsolized soils with loose and weak clayey sand texture. Soils of BMsw sites vary, though they generally were classified into two classes of rusty brown or rusty pseudogley soils. The grain size composition of the latter soils is typical of weak clayey and clayey sands with varying shares of silt fractions.

Table 1 Coverage indices of species with III-V constancy class in the forest ground layers [12].

Layer of plant community	Coverage indices (P) of species with III, IV and V constancy class in respective forest communities				
	Cladonio-Pinetum Dry (Lichen) Coniferous Forest	Leucobryo-Pinetum Peucedano-Pinetum Fresh Coniferous Forest	Querco-Pinetum	Fago-Quercetum	Tilio-Carpinetum Calamagrostietosum Fresh Mixed Forest (Deciduous)
			Mixed Coniferous –Deciduous Forest		
C - Herbaceous	190	5282	6335	5373	11543
D_1 - Moss	2710	7205	5389	4293	1031
D_2- Lichen	4060	47	-	-	-

Five types of forest communities (and corresponding site units) were derived from the vegetation analysis, including Cladonia-type dry coniferous wood, fresh coniferous wood, fresh mixed coniferous wood and two types of a fresh deciduous wood.

The results of phytosociological inventory have shown that the forest floor layer in Bs sites consists of lichens and brown mosses while vascular flora has very low abundance. The forest floor of Bsw sites is made up of dense moss layer, and vascular plants cover up to three fourths of the ground. In BMsw sites, mosses are scarce and vascular plants (herbaceous layer) dominate the forest floor (Table 1).

The community of Dry Coniferous Forest - *Cladonio-Pinetum* is encountered in pine stands on dry and poor sites. The pine has only the current year needles and does not regenerate naturally. Single birch trees (*Betula pendula*) are to be found only sporadically in stands. In the forest floor a few herbaceous species are sparse, including: *Vaccinium myrtillus*, *Calluna vulgaris*, *Deschampsia flexuosa* and *Vaccinium vitis-idaea*.

Stands on Fresh Coniferous Forest sites are composed of pine and birch trees, the latter being an admixture. Single oak trees (*Quercus robur*) or sometimes spruces (*Picea abies*) constitute the mostly poor undergrowth. In the forest floor made up of dwarf shrubs and mosses, bill- and cow- berries (*Vaccinium myrtillus* and *V.vitis-idaea*) dominate. Other more frequent vascular species include *Deschampsia flexuosa*, *Calluna vulgaris*, *Calamagrostis epigeios*, *Melampyrum pratense* and a clubmoss (*Diphasiastrum complanatum*). The moss layer creates dense carpet with lichens covering less than 20% of the average releve area.

Stands of Mixed Coniferous-Deciduous BMsw sites are composed of pine and birch with an admixture of oaks: *Quercus robur* and/or *Q. sessilis* and, regionally, of beech (*Fagus sylvatica*), European larch (*Larix europaea*) and spruce (*Picea abies*). The undergrowth layer is abundant with most frequently encountered species which make up the species composition of stand and alder buckthorn (*Frangula alnus*) and rowan tree (*Sorbus aucuparia*). The composition of forest floor layer is heterogeneous with a mixture of herb species typical of coniferous and deciduous forest site types. The most frequent is *Vaccinium myrtillus,* wavy hair-grass *Deschampsia flexuosa* and, less abundantly, brambles such as *Rubus idaeus*, *R. caesius* and other *Rubus* species. Other more frequent species include the ferns *Dryopteris carthusiana* and *Dryopteris filix-mas*. In the *Fago-Quercetum* community – species typical of deciduous forests such as rough small-reed (*Calamagrostis arundinacea)*, wood millet (*Milium effusum)*, May lily (*Maianthemum bifolium)* and wood sorrel (*Oxalis acetosella),* have markedly higher shares in the structure of the forest floor. In BMsw sites the moss layer is less well developed than the herbaceous layer.

Stands of Fresh Mixed Deciduous Forest (LMsw) sites, represented by the community of oak-hornbeam forest or *Tilio-Carpinetum calamagrostietosum*, are made up of hornbeam and pine with an admixture of beech (regionally) and common oak. Single spruce trees can also be found in the stand layer. Scarce undergrowth is composed of young hornbeam, linden and oak trees. The rich herbaceous layer is made up of species typical of deciduous forests. The main aspect in the releves make up May lily and wood sorrel, while species of coniferous forest such as *Vaccinium myrtillus* are only sporadically encountered. The moss layer is patchy, poor and built mainly of leafy moss species including *Mnium* spp.

The application of the coverage P index helps reveal significant differences in species coverage in c and d layers in the series of identified communities. The difference was especially evident when comparing dry and fresh coniferous forest types (e.g. a ten-fold increase in P index of herb layer in the latter type). A marked difference was also revealed when comparing coniferous wood phytocoenoses with that of the fresh deciduous forest (Table 1).

The selected parameters of soil solutions were considered in three groups of site types: Bs, Bsw and BMsw, and in horizons of the topsoil (Ofh, AE and Bv). These horizons store the major part of root mass, whereby the roots of herbaceous plants concentrate mainly in the organic and humic horizon.

It was found that the composition of soil solution in individual genetic horizons for the content of selected elements differs between sites (Table 2). The content of Ca + Mg in soil solution of the Ofh horizons in BMsw sites exceeds by about 40-50% that of soil solutions in Bsw and Bs sites. A statistically significant difference at $p<0.05$ has been found only between BMsw and Bsw sites. No

Table 2. Soil solution characteristics at different sites.

Site	Parameter	Ofh						A, AE, A(E)						Bv, BvBbr					
		n	content (mmolc/kg)			share in ∑ (%)		n	content (mmolc/kg)			share in ∑ (%)		n	content (mmolc/kg)			share in ∑ (%)	
			Ca+Mg	Al	∑	Ca+Mg	Al		Ca+Mg	Al	∑	Ca+Mg	Al		Ca+Mg	Al	∑	Ca+Mg	Al
Bs	mean	9	7.12	4.32	27.99	25.4	15.4	9	0.55	0.47	2.33	23.6	20.2	9	0.51	0.27	1.80	28.3	15.0
	v%		63	73	38				97	19	24				79	31	27		
Bsw	mean	39	6.50	2.64	23.47	27.7	11.2	37	0.43	0.52	2.13	20.2	24.4	23	0.62	0.26	1.79	34.6	14.5
	v%		59	109	31				86	29	21				110	52	36		
BMsw	mean	24	9.95	1.80	32.16	30.9	5.6	32	1.07	0.96	4.60	23.3	20.9	32	0.70	0.44	2.32	30.2	19.0
	v%		35	46	30				45	41	42				44	95	46		

Bs -Dry Coniferous; Bsw - Fresh Coniferous, BMsw - Mixed Deciduous-Coniferous; ∑ - sum of Ca, Mg, K, Na, Al, Fe, Mn, NH_4, Cl, SO_4, NO_3, v% - coefficient of variation, n - number of samples

significant difference was found between the mean values of Ca+Mg content in soil solutions of Bs and BMsw sites. This is probably due to a relatively smaller amount of soil solution samples taken from Bs sites as compared to other sites. Noteworthy is the fact that from the Ofh horizon of soils in Bs and Bsw sites almost the same amount of Ca + Mg was released to water, these amounts having similar values of variation coefficients. As compared to Bs and Bsw sites, the combined amounts of Ca and Mg in soil solutions of BMsw sites are characterized by a lower variation coefficient.

The Al content in soil solutions of the Ofh horizons decreases in the series from the Bs to Bsw to BMsw sites. For BMsw sites this content is two-fold lower than in Bs sites, while for Bsw sites it is by about 40% less than in Bs sites. The latter differences were not statistically significant (at $p<0.05$). This could be attributed partly to a great variability of the Ofh horizon with respect to the release of aluminium to water solution. At the same time, the Al content in soil solutions of the Ofh horizons in all the site types examined is more differentiated than the Ca + Mg content as is testified by the values of variation coefficients given (Table 2).

Differences between forest sites could also be noted while comparing the concentration of soil solution expressed as the total sum (Σ) of all elements analyzed, including Ca, Mg, K, Na, Al, Fe, Mn, NH_4, Cl, SO_4, and NO_3. The highest Σ was determined in soil solutions of the Ofh horizons in BMsw sites, and the lowest in Bsw sites, the differences between Bsw and Bs being quite small (Table 2). Noteworthy are the similar values of variation coefficients of Σ in soil solutions in all sites (30-38%). This may testify to the fact that the total amount of elements released from the Ofh horizon to water solution in soils in different sites shows little variation unlike the contents of respective elements including Ca+Mg and Al. For the Ofh horizons the percent values of Ca+Mg share in the total element content Σ in soil solutions increase in the following order of sites: Bs<Bsw<BMsw, while the percent values of Al share in the Σ decrease in the same series.

The solubility of the elements analyzed in the AE horizon samples is lower than that in Ofh horizon. The soil solutions from AE horizons sampled in Bs and Bsw sites were found to contain similar amounts of Ca + Mg, Al and of the total content of all elements examined. The values of selected parameters in soil solutions taken from A horizons in BMsw sites are considerably higher. The values of the percent share of Ca + Mg and of Al in the Σ in soil solutions of this horizon are similar in the compared sites (Table 2).

The analyzed parameters in soil solutions from weathering horizons (Bv, BvBbr) appear to have similar values in all sites while both the content of Al and its share in the element sum are highest in soil solutions of BMsw sites (Table 2).

The Ca:Al molar ratio in soil solutions are reported as an indicator of soil quality. The value of the ratio below one is thought to be indicative of unfavourable conditions

Table 3. Ca:Al molar ratio in the soil solution from different site.

Site	Ofh		A, AE, A(E)		Bv, BvBbr	
	mean	range	mean	range	mean	range
Bs	2.0	1.5 - 3.1	4.1	0.9 - 29.2	7.7	1.3 - 25.5
Bsw	1.4	0.2 - 4.1	1.1	0.1 - 4.4	1.2	0.2 - 2.0
BMsw	2.9	0.4 - 9.3	2.4	0.4 - 7.7	3.0	0.3 - 8.6

Table 4. Selected properties of the soil at different sites.

Site	Parameter	Ofh					A, AE, A(E)					Bv, BvBbr				
		n	C_{org}	C:N	Ca+Mg	Al_{ex}	n	C_{org}	C:N	Ca+Mg	Al_{ex}	n	C_{org}	C:N	Ca+Mg	Al_{ex}
			%		mmolc/kg			%		mmolc/kg			%		mmolc/kg	
Bs	mean	9	31.69	31.4	56.6	43.2	9	0.953	26.3	1.8	15.7	9	0.444	22.1	0.6	7.6
	v%		16	9	40	32		30	22	33	21		16	12	36	25
Bsw	mean	39	38.55	30.7	69.5	59.6	37	1.246	28.1	2.4	20.1	23	0.574	21.0	1.4	9.7
	v%		24	18	37	53		45	31	63	35		95	23	78	32
BMsw	mean	24	36.88	27.5	99.5	28.4	32	2.747	19.5	7.8	34.3	32	0.788	16.0	3.8	20.3
	v%		17	16	58	48		35	19	48	33		51	19	77	69

n - number of samples, v% - coefficient of variation, Ca+Mg - sum of exchangeable Ca and Mg

of plant growth and may result in root damage due to large amounts of aluminium [16, 17, 18]. In this study, the mean values of Ca:Al ratio in soil solutions in the horizons examined of all site types are higher than one (Table 3). However, if all the values of the above ratio (for every horizon in all site types) are to be taken into account, the fluctuation of the ratio is quite pronounced. For the soil solutions of Bs sites it was noted that only in the AE horizon were the extreme values of Ca:Al ratio lower than one, whereas all the values calculated for the Ofh and Bv horizons exceeded one.

In soil solutions of all the horizons in Bsw and BMsw sites the extreme values of Ca:Al ratio amounted to 0.1-0.2, at the average values higher than one. The latter may be explained by a great variability among the examined soils with respect to the content of Ca and Al. The soils of Bs sites are very poor, and the total amounts of elements are low though, at the same time, a relatively large amount of elements is released from this pool to the water solution. Soils at BMsw sites are weak clayey- and clay sands, and consequently contain a larger pool of all elements, from which a larger amount of elements is released than in soils of other sites. The solubility of Ca is higher than that of Al, therefore low values of Ca:Al ratio may testify to an advanced process of soil decalcitation in the series of examined site types, especially in Bsw sites.

The quality of soil solution with respect to the selected features was compared with the quality of soil sorption complex. As follows from Table 4, the respective genetic horizons in the sites examined differ markedly with respect to the contents of exchangeable bivalent cations and exchangeable Al. The site type in forest typology refers to the quality of soils on which a given site has been developed. The exchangeable Ca + Mg content in Ofh horizons is about 80% higher in BMsw than in Bs sites, while the content of exchangeable Al is lower by about 35%, respectively. Additionally, in the soils of Bsw sites the exchangeable Ca+Mg has intermediate values situated between those obtained for soils in the remaining site types. At the same time, the amount of exchangeable Al is more than twice higher in Bsw than in BMsw sites. Organic horizons in Dry Coniferous Forest sites are the poorest with respect to the exchangeable bivalent cations. Whereas the organic horizon of Bsw sites is the least favourable for plant growth as concerns the content of exchangeable Al. The underlying genetic horizons A and B may be ordered with respect to increasing amounts of exchangeable Ca + Mg and Al in the following series of sites: Bs<Bśw<BMśw (Table 4).

The statistical analysis (Tukey RIR test with variable n) showed that the mean values of exchangeable Ca + Mg differ significantly (at $p<0.05$) in all the genetic horizons examined between Bs and BMsw and between Bsw and BMsw sites. The difference between the mean exchangeable Ca+Mg contents in soils of Bs and Bsw sites is not significant. A significant difference was found only between the mean contents of exchangeable Al in Ofh horizon (at $p<0.05$) between Bsw and BMsw sites, while differences between the remaining sites were not significant. Significant differences were also found as to the contents of exchangeable Al in the A and B horizons between Bs and BMsw sites and between Bsw and BMsw sites. The results of statistical analysis corroborate the fact that soils of BMsw sites are significantly different than the soils of Bs and Bsw sites with respect to the contents of exchangeable Ca+Mg and Al.

Generally, the differentiation of contents of both exchangeable Ca + Mg and Al in the soil sorption complex supports the finding that there are differences between respective soil solutions. For all horizons analyzed, the highest amounts of elements are to be found in soils of BMsw sites, whereas differences between soils of Bs and Bsw sites are for the most part not significant at $p<0.05$.

Establishing the relationships between the quality of soil solution and the site type is difficult. Generally, the concentration of soil solution decreases with depth from the Ofh down to Bv horizon. Thus, it can be said that the main source of ions migrating from the solid to liquid phase of the soil is the soil organic matter. Differences between sites are visible in the contents of organic matter. The Ofh horizons of Bs sites contain less organic carbon than the respective horizons of Bsw and BMsw sites (Table 4). A significant relationship was found between the organic soil carbon content and the total content of elements in soil solutions (correlation coefficient 0.87). The concentration of soil solutions expressed as Σ in Ofh and AE horizons is slightly higher in Bs than in Bsw sites (Table 2). This could corroborate the finding by Ostrowska [19] that the mineralization of organic matter is higher in Bs than in Bsw sites.

The difference between sites is especially visible in the quality of the soil sorption complex, i.e. in the contents of exchangeable Ca + Mg and exchangeable Al while there is no such visible difference when comparing the quality of soil water extracts. Therefore, on the basis of a comparison of parameters selected in this study it is hard to establish a direct influence of forest floor vegetation on the quality of soil solution.

Conclusions

- The type of forest site is related to the quality of soils whereupon a given site type has been developed. The total content of Ca and Mg in the sorption complex of soils from Ofh horizons in the BMsw forest is by about 80% higher than that of soils from the Bs forest in contrast to the Al content which is respectively lower by about 35%. The Ofh horizon in soils of the dry-conifer forest site is the poorest in bivalent exchangeable cations and the Ofh horizon in soils of the fresh-conifer forest site is the least favourable for plants with respect to the content of exchangeable Al.
- Percent shares of Ca + Mg in the element pool in soil solutions sampled from Ofh horizons increase in the series of the sites examined in the following order: Dry-conifer < Fresh conifer < Mixed deciduous-conifer forest while the percent share of Al in the element pool decrease in the same order.
- Relationships between the soil solution chemistry and the forest site type are hard to establish. The results of study presented have not revealed any relationship which would point out to the direct effect of herbaceous plants of the forest floor upon the quality of soil solutions. It may be concluded that the composition of soil solution in the coniferous forest sites is to a great extent determined by soil properties.

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