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Acrisols on the territory of Training and Experimental Forest Range "Petrohan"

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Abstract

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The aim of the study was to analyze the diagnostic properties of soils on territory of Training and Experimental Forest Range (TEFR) "Petrohan" in order to classify them according to the modern requirements of World Reference Base for soil resources. Seven soil profiles were studied. Soil samples were collected from territories in which it was known that the soils are with a clay – enriched subsoil (Luvisols). Soil classification indicators have been investigated according to the requirements of World Reference Base for soil resources. Five soil profiles were classified as Acrisols and two as Lixisols. On the second taxonomy level for Acrisols apply Vetic prefix qualifier. Lixisols were identified as Vetic and Haplic. Acrisols and Lixisols were established on the territory of the TEFR „Petrohan" in beech forests of the temperate climate zone. We assume that specific weathering processes and acidifying effect of beech forests have been playing a key role for Acrisols and Lixisols formation.

Keywords: Acrisols, soil classification, *argic* horizon, beech forests, cation exchange capacity, acid rocks

Introduction

Acrisols are one of the soil units in Soils with clay – enriched subsoil (WRB, 2006, 2007). Acrisols are characterized with a very long soil forming process – several times longer than the Holocene. Their geographic distribution is associated with variation in Paleozoic period and its cumulative manifestation. "Paleosols have particular spatial pattern. They typically show limited extension, but their occurrence is probably in almost every environment. They are usually independent of the current climate, topography, vegetation, and underlying substratum"(Costantini et al., 2013).

Acrisols were first defined in the legend of the FAO-UNESCO World Map of the World (1971-1981) and were noted in its 1974, 1997, 1981, 1981 editions. They are presented in the WRB classifications (1998; 2006, 2007; 2014, 2015). A number of authors have characterized modern factors of Acrisols soil formation. In the studies of Fritsch et al. (2006) and Schaetzl & Anderson (2009) it was indicated that relief is one of the major factors for the formation of Acrisols.

They are developed mostly on old land surfaces with hilly or undulating topography (Verheye, 1998). Being quite sensitive to erosion, Acrisols are often the dominant soil group on an old erosional or depositional surface (Toth et al., 2008). The rocks are varied, most often deeply leached, acidic silicates rich in quartz (Blume et al., 2015). Deep weathering also includes clay minerals (WRB, 2007). The climate is humid tropical, subtropical or warm (WRB, 2007; Buol, 2005). The vegetation is woody. According to Peters (1997), Acrisols are important for the propagation of *Fagus sylvatica* L. in the southern parts of its area in North America and Asia.

Globally, around 1 000 million hectares have been identified. Acrisols are widely distributed in Southeast Asia, the southern parts of the Amazon River basin, southeast of the United States of America, East and West Africa, Southeast China, the northern parts of Brazil (WRB, 2006, 2007, 2014;

Blume et al., 2016) and others. In Europe, Acrisols occupy less than 0.26% of the European Union territory (Soil Atlas of Europe, 2005). Found in the Iberian Peninsula, Greece, South England, and Denmark. Acrisols occur in limited areas in Romania and Bulgaria (Toth et al., 2008). They are also spread in southern Turkey (Fraters et al., 1993). In Italy, they occupy 51 km^2. Five soil units of the Acrisols Soil Reference Group can be found in European Union (*Ferric, Gleyic, Haplic, Humic* and *Plinthic*). Gleyic Acrisols and Haplic Acrisols occupy more than 90% of their area (Toth et al., 2008).

In Bulgaria for the spread of Acrisols were pointed areas occupied by Zheltozems. They are located in the southeast parts of Strandja Mountain (Koinov, 1968; Koinov, 1998). Ninov (2002) includes Acrisols to order G along with 5 other major soil groups which are strongly weathered. In some of them *Bt* (argic) horizon is formed. According to the same author, in their further development under specific conditions, some of which are highly acidic can be defined as Acrisols. In the correlation of the National soil classification of Bulgaria with that of WRB (2006) and Soil Taxonomy System USDA Shishkov (2011) indicates the presence of *cutanic, haplic*, and *leptic* Acrisols. Their distribution is within the range of Zheltozems podzolic soils. According to Jordanova (2017), the discussion about the correct correlation of Acrisols with that of the Bulgarian Soil Classification is still ongoing. Our opinion is that for now there is still no conclusive evidence of the presence of Acrisols in Bulgaria due to the lack of analytical data on the cation exchange capacity values determined by WRB requirements (2006, 2007).

In Bulgaria, from the group of Soils with a clay – enriched subsoil (WRB, 2006, 2007) are spread also and Arenosols along the Black Sea Coast (Kirilov, 2013). Luvisols are the most widely distributed.

The studied area is characterized by soils that according to the Basic classification of soils in the country (Penkov et al., 1992) are first taxonomically defined as Luvisols, *gray* and on second level as *haplic*, *mollic* or *albic*. In the WRB (2006, 2007), the *gray* prefix qualifier is absent in Luvisols. This indicates that additional studies are needed to classify soils according to WRB requirements (2006, 2007). The aim of the present study was to analyze the diagnostic characteristics of soils defined as Luvisols from the territory of the Training and Experimental Forest Range (TEFR) „Petrohan" and their classification according to WRB requirements (2006, 2007).

Materials and Methods

The subject of the present study is the soils of the territory of TEFR "Petrohan". The forest range is located in the western Balkan area, Moesian forest district, northern Bulgaria subdistrict. Its total area is 7290.4 ha. It is located on the northern slope of Balkan Mountains.

The genesis of modern soils in this region is closely related to the geomorphological processes in the past. Discovered Silurian shales in the western Balkan Mountains reveal numerous floods from different depths and depths of sea basins, their elevations, and regressions. Contemporary relief and petrographic composition are result of the orogenesis between the Silurian and the Devonian period. Magnetic activity has contributed to the introduction of granite intrusions. Gneisses and granite in the area are part of the oldest rock formations on the surface. In some places, limestones were also deposited (Georgiev, 1985). According to Ajdanlijsky (2010) the last stage of sedimentary paleoenvironments development in the area is characterized with mass scale paleosoil development.

The altitude of the forest range is between 350 m and 1900 m. The grade of slopes is also an important component. Steep slopes and inclined terrains are predominant. Most of the terrains are with northern exposition (Regional forest development plan of the Berkovitsa and Varshets municipalities, 2016).

According to the climatic zoning of Bulgaria, the territory falls into the Pre-Balkan alpine and low-mountain climatic region of the Moderate Continental Climatic Sub-Area of the European-Continental Climate Area. Winter is cold. In January the average temperature in the lower parts is -1.9°. The continental character of the climate is strongly expressed. Absolute air temperature minima reach -28.0°C. The temperatures in July are between 19.6°C and 20.2°C, reaching 26.0 – 27.0°C. The vegetative rainfall ranges from 450 mm to 500 mm (Koleva-Lizama, 2018).

The vegetation is woody represented mainly by natural beech formations (*Fagus sylvatica* L.), mixed deciduous plantations including beech (*Fagus sylvatica* L.), oak (*Quercus petraea* L.), hornbeam (*Carpinus betulus* L.), aspen (*Populus tremula* L.), black alder (*Alnus glutinosa* (L.) Gaertn.) and others.

A total of 7 soil profiles were investigated that are previously known to be Luvisols (Dobrichov, 2016). Their altitude is in the range of 587 m to 754 m. For analysis, diagnostic parameters were selected to allow soil classification according to WRB requirements (2006, 2007). The following parameters were analyzed: soil texture – (ISO 11277); cation exchange capacity (determined as a sum of the basic cations and the exchangeable acidity); pH_{H_2O} (ISO 10390); pH_{CaCl_2} (ISO 10390), Organic carbon – Modified Turin's method (Kononova, 1963; Filcheva & Tsadilas, 2002); Mineral composition of the fine earth – ETC 7.2.1-29/2016.

Results

In the soil profiles was established an *argic* diagnostic horizon. Texture differentiation varies between 1.2 and 1.4 (Table 1). The cation exchange capacity of this horizon is less than 24 cmol (+).kg^{-1} (Table 2). In five of the soil profiles the soil is unsaturated with bases and in 2 is saturated. According to the diagnostic criteria of the group Soils with a clay – enriched subsoil WRB (2006, 2007) the unsaturated can be classified as Acrisols and the saturated as Lixisols.

Acrisols occupy flat and slanting (profiles 1, 3 and 4 of Table 1) or steep terrain (profiles 2 and 5 in Table 1). The soil-forming rocks are acidic silicate – gneisses (profiles 1, 2, 3 and 4) and granite (profile 5). The litter is present in soil profiles 2, 4 and 5. It consists of 2 layers, of which L is pronounced and F – torn and of insignificant depth. The litter is composed mainly of leaves, twigs and beech fruits (*Fagus sylvatica* L.) According to morphological features, the litter is defined as *mull* type. For profiles 1 and 3, the soil surface was covered with grass due to the higher age of the stands and the open spaces created. Depending on the intensity of erosion processes in the past, the surface horizon ranges from 5 cm to 27 cm (Table 1). Soil density increases in depth with

Table 1. Soil texture of Acrisols and Lixisols

Profile	Horizon	Soil depth, cm	Sand, %	Silt, %	Clay %
1	A	0-27	57.17	25.52	17.31
	Bt1	27-52	50.19	29.11	20.70
	Bt2	52-82-↓	53.35	25.02	21.63
2	A	0-5	67.98	18.77	13.25
	Bt	5-47	62.25	22.26	15.49
	C	47-↓	68.23	21.83	9.94
3	A	0-13	67.54	18.66	13.79
	Bt	13-42	60.45	22.35	17.20
	C	42-↓	65.81	19.26	14.93
4	A	0-15	48.76	30.37	20.88
	B	15-55	43.49	34.18	22.34
	Bt	55-102	48.44	26.68	24.88
5	A	0-7	60.26	24.74	15.00
	B	7-23	55.51	32.51	11.98
	Bt	23-105	49.71	29.53	20.76
	C	105-↓	64.86	23.08	12.06
6	A1	0-14	24.66	49.41	25.93
	A2	14-28	23.54	53.23	23.23
	Bt1	28-110	26.57	45.68	27.75
	Bt2	110-140↓	25.42	37.03	37.55
7	A	0-11	39.05	33.66	27.30
	Bt1	11-51	38.04	30.05	31.91
	Bt2	51-81	35.67	26.68	37.64

well-defined morphological features of the *argic* diagnostic horizon. The transition to *C* horizon is clear. The structure is characterized as week, predominantly granular or massive.

The results of the laboratory analysis confirm the presence of the *argic* diagnostic horizon. Its texture corresponds to the criteria set out in the WRB (2006, 2007). It is finer than loamy sand. The profile 1 is assessed as loam and sandy clay loam in the both parts of the *argic* horizon, in profiles 2 and 3 it is sandy loam, profile 4 it is sandy clay loam and in profile 5 is loam. The clay content of the fine earth in all profiles is higher than 8%. The depth of the *argic* horizon is more than 15 cm and more than 1/10 of the sum of the thicknesses of all the overlaying horizons.

Texture differentiation has different manifestations in the profiles. *Argic* horizon is morphologically homogeneous in profiles 2 and 3, and it is divided into 2 parts in profile 1. In profiles 4 and 5 is formed at the lower part of the horizon.

Throughout the depth of the profiles the sand and silt fractions of the soil texture are predominant. In the surface horizon they are in the range of 74% – 87%. Generally these fractions are carriers of primary minerals in the soil. The mineral composition of Acrisols is presented in Figure 1 to Figure 6 for profiles 1 and 4. On Figures 1, 2 and 3 is presented X-ray analysis of secondary clay minerals in Profile 1 by horizons.

Figures 4, 5 and 6 present X-ray analysis of secondary clay minerals in Profile 4 by horizons.

The results show that in the fine earth, the predominant participation is quartz. In the surface horizon the quantity reaches 45% (profile 1) – 49% (profile 4). In depth of the *Bt* horizon it decreases – to 38% (profile 1) and to 40% (profle 4). Primary minerals with higher amounts also contain microcline (17% – 25%) and albite (10% -19%). Clay minerals are absent or difficult to determine due to their low content. The presence of muscovite is main feature for secondary minerals. It is known that muscovite transforms in time into kaolinite through two phases – mica and kaolinite (Stoch and Sikora, 1976). Its amount in the profiles varies between 8% to 17%. The composition of the mineral fraction is evaluated as oxides and hydroxides.

The texture and mineral composition of Acrisols should be considered in the context of the geomorphological development of the western Balkan Mountains. The surface magma rocks deposited in the past are characterized by specific spherical weathering. Forming the round terrain of the mountain of intrusive rocks – mostly granites, they created an impermeable geological base. It was the reason for the formation of a thick valley network with a emphasized surface runoff. Its influence on the soil formation process is expressed by the leaching of the fine particles formed from

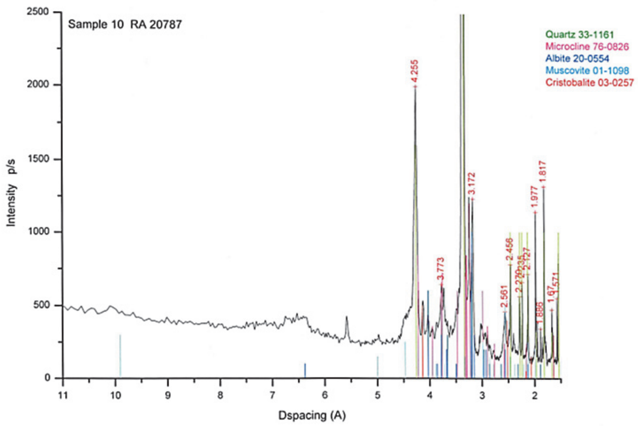

Fig. 1. X-ray analysis of secondary clay minerals in *A* horizon

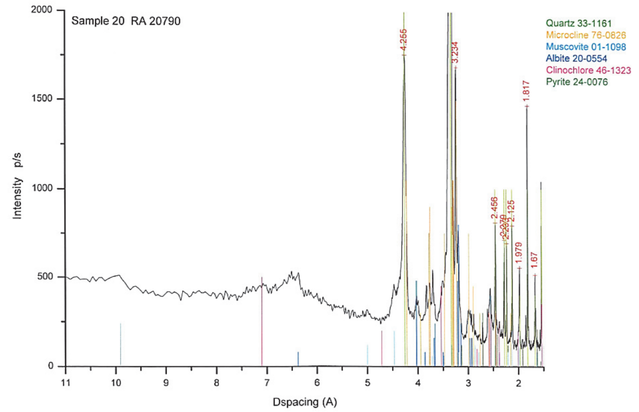

Fig. 4. X-ray analysis of secondary clay minerals in *A* horizon

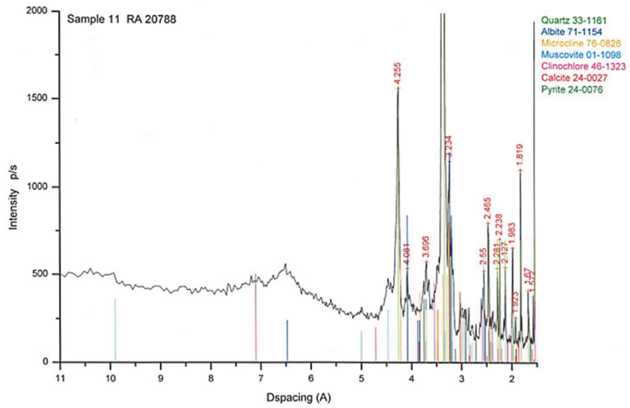

Fig. 2. X-ray analysis of secondary clay minerals in *Bt1* horizon

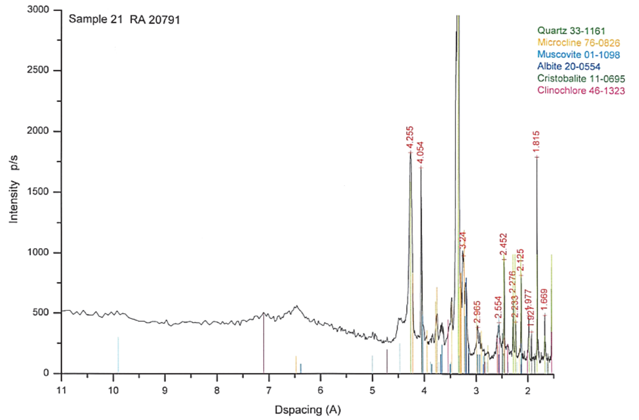

Fig. 5. X-ray analysis of secondary clay minerals in *Bt* horizon

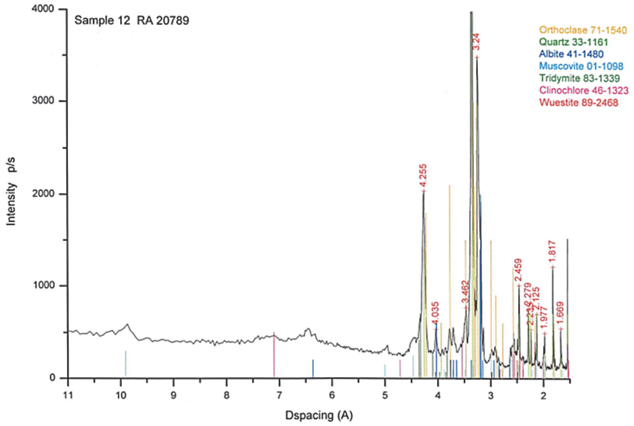

Fig. 3. X-ray analysis of secondary clay minerals in *Bt2* horizon

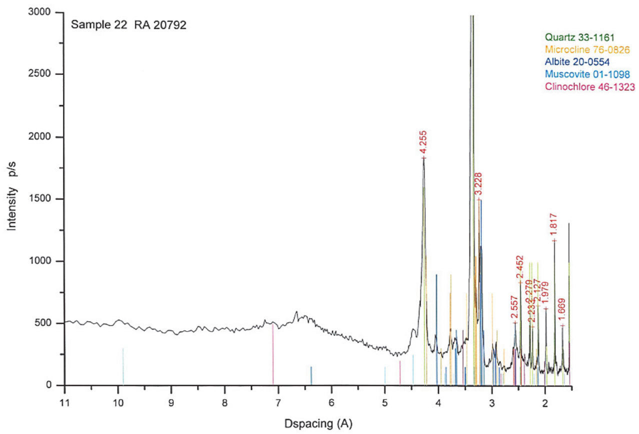

Fig. 6. X-ray analysis of secondary clay minerals in *Bt2* horizon

the weathering rocks (Georgiev, 1982). This is undoubtedly of great importance for the soil formation process in these territories.

The soil reaction (pH_{H2O}) is highly acidic in profiles 1, 2 and 3, and very acidic in profiles 4 and 5 (Table 2). In depth of profiles 1 and 3, the pH of the *argic* horizon decreases with 0.2-0.3 pH units. The high acidity in profiles 4 and 5 varies slightly in depth. Essential for them is that pH_{H2O} varies within the range ($pH_{H2O} < 4.8$), which is an indicator of the presence of free organic acids in the soil (Ganev, 1990). In all profiles a leaching process is performed and the basic cations are removed in depth. The exchange acidity (pH_{CaCl2}), estimated on the Ulrich scale (1983), shows that the buffer capacity of the soil is achieved by predominant proton exchange with base cations in highly acidic soils (profiles 1, 2 and 3) and also by the dissolution of Mn-oxides – in highly acidic (profiles 4 and 5). This is confirmed by the quantities of exch. Mn in their profiles. It can be noted a certain accumulation of Mn in the *A* horizon in the range of 0.06 cmol (+) kg^{-1} to 0.19 cmol (+) kg^{-1}. This process is due to an increased uptake of Mn from plants in the process of their mineral nutrition in an acidic environment and its returning through the litterfall and the litter back into the soil (Malinova, 2014).

As a reason for the high acidity of Acrisols, besides acidic soil-forming rocks, it is also worth noting the specific impact of beech forests on soils. The Falkengren-Grerup (1989) studies show that the stemflow is increased in comparison to the other tree species (Picea sp., Pinus sp., Larix sp., Quercus sp., Betula sp.). This can be explained by the presence of upright branches, the smooth bark and the formation of a large volume of stemflow that concentrates on a small area at the trunk base of the stem. The runoff is more acidic than the one that forms under the forest canopy and causes acidification of the soil. This effect is best expressed at a distance of 1.5 meters from the stem and can affect the soil in the *B* horizon (Falkengren-Grerup., 1989). It has been found that the stemflow in the forests has an acidifying effect on the soil (Falkengren-Grerup & Björk, 1991; Völker, 1992; Peters, 1997; Langenbruch et al., 2012). According to Beyer et al. (1991), in addition to acidifying effect, high acidity leads to processes of podzolization. The deposition of acidifying substances is two to four times

Table 2. Soil solution reaction, exchangeable cations, cation exchange capacity, base saturation and humus

Profile	Horizons	Soil Depth, cm	pH H_2O	pH $CaCl_2$	Exch. acidity	Exch. Ca	Exch. Mg	Exch. K	Exch. Na	Exch. Fe	Exch. Mn	Sum of basic cations	CEC	BS, %	Humus, %
					cmol (+).kg^{-1}										
1	A	0-27	5.4	4.5	1.72	2.80	0.25	0.06	0.02	0.01	0.06	3.13	4.85	65	4.20
	Bt1	27-52	5.1	4.3	1.51	1.17	0.16	0.03	0.02	0.01	0.03	1.38	2.89	48	1.22
	Bt2	52-82-↓	5.1	4.3	1.71	1.10	0.18	0.03	0.02	0.01	0.04	1.34	3.05	44	0.76
2	A	0-5	4.9	4.0	2.32	3.25	0.43	0.13	0.01	0.00	0.15	3.8	6.1	62	4.86
	Bt	5-47	4.9	4.0	2.90	0.82	0.13	0.06	0.03	0.01	0.06	1.0	3.9	26	2.73
	C	47-↓	5.6	4.8	0.69	1.60	0.29	0.03	0.06	0.01	0.02	2.0	2.7	74	0.26
3	A	0-13	5.2	4.2	0.70	2.65	0.61	0.12	0.00	0.01	0.10	3.38	4.08	83	4.60
	Bt	13-42	5.0	4.1	2.20	0.56	0.20	0.04	0.03	0.01	0.05	0.83	3.03	27	3.19
	C	42-↓	5.0	4.1	1.50	0.49	0.07	0.03	0.03	0.01	0.09	0.63	2.13	29	0.77
4	A	0-15	4.7	3.9	3.01	0.22	0.12	0.08	0.02	0.01	0.19	0.45	3.46	13	2.49
	B	15-55	4.7	3.9	2.51	0.20	0.13	0.05	0.03	0.01	0.22	0.42	2.93	14	0.87
	Bt	55-102	4.8	3.9	3.62	0.72	0.43	0.06	0.03	0.01	0.09	1.24	4.86	25	0.10
5	A	0-7	4.7	3.9	2.44	0.82	0.32	0.11	0.02	0.01	0.13	1.28	3.71	34	3.48
	B	7-23	4.7	3.9	2.73	0.26	0.08	0.04	0.02	0.00	0.10	0.40	3.14	13	1.72
	Bt	23-105	4.7	3.9	2.74	0.42	0.09	0.03	0.03	0.01	0.13	0.57	3.31	17	0.89
	C	105-↓	5.4	4.4	0.71	4.36	1.89	0.06	0.09	0.01	0.02	6.40	7.12	90	0.07
6	A1	0-14	4.5	3.7	4.82	1.53	0.34	0.06	0.02	0.01	0.17	2.0	6.8	29	2.75
	A2	14-28	4.6	3.8	4.20	1.65	0.33	0.05	0.03	0.01	0.16	2.1	6.3	33	2.37
	Bt1	28-110	4.8	4.1	2.27	2.56	0.63	0.04	0.02	0.01	0.09	3.3	5.5	59	1.46
	Bt2	110-140↓	5.0	4.3	2.15	6.66	2.19	0.08	0.03	0.01	0.14	9.0	11.1	81	1.07
7	A	0-11	5.4	4.6	1.11	9.20	1.30	0.19	0.08	0.01	0.34	10.8	11.9	91	4.16
	Bt1	11-51	5.1	4.2	1.90	4.25	0.96	0.06	0.03	0.00	0.16	5.3	7.2	74	1.35
	Bt2	51-81	5.0	4.2	2.53	6.71	2.37	0.06	0.05	0.01	0.08	9.2	11.7	78	0.57

higher close to the stem compared to in the stand in general. The stemflow water of beech contains increased H^+ loads, K^+, Mg^{2+}, Al^{3+}, Mn^{2+}, NO^- as well as heavy metals. It forms a sort of funnel that is also connected to the groundwater (Leuschner & Ellenberg, 2017). The stemflow increases with the increase of rainfall and the loss of basic cations. Cation exchange capacity decreases near the trunk base. According to Rampazzo and Blum (1992) in the trunk base areas of the beech trees, the base saturation is low, the Al content on the exchange complex is high and there is more intensive weathering features.

In addition to the stemflow, the litter is also acidic. Ellenberg (1986) pointed out that ammong the broadleaved trees beech leaves are slow to decompose, it takes about 3 years. For the western Balkan region, it was found that the reaction of the *mull* type of the litter in the beech stands was 4.97 ± 0.2 and the *moder* type – 5.04 ± 0.2. The difference between litter and the soil surface horizon reaching 1 pH unit (Malinova, 2014).

The beech forests in the studied area have been affecting the soil for thousands of years. For the territory of Europe it is known that a substantial increase in the area occupied by beech forests – expansion of the continent occurred 7500-5000 years (Willis, 1994). It can be assumed that the beech has settled on the northern slopes of Balkan Mountains before 5000 years at least. Such a period of influence on the soil formation process is significant.

The soil profiles are highly leached. The sum of the basic cations has average values only in the *A* horizon of profiles 1, 2 and 3. In profile 5 it is low and in profile 4 – very low (Vanmechelen scale, 1997). Acidity can also be estimated by the exch. Ca / exch. Mg ratio. Figure 7 shows the changes in the exch. Ca / exch. Mg ratio by genetic horizons of the studied profiles. In the surface soil horizon there are biogenic-accumulative processes of calcium. In the depth of the profiles there is a vertical migration of calcium.

The *argic* diagnostic horizon is characterized by a low to very low sum of the basic cations of 0.40 cmol (+).kg^{-1}-1.34 cmol (+). kg^{-1}. Acid cations predominate. It is unsaturated with bases – from 17% to 48%.

Cation exchange capacity has the highest values in the surface soil horizon. This is due to the accumulation of humus in it (2.5% – 4.9%) (Table 2), which compensates for the reduced amount of clay. Its content sharply decreased in depth and in *argic* horizon varies between 0.10% and 3.19%.

Cation exchange capacity values in the *argic* diagnostic horizon are lower than 6 cmol (+). kg^{-1}, in some subsurface layers. This allows for a second taxonomic level for Acrisols to apply *vetic* prefix qualifier.

By applying the WRB diagnostic features (2006, 2007) profiles 6 and 7 are classified as Lixisols. Morphologically they are similar to Acrisols. On the field was established the

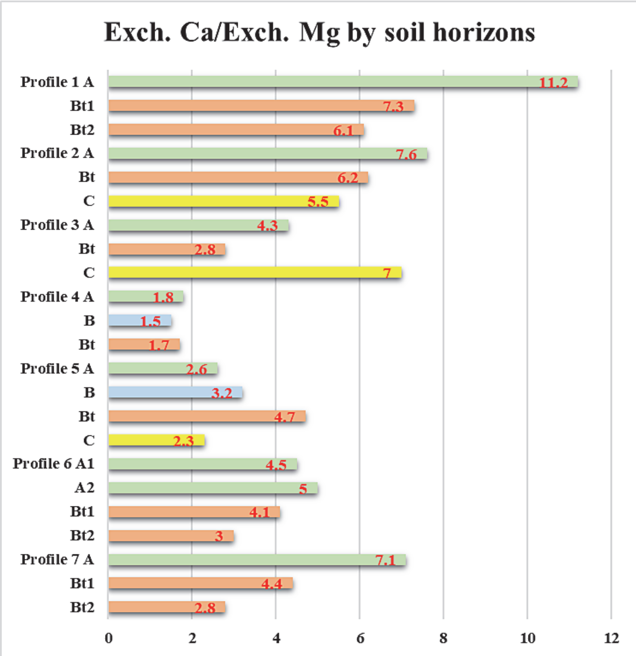

Fig. 7. Exch. Ca: exch. Mg ratio in Acrisols soil profiles by horizons

presence of clay-enriched *Bt* horizon. Texture coefficient in the profiles is 1.2 and 1.4 (Table 1). The migration of clay in depth is clearly expressed. Cation exchange capacity is similar to Acrisols, it is lower than 24 cmol (+). kg^{-1} (Table 2). The mineral composition (Figures 8 -11) is similar to that of Acrisols but also contains calcite. On Figure 8, 9, 10 and 11 is presented X-ray analysis of secondary clay minerals in Profile 6 by horizons.

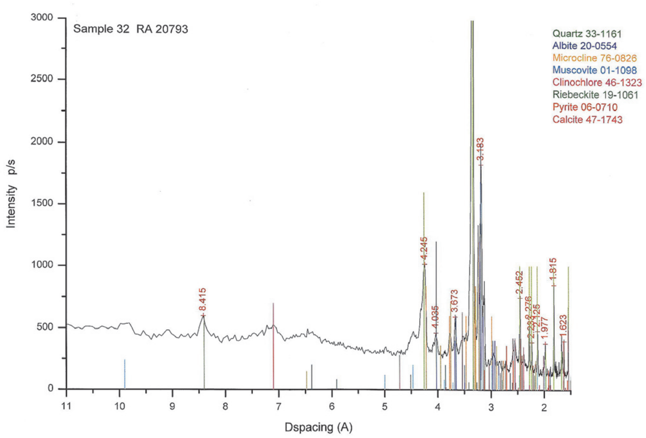

Fig. 8. X-ray analysis of secondary clay minerals in *A1* horizon

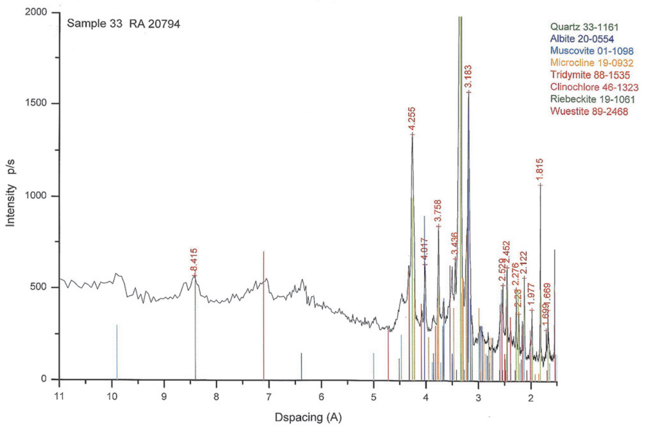

Fig. 9. X-ray analysis of secondary clay minerals in *A2* horizon

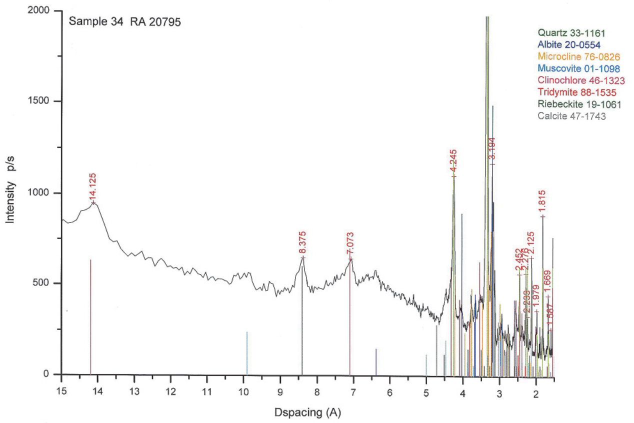

Fig. 10. X-ray analysis of secondary clay minerals in *Bt1* horizon

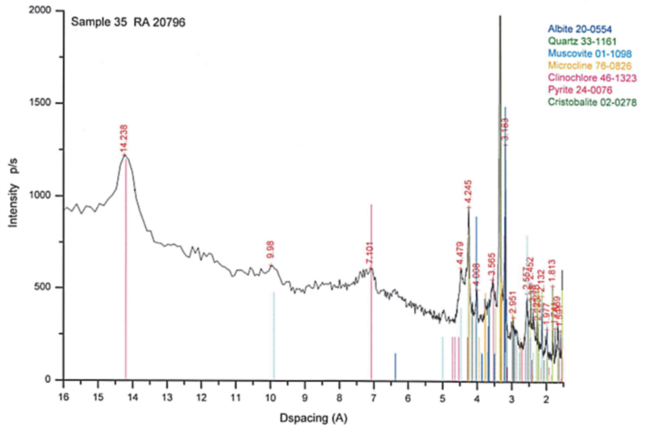

Fig. 11. X-ray analysis of secondary clay minerals in *Bt2* horizon

Its quantity is low – 1%. It originates from soil-forming rocks in which carbonate materials are involved, and this has an impact on the soil-forming process.

Argic diagnostic horizon in these profiles is saturated with bases. This is their main difference with Acrisols. In the WRB classification (2006, 2007) Lixisols are classified as a separate soil unit in the group of Soils with clay – enriched subsoil. Depending on cation exchange capacity, Lixisols on the second taxonomy level are identified as *vetic* – CEC lower than 6 cmol (+). kg^{-1} (profile 6) and *haplic* (profile 7).

Conclusion

Acrisols and Lixisols were found in beech forests of the temperate climate zone. For Acrisols *vetic* prefix qualifier was applied and for Lixisols – *vetic* and *haplic*. We assume that specific weathering processes and acidifying effect of beech forests have been playing a key role for Acrisols and Lixisols formation.

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