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CONTENTS OF EXCHANGEABLE CATIONS OF SOILS FORMED UPON LIMESTONES AND DOLOMITES

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Abstract. Contents of exchangeable cations of the soils formed upon limestones and dolomites were examined at 52 sites on the slopes of the Mount Massive of Galicica (40°56′29.7″N 20°48′22.5″E), Jablanica (41°12′17.4″N 20°34′19.8″E), Suva Gora (41°49′06.4″N 21°05′27.5″E), Ilinska Planina (41°18’04.7″N 20°58’08.5″E) and in the region of Doiran Lake (41°11′21.3″N 22°43′14.4″E). The research results show that 34 profiles are with Rendzic Leptosols, 13 with Chromic Leptic Luvisol on hard limestones and 5 profiles of Rhodic Leptic Luvisol on hard limestones. The exchangeable basic cations are determined by the method of Hendershot and Duquette (1986) and exchangeable acid cations by the Melich method (1948). The research show that these soils have high cation exchange capacities (CEC), which vary in wide ranges, from 24.69 to 99.39 cmol (+) kg^{-1}. The high values of the CEC are the result of the high content of clay and organic matter. The values of total exchangeable bases (S) and degree of base saturation (V) indicated that the CEC is highly saturated with basic cations. The exchangeable Ca^{2+} is dominant in the adsorptive complex (average 59%) and further follow $H^+ + Al^{3+}$ (average 27%), Mg^{2+} with 13% and K^+ and Na^+ with less than 1% of CEC.

Keywords: Rendzic Leptosols, Chromic Leptic Luvisol and Rhodic Leptic Luvisol on hard limestones, exchangeable cations: Ca^{2+}, Mg^{2+}, K^+, Na^+, $H^+ + Al^{3+}$

AIMS AND BACKGROUND

The soils formed upon limestones and dolomites occupy a significant part of the soil cover of the Republic of Macedonia. Based on the pedological map[1] these soils occupy around 2 571 300 ha, that is 12.45% of the total area of Macedonia. Rendzic Leptosols (RL) cover around 220 000 ha or 8.55%, Chromic Leptic Luvisols on hard limestones (CLL) cover around 100 000 ha or 3.88% and Rhodic Leptic Luvisol on hard limestones (RLL) rarely form continuous soil coverage. Those soils are covering small areas of concave forms of the karst relief, with mosaic and fragmentation characteristics and cover around 260 ha or 1% of the total area[2].

The literature in Macedonia is poor when it comes to data about these soils, and especially when it comes to the research of the content of cations in the soil

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adsorption complex. In order to give small contribution for better understanding, we have started research about the composition of exchangeable cations in the adsorption complex in the soils formed upon limestones and dolomites.

EXPERIMENTAL

The field research of soils formed upon limestones and dolomites were carried out on various locations in the country. We excavated 52 basic pedological profiles (34 profiles of (RL), 13 (CLL) and 5 (RLL)) and data were collected regarding the soil genesis conditions (parent material, relief, climate, vegetation and human factor)[3,4]. The exchangeable acid cations (H^+ and Al_3) were determined according to the Melich method with barium chloride – triethanolamine extraction (pH 8.1), in glass columns. Titration was carried out in the extract with 0.04 N HCl and mixed indicator[5–9].

The extraction of exchangeable cations (Ca^{2+}, Mg^{2+}, K^+, Na^+) in noncarbonate samples was carried out with $BaCl_2$ using the ICP spectrophotometer of the type 'Agilent Technologies 700 Series ICP – OES' (method of Hendershot and Duguette[10]). The cation$^-$ exchange capacity (CEC), the total exchangeable basis (S), the base saturation percentage (V) and the percentage of separate exchangeable cations were calculated.

As for the composition of exchangeable cations in both horizons, variance analysis (ANOVA) has been made for samples of various sizes. The influence of the substrate, the soil type and their interaction over the variability of the composition of the exchangeable cations has been determined. The significant of the differences between the medium values of the analysed parameters, by substrates and soil types, has been determined by means of the Tukey test, for level $p < 0.05$. All statistical analyses have been made with the software package R.

RESULTS AND DISCUSSION

Qualitative and quantitative determinations of cations in the adsorption complex of the soil gives very important data on the condition and the running of the soil forming process, as well as information on the soil fertility.

The composition and the quantity of particular exchangeable cations at soils formed upon limestones and dolomites, depend on the parent material and its mineral composition, as well as on the biological accumulation of basic ions in the Amo horizon[11].

It can be seen from Tables 1 and 2 that the basic cations (Ca^{2+}, Mg^{2+}, K^+, Na^+) prevail over the acidic cations ($H^+ + Al^{3+}$, Fe^{3+}, Mn^{2+}) in the adsorption complex of the soils formed upon limestones and dolomites.

Table 1. Exchangeable cations (average values in cmol (+) kg^{-1}), horizon Amo

Soil tipe	N	Ca^{2+}		Mg^{2+}		K^+		Na^+		(BCE)		$H^+ + Al^{3+}$		T		V	
		X	S.D	X	S.D	X	S.D	X	S.D	X	S.D	X	S.D	X	S.D	X	S.D
1	7	38.15b	9.58	4.46a	2.21	0.35	0.08	0.14	0.07	43.09a	11.06	10.70ab	5.19	53.82	14.60	80.59b	6.80
2	22	29.84ab	8.94	18.02b	18.86	0.44	0.27	0.14	0.10	48.43ab	21.16	9.36a	7.31	57.83	18.91	81.82b	14.15
3	5	23.57a	2.14	4.49a	1.65	0.37	0.18	0.11	0.05	28.54a	2.66	13.15ab	3.70	41.79	4.21	68.60a	6.91
4	13	33.65ab	9.33	12.92ab	14.64	0.71	0.39	0.14	0.07	47.42ab	19.95	12.31ab	6.22	59.78	16.22	77.08b	13.46
5	5	29.57a	5.10	2.98a	1.44	0.47	0.44	0.10	0.03	33.11a	5.65	16.66b	3.79	49.83	7.58	66.45a	6.12
P.M	N	X	S.D	X	S.D	X	S.D	X	S.D	X	S.D	X	S.D	X	S.D	X	S.D
M.L	19	33.68	7.36	4.58a	2.59	0.51	0.34	0.17b	0.11	38.94a	8.79	14.51b	5.20	53.51a	10.36	72.59a	9.30
D.L	7	26.70	6.90	2.34a	1.12	0.24	0.06	0.05a	0.04	29.33a	7.03	15.66b	5.20	45.01a	8.76	65.18a	9.15
B.L	7	32.38	6.77	6.89a	4.18	0.62	0.50	0.13ab	0.05	40.02a	10.78	6.53a	2.40	45.57a	10.17	85.51b	6.00
P.L	8	26.92	8.36	6.23a	3.16	0.53	0.16	0.13ab	0.02	33.80a	10.80	14.52b	5.49	48.45a	14.29	69.62a	7.41
D.M	5	29.17	2.16	43.44c	6.97	0.48	0.05	0.12ab	0.01	73.22b	7.25	2.85a	1.39	76.09b	7.86	96.27b	1.58
L.D.C	6	35.32	17.75	35.68b	14.39	0.52	0.40	0.15ab	0.03	71.67b	21.13	4.76a	2.84	76.45b	21.92	93.72b	3.88

1 – Rendzic Leptosols (RL) -organogenic; 2 – Rendzic Leptosols (RL) organomineral/haplic; 3 – Rendzic Leptosols, chromic luvic/brownised (CLRL); 4 – Chromic Leptic Luvisol on hard limestones (CLL); 5 – Rhodic Leptic Luvisol on hard limestones (RLL); P.M – Parent material; M.L – Massive limestone; D.L – Dolomitic limestone; B.L – Bituminous limestone; P.L – Plate limestone; D.M – Dolomitic marbles; L.D.C – Laminated (plate) dolomite and calcite.

Table 2. Exchangeable cations (average values in cmol (+) kg^{-1}), horizon (B)rz

Soil type	N	Ca^{2+}		Mg^{2+}		K^+		Na^+		(BCE)		$H^+ + Al^{3+}$		T		V	
		X	S.D	X	S.D	X	S.D	X	S.D	X	S.D	X	S.D	X	S.D	X	S.D
3	5	25.63	8.36	2.57a	2.14	0.22	0.15	0.12	0.06	28.27a	10.33	14.05	4.48	42.34	11.44	66.11	8.39
4	14	26.52	3.99	9.56b	13.35	0.31	0.21	0.15	0.05	36.54b	12.43	11.73	4.96	48.58	9.85	74.10	10.86
5	7	27.31	2.66	4.10a	2.08	0.62	0.55	0.11	0.03	32.13ab	4.28	16.42	3.99	48.61	5.15	66.25	6.69
P.M	N	X	S.D	X	S.D	X	S.D	X	S.D	X	S.D	X	S.D	X	S.D	X	S.D
M.L	11	27.39	2.45	4.10a	2.08	0.49	0.48	0.15b	0.06	32.13a	3.90	15.46	5.08	47.65ab	4.79	67.85	9.04
D.L	4	21.86	5.04	1.55a	0.68	0.13	0.02	0.09a	0.06	23.62a	4.87	12.90	3.38	36.54a	6.81	64.75	5.62
B.L	4	27.40	5.46	7.94a	1.91	0.42	0.27	0.15b	0.01	35.92a	7.19	8.50	1.59	45.44ab	5.91	78.56	6.69
P.L	5	29.65	5.28	3.63a	2.57	0.29	0.14	0.12ab	0.02	33.68a	7.51	15.72	2.64	49.43b	5.46	67.52	7.62
D.M	1	22.16	/	52.03c	/	0.27	/	0.15b	/	74.61b	/	3.54	/	78.16c	/	95.46	/
L.D.C	1	20.51	/	22.11b	/	0.48	/	0.18b	/	43.28a	/	11.46	/	54.75c	/	79.05	/

3 – Rendzic Leptosols, chromic luvic/brownised (CLRL); 4 – Chromic Leptic Luvisol on hard limestones (CLL); 5 – Rhodic Leptic Luvisol on hard limestones (RLL); P.M – Parent material; M.L – Massive limestone; D.L – Dolomitic limestone; B.L – Bituminous limestone; P.L – Plate limestone; D.M – Dolomitic marbles; L.D.C – Laminated (plate) dolomite and calcite.

From the presented average values about the composition of the exchangeable basic cations (Tables 1 and 2) for the soils formed upon limestones and dolomites, the following has been determined: highest average value of exchangeable Ca^{2+} (38.15 cmol (+) kg^{-1}) in Amo humus-accumulative horizon was observed at the subtype organogenic (RL), then (29.84 cmol (+) kg^{-1}) at organomineral and (23.57 cmol (+) kg^{-1}) at brownised Rendzic Leptosols (CLRL). Small increase of the content of exchangeable Ca^{2+} was noticed at the subtype brownised Rendzic Leptosols (CLRL) along the depth of the profile, whereby in the cambic horizon (B)rz, this amounts to 25.63 cmol (+) kg^{-1}.

Expressed as a percentage of the cation-exchange capacity (CEC), (Tables 3 and 4), the average amount of the exchangeable Ca^{2+} in the Amo horizon at the organogenic (RL) amounts to 71.39%, (54.28%) in the organomineral and 56.61% at the brownised Rendzic Leptosols (CLRL). In the cambic horizon (B)rz at (CLRL), the exchangeable Ca^{2+} amounts to 59.47%. Many authors[12–17], in the studies of soils formed upon limestones and dolomites, point out that the exchangeable Ca^{2+} prevails in the adsorption complex. In one such profile in the Demir Hisar region Filipovski[18] points out to the higher presence of exchangeable Ca^{2+} (95.30%).

The exchangeable (Ca^{2+}) plays important role in the creation of stable granular structure. The calcium salts neutralise the minerals and the humus acids, and create insoluble Ca-humates. This cation is really important macro biogenic element in the nutrition of the plants. The lack of Ca^{2+} is rarely found in the soil, only in the soil with very low cation-exchange capacity Pantovic[13], less than 2 cmol (+) kg^{-1}.

The average content of exchangeable Mg^{2+} in the humus-accumulative Amo horizon is the highest at the organomineral (RL) and amounts to 18.02 cmol (+) kg^{-1}, then 4,49 cmol (+) kg^{-1} at (CLRL) and 4.46 cmol (+) kg^{-1} at organogenic (RL). In the cambic horizon (B)rz at (CLRL) the average content of Mg^{2+} amounts to 2.57 cmol (+) kg^{-1}. Expressed from (CEC), the average exchangeable Mg^{2+} has (26.41%) in the organomineral (RL), 10.84% at (CLRL) and 8.29% at organogenic (RL) and 5.84% in (B)rz at (CLRL). Similar to the calcium, magnesium is a biogenic element necessary for plants. Magnesium deficit appears at soils that contain exchangeable Mg^{2+} less than 0.2 cmol (+) kg^{-1} soil[19].

Exchangeable (K^+ and Na^+) cations are found in minimum quantities. The average content of potassium in the humus-accumulative horizon (Amo) in organogenic (RL) is 0.35 cmol (+) kg^{-1}, or 0.66% of (CEC), in organomineral (RL) it is 0.44 cmol (+) kg^{-1} or 0.86% of (CEC) and 0.37 cmol (+) kg^{-1} or 0.88% of (CEC) in (CLRL). In the cambic (B)rz horizon in (CLRL) the average value of exchangeable K^+ is 0.22 cmol (+) kg^{-1} or 0.50% of (CEC).

Table 3. Exchangeable cations (average values in %), horizon Amo

Soil type	N	Ca^{2+}		Mg^{2+}		K^{+}		Na^{+}		(BCE)		$H^{+} + Al^{3+}$		T	
		X	S.D	X	S.D	X	S.D	X	S.D	X	S.D	X	S.D	X	S.D
1	7	71.39b	4.34	8.29a	3.22	0.66	0.09	0.26	0.16	80.60c	6.79	19.40a	6.80	53.82	14.60
2	22	54.28a	14.69	26.41c	23.52	0.86	0.81	0.25	0.17	81.80c	14.16	18.17a	14.15	57.83	18.91
3	5	56.61a	4.92	10.84ab	4.35	0.88	0.37	0.27	0.12	68.60ab	6.91	31.39bc	6.91	41.79	4.21
4	13	57.07a	9.84	18.62bc	15.63	1.19	0.59	0.24	0.13	77.13bc	13.36	22.86ab	13.35	59.78	16.22
5	5	59.28a	4.62	6.00a	2.92	1.02	0.98	0.22	0.07	66.52a	6.19	33.47c	6.18	49.83	7.58
P.M	N	X	S.D	X	S.D	X	S.D	X	S.D	X	S.D	X	S.D	X	S.D
M.L	19	63.28cd	8.19	8.33a	3.97	1.06	0.94	0.30b	0.16	72.98a	9.29	27.02bc	9.29	53.51a	10.36
D.L	7	59.15bc	7.77	5.46a	3.03	0.54	0.15	0.12a	0.12	65.28a	9.02	34.71c	9.01	45.01a	8.76
B.L	7	70.17d	6.79	13.83a	6.01	1.22	0.71	0.29ab	0.15	85.51ab	6.01	14.48ab	6.01	45.57a	10.17
P.L	8	55.34bc	5.71	12.79a	4.59	1.13	0.31	0.29ab	0.08	69.55a	7.37	30.38c	7.41	48.45a	14.29
D.M	5	38.62a	4.19	56.84b	3.91	0.64	0.10	0.16ab	0.01	92.26b	1.57	3.73a	1.56	76.09b	7.86
L.D.C	6	45.30ab	14.37	45.58	17.36	0.63	0.30	0.20ab	0.06	93.71	26.08	6.29	3.11	76.45b	21.92

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Table 4. Exchangeable cations (average values in %), horizon (B)rz

Soil type	N	Ca^{2+}		Mg^{2+}		K^{+}		Na^{+}		(BCE)		$H^{+} + Al^{3+}$		T	
		X	S.D	X	S.D	X	S.D	X	S.D	X	S.D	X	S.D	X	S.D
3	5	59.47	5.27	5.84a	3.64	0.50	0.22	0.28	0.14	66.10a	8.40	33.89b	8.39	42.34	11.44
4	14	56.26	11.59	16.88b	17.40	0.65	0.43	0.31	0.12	74.11b	10.84	25.27a	11.09	48.58	9.85
5	7	56.45	5.25	8.28a	3.81	1.28	1.20	0.24	0.06	66.26a	6.69	33.70b	6.67	48.61	5.15
P.M	N	X	S.D	X	S.D	X	S.D	X	S.D	X	S.D	X	S.D	X	S.D
M.L	11	57.95b	7.21	8.55a	4.22	1.04	1.04	0.32	0.12	67.86a	9.04	32.11b	9.02	47.65b	4.79
D.L	4	59.63b	5.01	4.50a	2.69	0.37	0.12	0.24	0.19	64.74a	5.60	35.25b	5.61	36.54a	6.81
B.L	4	59.91b	4.33	17.42b	3.27	0.89	0.45	0.33	0.06	78.55b	6.69	19.27b	6.19	45.44ab	5.91
P.L	5	59.74b	5.00	6.98a	4.57	0.58	0.28	0.24	0.03	67.55a	7.60	32.44b	7.60	49.43b	5.46
D.M	1	28.35a	/	66.56c	/	0.34	/	0.19	/	95.44	/	4.55a	/	78.16c	/
L.D.C	1	37.46ab	/	40.38b	/	0.88	/	0.32	/	79.04	/	20.96	/	54.75b	/

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The data on the exchangeable Na^+ show no big differences among different subtypes of (RL). The average content of Na^+ in the humus Amo horizon is 0.14 cmol (+) kg^{-1} soil in organogenic (RL) and 0.14 cmol (+) kg^{-1} in organomineral (RL) or 0.26% and 0.25% of (CEC). The average content of Na^+ in (CLRL) is 0.11 cmol (+) kg^{-1} or 0.27% of (CEC), and in the cambic (B)rz horizon it is 0.12 cmol (+) kg^{-1} or 0.28% of (CEC). The low sodium content in the adsorption complex is due to the ease of leaching of this cation from the soil due to the presence of large hydration coating (water film) which reduces its ability for adsorption, poor presence of silica residium which is released by dissolving the limestone and dolomite and the impossibility for its biological accumulation in the Amo horizon due to the low presence in the organic matter[11].

According to their presence, the exchangeable acidic ions ($H^+ + Al^{3+}$) follow the Ca^{2+} and Mg^{2+} cations. The presence of ($H^+ + Al^{3+}$) and the other acidic cations Fe^{3+} and Mn^{2+} in the adsorption complex are affected by factors among which the most important are: climate, vegetation, altitude, exposition, soil development and other factors. Soils that are at higher altitudes are influenced by higher quantity of rainfall during the year and thus there is higher leaching of the Ca^{2+} and Mg^{2+} cations. This causes a decrease in the pH reaction of the soil and increased presence of exchangeable acidic cations ($H^+ + Al^{3+}$).

The average content of ($H^+ + Al^{3+}$) in (RL) in the humus-accumulative Amo horizon is different. In the subtype organogenic (RL) it is 10.70 cmol (+) kg^{-1} or 19.40% of (CEC), in organomineral (RL) it is 9.36 cmol (+) kg^{-1} or 18.17% of (CEC) and 13,15 cmol (+) kg^{-1} or 31.39% of (CEC) in (CLRL) and in the cambic (B)rz horizon in the same subtype it is 14.05 cmol (+) kg^{-1} or 33.89% of (CEC).

In (CLL) the average content of exchangeable Ca^{2+} in the humus-accumulative Amo horizon is 33.65 cmol (+) kg^{-1} or 57.07% of (CEC), and in the cambic (B)rz horizon (26.52 cmol (+) kg^{-1}) or 56.26% (CEC). The high percentage of exchangeable Ca^{2+} in tested (CLL) is a result of the impact of the substrate whose dissolution releases the calcium and it is adsorbed in the adsorption complex, with its valence and size of the atom. Ca^{2+} cations compared to other basic cations Mg^{2+}, K^+ and Na^+ are characterised by higher substitution strength, i.e. attract with higher energy by the soil colloids. The favourable physical properties of CLL) are largely due to the higher content of Ca^{2+} and therefore soils have lower swelling in wet conditions and have higher permeability to water and air.

In (CLL) the average content of exchangeable Mg^{2+} in the Amo horizon is 12.92 cmol (+) kg^{-1} or 18.62% of (CEC), and in the cambic horizon it is 9.56 cmol (+) kg^{-1} or 16.88% of (CEC).

The content of other basic (K^+ and Na^+) cations is much lower compared to Ca^{2+} and Mg^{2+} cations. The average content of exchangeable K^+ in the Amo horizon is 0.71 cmol (+) kg^{-1} or (1.19% of CEC), and gradually decreases and in the cambic horizon it is 0.31 cmol (+) kg^{-1} or (0.65% of CEC). The low potassium content in adsorbed state is a result of its content in the parent material and the smaller capacity of adsorption in terms of Ca^{2+} and Mg^{2+}, so it can be easily pushed out of the adsorption complex and leached. The low content of K^{+} in adsorbed state is affected by the appearance of its fixation in the crystal lattices of clay minerals (illite)[11].

The average content of exchangeable Na^{+} in the Amo horizon is 0.14 cmol (+) kg^{-1} or 0.24% of (CEC), and in the cambic horizon it is 0.15 cmol (+) kg^{-1} or 0.31% of (CEC).

The data on the average values of exchangeable (H^{+}+Al^{3+}) and other acidic cations (Fe^{3+} и Mn^{2+}) show that in both horizons their quantity is similar. In the humus-accumulative horizon there is 12.31 cmol (+) kg^{-1} or 22.86% of (CEC), and 11.73 cmol (+) kg^{-1} or 25.27% of (CEC) in the cambic (B)rz horizon in (CLL).

In (RLL) the average content of exchangeable Ca^{2+} in the humus-accumulative horizon (Amo) is 29.57 cmol (+) kg^{-1} or 59.28% of (CEC). In the cambic (B)rz horizon it is 27.31 cmol (+) kg^{-1} or 56.45% of (CEC). Filipovski[6] shows data on the exchangeable calcium and points out that the calcium cations are in absolute dominance in (RLL). On average in the Amo horizon there is 27.39 cmol (+) kg^{-1} or 83.26% of (CEC) and in the (B)rz horizon there is 30.61 cmol (+) kg^{-1} or 86.59% of (CEC).

Acidic cations (H^{+}+Al^{3+}) are second most present according to the composition of the exchangeable cations (RLL) and their average value in the Amo horizon is 16,66 cmol (+) kg^{-1} or 33.47% of (CEC) and in the (B)rz horizon it is 16.42 cmol (+) kg^{-1} or 33.70% of (CEC). The exchangeable magnesium is third most present according to the average content of 2.98 cmol (+) kg^{-1} or 6.00% of (CEC) in the Amo horizon and 4.10 cmol (+) kg^{-1} or 8.28% of (CEC) in the cambic (B)rz horizon.

The content of exchangeable (K+ and Na^{+}) cations is minimum. The average content of K^{+} in the Amo horizon is 0.47 cmol (+) kg^{-1} (or 1.02% of CEC) and in the cambic horizon it is 0.62 cmol (+) kg^{-1} or 1.28% of (CEC), and Na^{+} in the Amo horizon is 0.10 cmol (+) kg^{-1} or 0.22% of (CEC) and 0.11 cmol (+) kg^{-1} or 0.24% of (CEC) in the cambic (B)rz horizon.

If we compare the data on the exchangeable cations in our investigated (RLL) with (RLL) from other Republics of former Yugoslavia we can find the following differences: (RLL) in other countries have lower percentage of exchangeable calcium with average of 53.98% of (CEC) because they are formed over limestones richer in magnesium, where the average content of Mg^{2+} is (20.45% of CEC); also they (RLL) have a higher percentage of exchangeable (K^{+} and Na^{+}) cations (average K^{+} 3.64% and Na^{+} 8.28% of CEC); what is characteristic for these (RLL) is that some of them show significant amounts of exchangeable Fe^{3+} ions (1.42–4.80% in the Amo horizon) and Mn^{2+} cations (4.62–6.72% in the same horizon). In our research the presence of Fe^{3+} and Mn^{2+} is much smaller and amounts to (0.93% of CEC for Fe^{3+}) and (0.03% of CEC) for Mn^{2+}.

The analysis of the variance (Table 5) shows that the soil type has a significant impact on the variability of the composition of exchangeable cations in the Amo horizon for the cations of Ca^{2}+, Mg^{2+}, Mn^{2+}, Fe^{3+} and ($H^+ + Al^{3+}$), as well as impact on the variability of exchangeable Mg^{2+} in the (B)rz horizon. The parent material affects the variability of exchangeable cations in the Amo horizon and the cations of Mg^{2+}, Na^+, Mn^{2+}, Fe^{3+} and ($H^+ + Al^{3+}$), and impacts the variability of exchangeable Mg^{2+} and Na^+ cations in the (B)rz horizon.

Table 5. Analysis of the variance of the exchangeable cations in Amo and (B)rz horizons

Hor.	Factors	(Mean square)							
		df	Ca^{2+}	Mg^{2+}	K^+	Na^+	S (BCE)	$H^+ + Al^{3+}$	T
Amo	Soil type	4	395.37***	795.27***	0.38	0.0037	370.87***	366.32***	369.77
	Parent material	5	711.39***	2587.52***	0.60	0.060*	995.68***	987.44***	1260.83***
	Soil type × parent material	9	54.56	48.55	0.27	0.016	44.54	44.34	113.09
	Error	33	58.92	40.84	0.52	0.017	48.13	47.92	149.19
(B)rz	Soil type	2	20.180	307.72***	1.207	0.014	202.698	233.118*	78.706
	Parent material	5	263.126**	753.39***	0.123	0.028	172.181	190.003*	276.408***
	Soil type × parent material	2	31.287	21.96	0.111	0.009	103.090	103.110	65.495
	Error	16	40.272	16.76	0.671	0.008	63.359	62.089	26.955

*Significant level 0.05; ** significant level 0.01; *** significant level 0.001.

Regarding the impact of the substrate (Tables 3 and 4) over the composition of exchangeable cations, there is the lowest content of exchangeable Mg^{2+} in the Amo horizon in soils formed over dolomitic limestone (5.46% of CEC), massive limestones (8.33% of CEC), plate limestones (12.79% of CEC) and on bituminous limestones (13.83% of CEC), and the other substrates have the highest statistical values for exchangeable Mg^{2+} (on plate dolomite and calcite 45.58% of CEC) and on dolomitic marbles (56.84% of CEC). In the cambic (B)rz horizon there is the highest value for exchangeable Mg^{2+} in soils formed over dolomitic marble (66.56% of CEC), then follow the soils formed over plate dolomites and calcite (40.38% of CEC), and the rest of the soils formed over other substrates have the lowest statistical values for exchangeable Mg^{2+}. The parent material also shows influence over the content of the exchangeable Na^+ in the Amo horizon where it can be noted that the lowest content occurs in soils formed on dolomitic limestone (0.12% of CEC), and the highest content occurs in soils formed on the massive limestone (0.30% of CEC), and other substrates have similar values of exchangeable Na^+.

The impact of the parent material can also be seen in acidic cations ($H^{+} + Al^{3+}$). In the Amo horizon there is the lowest content of ($H^{+} + Al^{3+}$) in soils formed over dolomitic marbles (3.73% of CEC), plate dolomites and calcite (6.29% of CEC), and there is the highest content in soils formed on the massive limestone (27.02% of CEC), plate limestone (30.38% of CEC) and dolomitic limestone (34.71% of CEC). In the (B)rz horizon there is the lowest content of ($H^{+} + Al^{3+}$) in soils formed on dolomitic marbles (4.55% of CEC), and the other substrates have higher values.

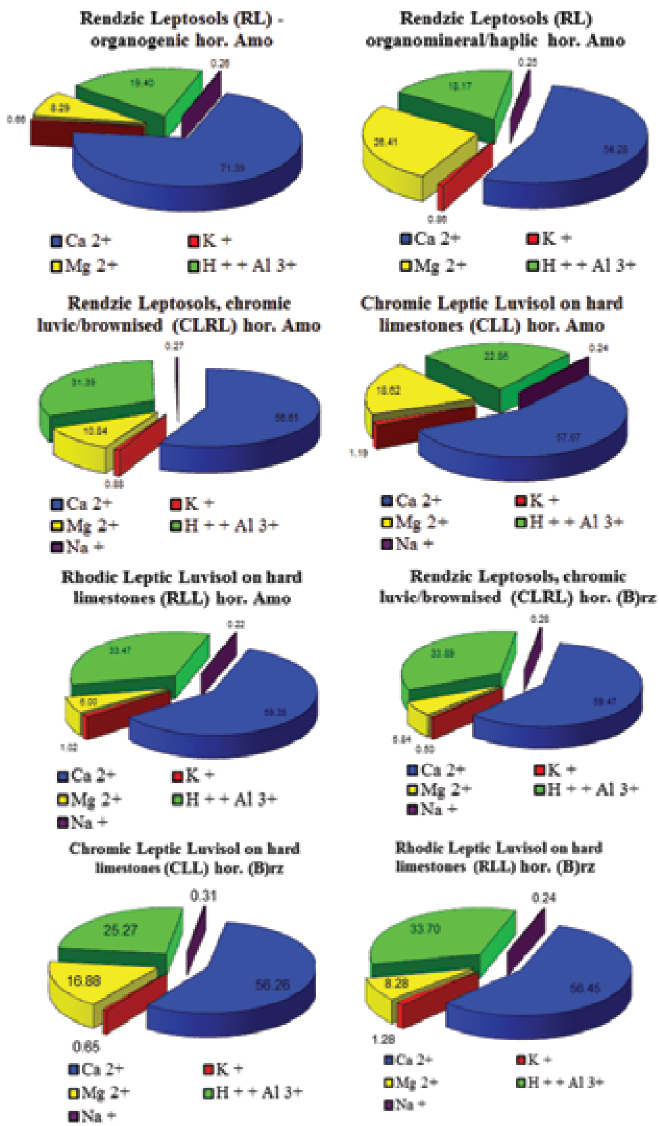

Fig. 1. Composition of exchangeable cations as a percentage of (CEC) in soils formed on limestones and dolomites

CONCLUSIONS

Finally, as a conclusion, the composition of exchangeable cations as a percentage of (CEC) in soils formed on limestones and dolomites is shown (Fig. 1).

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