POLISH JOURNAL OF SOIL SCIENCE
VOL. LIII/2 2020 PL ISSN 0079-2985

DOI: 10.17951/pjss/2020.53.2.307

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SPATIAL VARIABILITY OF MACROELEMENTS IN SOILS IN THE LIER RIVER VALLEY (BUSKERUD REGION, SOUTHERN NORWAY)

Received: 18.11.2020
Accepted: 30.11.2020

Abstract. The total content and relationships between macroelements (Ca, Mg, K, Na, Mn, Fe and Al) and soil properties along the soil catena in the hilly valley of Lier River, S Norway, are discussed in the paper. The upper and middle part of the Lier River valley is covered with Stagnic Phaeozems formed from silt loam and sandy loam. In some parts of middle slope, Haplic Phaeozems (Anocolluvic) formed from silt loam and sandy loam occurred. The flat areas in the lower part of slope were covered with Mollic Gleysols formed from silt and silt loam. The average total amounts of macroelements were not high: Ca – 4.04g kg^{-1}, Mg – 4.34g kg^{-1}, K – 4.31 g kg^{-1}, Na – 0.53 g kg^{-1}, Fe – 19.05 g kg^{-1}, Mn – 0.32 g kg^{-1} and Al – 20.22 g kg^{-1}. These total amounts showed little vertical and horizontal variance in the soil profiles. The principal component analysis showed that the total amounts of elements in analysed soils was dependent mainly on sand and silt, and the similarity of soil horizons, in the cluster analysis, proves the translocation of macroelements was probable.

Keywords: macroelements, soil erosion, soil catena, slope

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INTRODUCTION

The content of macroelements in soils depends on lithological factors (e.g. particle size distribution and mineral composition), pedological factors such as soil-forming processes and anthropogenic factors, mostly land use. Sources of macroelements in the soil can be primary and secondary minerals, soil organic matter and mineral and organic fertilization (Kobierski *et al*. 2014, Smólczyński *et al*. 2020).

The soils developed from the Pleistocene and Holocene sediments have varied content of macroelements (Orzechowski *et al*. 2020a, 2020b, Smólczyński and Orzechowski 2010, Smólczyński *et al*. 2020, Sowiński 2016). Soils occurring in young glacial river valleys are modified by the processes of translocation of soil material down the slope due to anthropogenic denudation. The effect of anthropogenic denudation is the altered thickness of soil humus horizon on the slope. In the upper parts of slopes progressive shallowing of topsoil and increasing thickness of colluvial materials in lower part of slopes is observed (Metecka and Świtoniak 2020, Sowiński 2014).

The rate of soil transformation as a result of anthropogenic denudation depend on many factors, e.g. shape of slope, lithology, soil susceptibility to erosion, type of land use, etc. Processes of soil erosion and impact of land use on physical and chemical soil properties is also important. The interaction between the position on slope and type of soil management practices could be one of the most important factors affecting several soil properties (Kobza and Pálka 2020, Šimanský *et al*. 2019, Zukaitis and Liaudanskiene 2020). Translocation of soil mineral material may lead to a decrease in the content of easily dissolved macroelements (e.g. Ca and Mg) which are accumulated in lower parts of the slope or in depressions. Understanding these relationships may be helpful in the proper management of soils in the areas with diversified relief (Bechmann 2012, Li *et al*. 2011, Metecka and Świtoniak 2020).

The aim of this paper was to determine the content and spatial variability of Ca, Mg, K, Na, Fe, Mn and Al and their relationships with soil properties. Vertical and horizontal distribution of macroelements in soils occurring in the soil catena in Lier River valley, S Norway, were discussed. Multivariate techniques of PCA were used for the analysis of relationship between the content of macroelements and soil properties.

MATERIALS AND METHODS

The study comprised the soil catena in the lower course of the Lier River (Buskerud Region, Southern Norway – Fig. 1, 59°47'31.40" N, 10°14'53.04" – WGS 84). The study area represents a typical landscape of Southern Norway.

The origin of the deposits in the river valley was related to different activities of the glacier, sea, river and humans in Pleistocene and Holocene. The postglacial valley, currently used by the Lier River, is filled with marine deposits that built the hills. Flat areas, located closer to the river, are related to the accumulation of alluvial deposits. The deposits have silt loam (SiL), sandy loam (SL) and silt (Si) texture. Main land use types of the Lier River valley are complex cultivation patterns, non-irrigated arable land and urban fabric (Fig. 1). The erosional risk determined according to the USLE model, ranged from high at the top of the hills to low on the flat areas. The soil cover of the studied area included two main soil units: Phaeozems and Gleysols (according to WRB 2015). These soils had mostly medium (3–6%) organic matter content (Sowiński 2014).

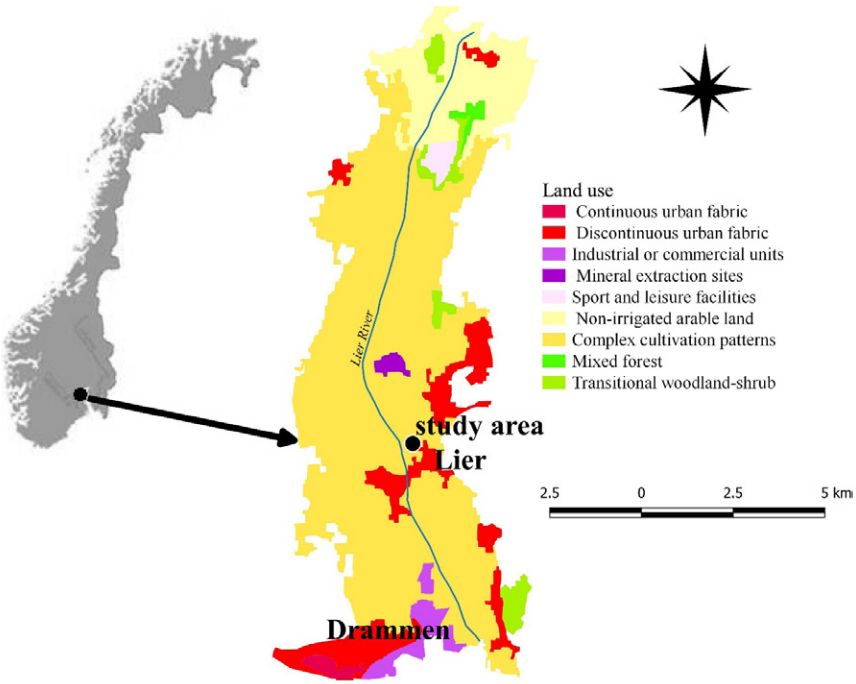

Fig. 1. Location of study area and land use of the Lier River valley (according to CORINE Land Cover 2018)

Twenty soil samples were collected from genetic horizons of six soil profiles. The following properties were analysed: particle size distribution, organic matter content (OM), organic carbon (C_{org}), total nitrogen (N_{tot}), total phosphorus (P_{tot}), soil pH and content of $CaCO_3$. The methods and results of physical-chemical analyses have been already described in the previous paper (Sowiński 2014).

The total contents of Ca, Mg, K, Na, Mn, Fe and Al were measured by inductively coupled plasma optical emission spectrometry (iCAP 7400 ICP-OES

Termo Scientific) after ultrawave mineralization (Ultrawave Milestone). Statistical calculations (mean, correlation coefficients, standard deviation) were carried out using Statistica 13.1. Principal component analysis (PCA) was applied to show relationships between the studied variables (Ca, Mg, K, Na, Mn, Fe, Al and OM, C_{org}, N_{tot}, P_{tot}, pH H_2O, pH KCl, $CaCO_3$ and soil granulometric fractions). A dendrogram plotted according to the Ward method showed similarities between the analysed soil horizons (without granulometric fractions).

Soils were classified according to the WRB system (IUSS Working Group WRB 2015), the soil texture classes were determined according to the classification of the Polish Society of Soil Science (Polskie… 2009) and horizon symbols were given according to the Polish Soil Classification System (Polish… 2019, Kabała *et al.* 2019).

RESULTS AND DISCUSSION

The Lier River valley is covered with Stagnic Phaeozems (Siltic or Endosiltic) formed from silt loam and sandy loam (upper and middle parts of slope). Haplic Phaeozems (Endosiltic or Siltic and Anocolluvic), also formed from silt loam and sandy loam, occur in the middle and lower part of slope. The last chain in the studied toposequence is Mollic Gleysol (Siltic) formed from silt and silt loam.

The average total amounts of macroelements were the following: Ca – 4.04g kg^{-1}, Mg – 4.34g kg^{-1}, K – 4.31 g kg^{-1}, Na – 0.53 g kg^{-1}, Fe – 19.05 g kg^{-1}, Mn – 0.32 g kg^{-1} and Al – 20.22 g kg^{-1}. The highest amount of macroelements was obtained for Stagnic Phaeozems (Endosiltic) in 2C horizon – Mg, K and Al (profile 3) and in Cg horizon – Na and Mn (profiles 3 and 4). The highest content of Ca and Fe was stated in Ap horizon in Mollic Gleysol (Siltic) (Table 1). Generally, higher amounts of macroelements (except for Ca and Fe) were found in parent materials. In the majority of studied soil profiles (i.e. soil profiles 1, 4, 5 and 6) the amounts of macroelements were decreasing in deeper horizons in the soil profile. In the soil profiles 2 and 3, these amounts were increasing with the depth in the soil profile. Except for manganese, no statistically significant differences were found between the values in humus horizons and parent materials (Table 2). Similarly, there was no catenal variance for most of the studied macroelements. Only, higher amounts of Ca and Fe were detected in A horizon of Mollic Gleysol (profile 6), located in the lower part of the slope. Higher amounts of Fe were related to water properties and redox conditions. Iron is frequently accumulated in a reduced form as a result of capillary rise and is later oxidized (Orzechowski *et al.* 2020a, 2020b, Pankiv and Yamelynets 2020). Calcium is a labile component and can be translocated in a solution and accumulated at lower parts of the relief (Smólczyński *et al*. 2020, Sowiński 2016).

Table 1. Total amounts of macroelements in the studied soil horizons

Horizon	Depth (cm)	Textural class	Ca	Mg	K	Na	Fe	Mn	Al
			g kg^{-1}						
Profile 1 – Stagnic Phaeozem (Siltic)									
Ap	0–40	SiL	4.31	4.19	4.87	0.60	13.80	0.37	21.10
C1g	40–50	SiL	3.88	4.39	4.76	0.49	14.16	0.30	21.59
C2	50–150	SiL	3.55	3.84	3.76	0.41	13.15	0.34	19.91
Profile 2 – Haplic Phaeozem (Endosiltic, Anocolluvic)									
Ap	0–32	SL	3.08	3.27	2.85	0.38	11.35	0.25	17.02
A2	32–56	SL	3.18	3.66	2.95	0.34	12.36	0.29	17.11
Ab	56–92	SiL	3.87	4.16	4.45	0.48	14.33	0.35	20.20
C1g	92–118	SiL	3.20	3.99	3.55	0.50	19.16	0.27	20.42
C2	118–150	SiL	3.47	4.32	3.84	0.54	20.75	0.30	22.13
Profile 3 – Stagnic Phaeozem (Endosiltic)									
Ap	0–38	SiL	4.15	4.24	4.43	0.61	20.47	0.35	21.01
Cg	38–62	SL	5.97	4.47	2.97	0.72	17.44	0.22	17.22
2C	62–150	SiL	3.63	5.46	6.57	0.70	25.13	0.28	23.89
Profile 4 – Stagnic Phaeozem (Endosiltic)									
Ap	0–45	SiL	4.06	4.32	4.70	0.57	20.37	0.35	20.76
Cg	45–64	SL	3.68	3.85	3.41	0.51	18.17	0.37	16.71
2C	64–150	SiL	3.53	5.31	6.39	0.68	24.44	0.27	23.24
Profile 5 – Haplic Phaeozem (Siltic, Anocolluvic)									
Ap	0–33	SiL	4.16	4.47	4.59	0.50	21.16	0.35	20.62
A2	33–46	SiL	4.13	4.39	4.66	0.59	21.30	0.34	20.78
A3	46–86	SiL	3.85	4.86	5.24	0.50	22.75	0.35	22.69
Cgg	86–150	SiL	3.90	4.27	3.40	0.43	21.19	0.30	17.61
Profile 6 – Mollic Gleysol (Siltic)									
Ap	0–32	Si	7.14	4.86	5.12	0.53	27.12	0.34	21.77
Gc	32–150	SiL	4.14	4.54	3.61	0.45	22.49	0.32	18.69

SiL – silt loam, Si – silt, SL – sandy loam

Statistical analyses revealed insignificant differences between average amounts of studied macroelements in humus horizons (A) and parent materials (C). The values of standard deviation ranged between 0.04 (Mn) and 5.20 (Fe) in A horizons, and 0.04 (Mn) and 4.01 (Fe) in parent materials (Table 2). The value of coefficient of variance for humus horizons oscillated between 9.06 (Al) and 28.08 (Fe) and for parent materials – between 12.47 (Mg) and 30.11 (K). Similar, little variance of the amounts of macroelements, was found in the soils of ice-dammed lakes origin in Poland (Orzechowski *et al*. 2020a, 2020b, Smólczyński *et al*. 2015, Smólczyński *et al*. 2020). In these young Polish soils, developed from glaciolacustrine sediments and showing poor weathering, the release, leaching and translocation of nutrients was low.

Among all studied elements, only Mn showed no statistically significant correlations with the soil properties (Table 3). Calcium was significantly correlated with pH values ($r = 0.581$ and $r = 0.612$, $p = 0.01$). The contents of Mg, K, Na, Fe, Mn, and Al were significantly correlated with sand or/and gravel (negatively) and silt and/or clay (positively). Aluminum, iron, natrium and potassium were positively significantly correlated with other macroelements. In humus horizons of studied soils, amounts of macroelements were positively significantly correlated with organic matter, C_{org}, N_{tot} and P_{tot}. Magnesium, potassium and aluminum were correlated with all properties (Table 4).

Table 2. Average amounts of studied elements in humus horizons (A) and parent materials (C)

Macro-element	Value	Soil horizon		Statistically significant differences
		A **(1)**	C **(2)**	$\alpha = 0.05$
Ca	X	4.19	3.90	
	SD	1.12	0.78	
	CV	26.65	19.89	
Mg	X	4.24	4.44	
	SD	0.49	0.55	
	CV	11.49	12.47	
K	X	4.39	4.23	
	SD	0.83	1.27	
	CV	18.87	30.11	
Na	X	0.51	0.54	
	SD	0.09	0.11	
	CV	17.67	21.16	
Fe	X	18.50	19.61	
	SD	5.20	4.01	
	CV	28.08	20.43	
Mn	X	0.33	0.30	
	SD	0.04	0.04	**1 > 2**
	CV	10.56	13.47	
Al	X	20.31	20.14	
	SD	1.84	2.55	
	CV	9.06	12.66	
Gravel	X	7.00	18.90	
	SD	5.50	25.88	
	CV	78.54	136.92	
Sand	X	33.50	34.30	
	SD	8.95	13.99	
	CV	26.71	40.79	
Silt	X	61.90	62.50	
	SD	9.12	12.16	
	CV	14.74	19.45	
Clay	X	4.70	3.70	
	SD	2.95	3.27	
	CV	62.68	88.32	

X – mean, S – standard deviation, CV – coefficient of variance

Table 3. Correlation coefficients between the soil properties and content of macroelements

	Mg	K	Na	Fe	Mn	Al	Gravel	Sand	Silt	Clay	$pH(H_2O)$	pH(KCl)
Ca	0.338	0.107	0.362	0.392	0.075	0.047	0.335	-0.097	0.117	-0.058	0.581**	0.612**
Mg	-	0.837**	0.680**	0.809**	-0.045	0.743**	-0.136	-0.677**	0.596**	0.449*	-0.111	-0.049
K	-	-	0.574**	0.580**	0.208	0.892**	-0.492*	-0.779**	0.682**	0.528*	-0.307	-0.173
Na	-	-	-	0.496*	-0.153	0.495*	0.300	-0.164	0.083	0.304	-0.189	-0.252
Fe	-	-	-	-	0.075	0.537*	-0.075	-0.554*	0.520*	0.324	0.055	0.129
Mn	-	-	-	-	-	0.167	-0.338	-0.251	0.233	0.062	0.130	0.371
Al	-	-	-	-	-	-	-0.570**	-0.803**	0.780**	0.353	-0.304	-0.174
Gravel	-	-	-	-	-	-	-	0.724**	-0.696**	-0.292	0.241	0.024
Sand	-	-	-	-	-	-	-	-	-0.952**	-0.465*	0.073	-0.119
Silt	-	-	-	-	-	-	-	-	-	0.189	-0.003	0.192
Clay	-	-	-	-	-	-	-	-	-	-	-0.282	-0.264
$pH(H_2O)$	-	-	-	-	-	-	-	-	-	-	-	0.902**

* significance level at $\alpha = 0.05$, ** significance level at $\alpha = 0.01$

Table 4. Correlation coefficients in humus horizons

Macro-element	OM	C_{org}	N_{tot}	P_{tot}
Ca	0.451	0.578	0.489	0.804**
Mg	0.668*	0.865**	0.876**	0.837**
K	0.794**	0.896**	0.928**	0.728*
Na	0.631	0.729*	0.727*	0.459
Fe	0.497	0.793**	0.709*	0.879**
Mn	0.738*	0.742*	0.859**	0.475
Al	0.809**	0.926**	0.950**	0.710*

* – significance level at $\alpha = 0.05$, ** – significance level at $\alpha = 0.01$

The principal component analysis showed that the total contents of elements in analysed soils was dependent mainly on sand and silt (Fig. 2). The first principal component PC1 explained almost 43% of the total variability of data and was correlated with Mg (-0.869), K (-0.920), Fe (-0.746), Al (-0.896), sand (0.912), silt (-0.844). The second principal component explained 19% of the total variance and was correlated with Ca (0.874), pH (0.838) and calcium carbonate (0.766). Fig. 3 presents a dendrogram plotted with the Ward method to illustrate which soil horizons were similar in the context of studied elements. Three groups of soil horizons can be distinguished:

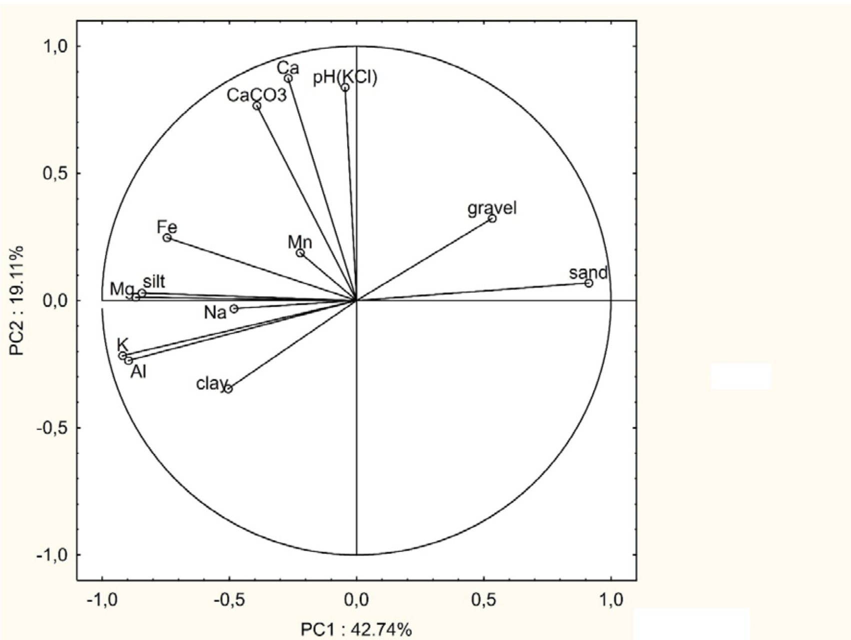

Fig. 2. Principal component analysis

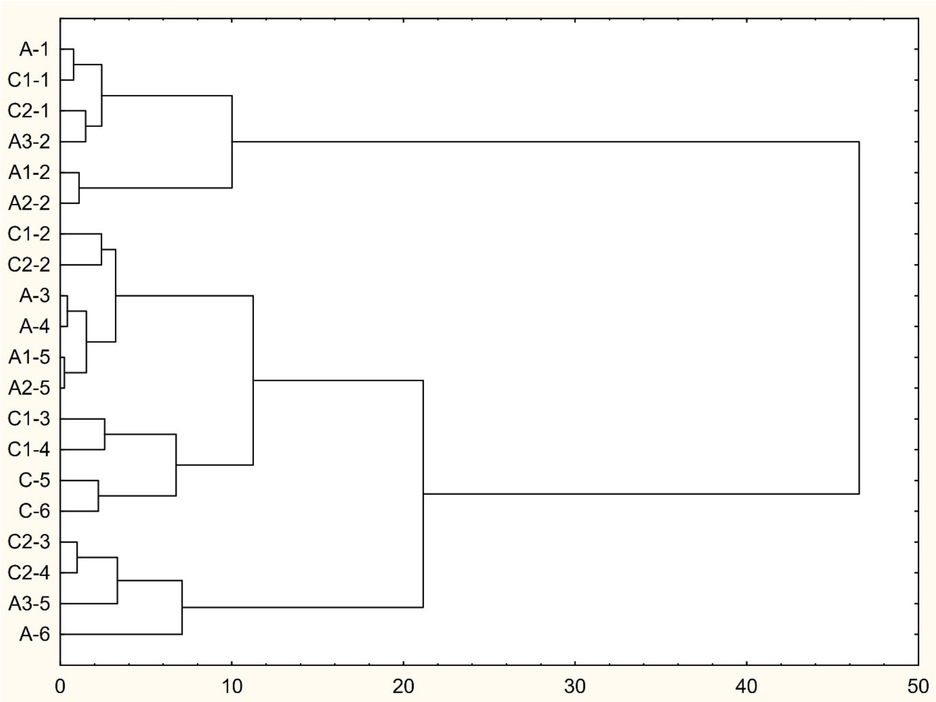

Fig. 3. Dendrogram according to the Ward method

1. Humus horizons of the soil profiles 1 and 2, and parent materials of the soil profile 1.
2. In this group additional two subgroups emerged: the first subgroup comprises humus horizons of the soil profiles 3, 4 and 5 as well as parent material in the soil profile 2. The second subgroup comprises parent materials of soil profiles 3, 4, 5 and 6 (for the soil profiles 3 and 4 only the upper C1 parent materials are included).
3. Humus horizons of the soil profiles 5 (A3) and 6, and parent materials (C2) of the soil profiles 3 and 4.

The above cluster analysis proved that the humus horizons in the Stagnic Phaeozem (profile 1) and Mollic Gleysol (profile 6) are very different. It proves that the translocation of elements was probable.

CONCLUSIONS

The Lier River valley is covered with the Stagnic Phaeozems, Haplic Phaeozems (Anocolluvic) and Mollic Gleysols formed from silt loam, sandy loam and silt. The analysed macroelements, were significantly positively correlated with silt, clay, pH values, organic matter, C_{org}, N_{tot} and P_{tot}. Most elements (Mg, K, Na, Fe, Mn, and Al) was negatively significantly correlated with sand or/and gravel. Al, Fe, Na and K were positively significantly correlated with other macroelements. The total amounts of macroelements showed little vertical and horizontal variance in the soil profiles. The principal component analysis showed that the content of macroelements in analysed soils was dependent mainly on sand and silt. The cluster analysis proves the translocation of elements was probable in study soils.

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