Original paper

BLACK SOILS IN SLOVAKIA

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Abstract

Black soils in Slovakia can be divide into the two basic groups: black soils according to the INBS (International network of black soils) and black soils outside the INBS specified criteria. Numerous soil profiles of soil databases (17 620 soil profiles from the General Soil Survey of Agricultural Land and 318 monitoring sites in Slovakia) were reviewed for their evaluation. According to the INBS criteria, the following parameters were evaluating: a thick layer of humus, a soil organic carbon (SOC) and soil organic matter (SOM). In addition, some qualitative parameters of black soils have been also evaluated (total nitrogen content – Nt, C/N ratio, C_{HA}/C_{FA} ratio and colour quotient Q^4_6). Based on obtained results there was determined that the area of black soils according to INBS criteria represents 93,654.63 ha what is 19.7% of all black soils mapped on agricultural land using land evaluation soil ecological unit's database in Slovakia. These soils are characteristic with average thick humus layer of 57 cm and soil organic carbon content (SOC) of 2.66% with high base saturation (96.65%) represented mostly by Chernozems and Phaeozems soil types. The 2nd group of black soils have depth of humus horizon often less than 25 cm with similar soil properties as previous group, resp. the soil properties are rather different (e.g. low value of $pH/H_2O < 5.5$), low base saturation (< 50%) with high content of SOM (≥ 5%) represented mostly by Andosols, particularly by Umbrisols in Slovakia.

Keywords: black soils, INBS criteria, soil monitoring, soil properties, Slovakia

INTRODUCTION

The launch of the International Network of Black Soils took place during the Global Symposium on Soil Organic Carbon (21.-23. March 2017) at GSP FAO headquarters in Rome, Italy. „Black soils" is a term used in some national soil classification systems that may cover very different types of soil. Under the term black soils, the soils with dark grey to black colour are included in various soil classification systems, e.g. in India these soils are classified as Vertisols (Roy *et al.* 1962). In China these soils correspond with high content of soil organic matter (6 – 8%) (Wen *et al.* 2001). It may be said that black soils are a great group of the Chernozems and are associated with sub-humid climates and tall-grass native vegetation and have relatively thick black A horizon. Black soils correspond with Mollisols in the United States Soil Taxonomy (Soil Survey Staff 1999), while in the WRB system (2015) (IUSS Working Group WRB 2015). Black soils would correspondent with three different but related reference soil groups: Chernozems, Kastanozems and Phaeozems. According to preliminary analysis 62 countries of the world, have more than 5% of black soils – in EU mostly Bulgaria, Czech Republic, Hungary, Romania and Slovakia, as well. Using the national soil classification system of Slovakia, these soils are classified as Chernozems (černozeme) and Phaeozems (čiernice) (Societas pedologica slovaca 2014).

Black soils are characteristic with dark grey to black colour with high to very high content of soil organic matter (SOM) in the range 2 – 20%. Concerning INBS criteria high content of SOM is not only one criterion for black soils. There have also min. depth of humus horizon (25 cm) and high base saturation (> 50%). From among the black soils in Slovakia all these criteria are not met.

Black soils criteria are also evaluating in this contribution. Limited indicators of black soils out of the INBS criteria are depth of humus horizon less than 25 cm, where the soil properties are practically the same as in black soils using the INBS criteria (represented by Chernozems and Phaeozems, particularly Umbrisols). The other special group of black soils with low soil reaction ($pH/H_2O < 5.5$ and $pH/KCl < 5.0$), low base saturation (< 50%) with high content of SOM (≥ 5%) is represented mostly by Andosols, particularly Umbrisols in conditions of Slovakia. Total area of these soils is about 8.7% of soil cover in Slovakia.

MATERIALS AND METHODS

Given the different perceptions of black soils, this group of soils is defining according to the INBS (International Network of Black soils) criteria as soils containing:

- a thick layer of humus horizon (minimum thickness of 25 cm);
- a soil organic carbon (SOC) content greater than 2% and minimum soil organic matter (SOM) content of 2% up to 20% (histic epipedons are excluded);
- high base saturation greater than 50%, umbric, also melanic and fulvic epipedons are excluded;
- well drained: poorly-drained soils are excluded

Despite of black soils using the INBS criteria also black soils out of the INBS criteria were evaluated (depth of humus horizon < 25 cm, content of SOC > 2% and content of SOM in the range of 2 – 20%, low base saturation (< 50 %)). These soils have been evaluated based on national information system (17,620 soil profiles from the General Soil Survey of Agricultural Land) and national soil monitoring sites of Slovakia (318) by GIS tools.

In addition, the basic soil properties (pH, SOC, Nt, base saturation (BS), C_{HA}/C_{FA}, Q^4_6, textural fractional composition, bulk density) were compared and evaluated on the example of 4 soil profiles of black soils outside the INBS specified criteria according to various land use (arable land, grassland and forest land).

As following that, problem of Andosols evaluation has been studied on the example of five soil profiles (classified according to WRB 2015 on the three various volcano mountains: Kalamárka – Poľana Mountains, Sitno – Štiavnické vrchy Mountains, Suchá hora 1 and 2 in Kremnické vrchy Mountains). Soil samples from soil profiles were analysed for the following parameters:

- pH/KCl (0.2 M KCl)
- pH/H_2O
- available phosphorus and potassium (according to Mehlich III method) - Kobza *et al.* (2011)
- soil organic carbon (SOC)
- fractional composition of humus (C_{HA}, C_{FA}, Q^4_6)
- fractional composition of humic acids
- ^{13}C NMR of humic acids (HA) parameters
- labile carbon (C_L)
- labile nitrogen (N_L)
- total nitrogen (Nt)
- iron in dithionite extract – Fed (according to Coffin method)
- oxalate iron Fe_{ox} (according to Tamm method)
- oxalate aluminium Al_{ox} (according to Tamm method)
- aluminium in dithionite extract – Al_d (according to Coffin method)
- allophane (according to Mizota & Van Reeuwijk, 1989)
- ferrihydride (according to Childs *et al.* 1990)
- mechanical fractional composition according to FAO – Societas pedologica slovaca (2014)
- bulk density in 100 cm^3 cylinders.

All chemical and physical procedures have been prepared according to the uniform working procedures of soil analysis (Kobza *et al.* 2011).

Common denominator of these soils is high to very high content of SOM, other indicators in com-

parison with black soils according to the INBS criteria as well as black soils outside the INBS specified criteria are evaluated in this contribution. Graphical outputs and mathematic/statistical evaluation of soil profiles data were evaluated by GIS tools.

RESULTS AND DISCUSSIONS

The common feature of black soils according to INBS criteria in Slovakia is accumulation of organic matter of Chernozem soil type with formation of mollic diagnostic horizon. Therefore, these soils are made up of very dark topsoil rich in organic matter and highly saturated bases with neutral pH values (6 – 7.5) pH in $CaCl_2$. Black soils in conditions of Slovakia create relatively homogenous associations of soils with low degree of internal contrast of soil structure.

Distribution of black soils in Slovakia according to the INBS criteria show Figure 1.

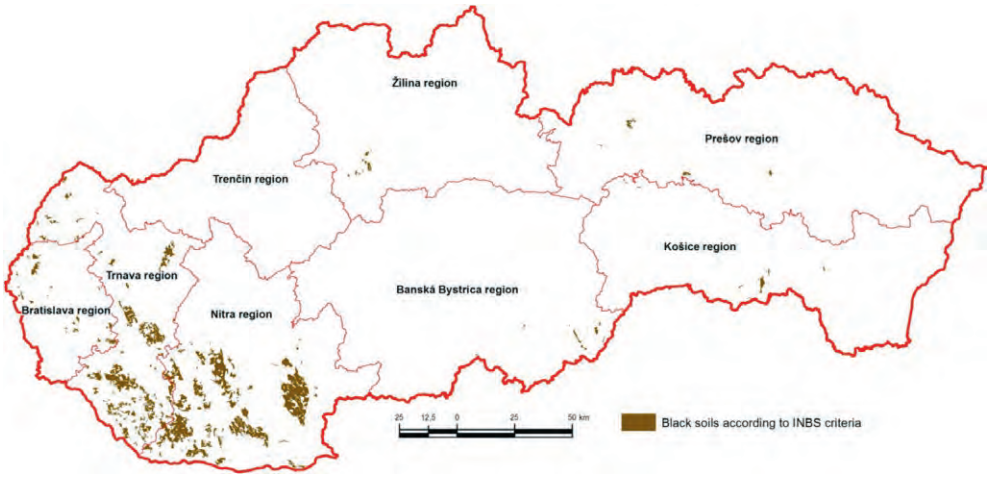

Figure 1 Distribution of black soils in Slovakia according to the INBS criteria

Black soils are mostly situated in south-western part of Slovakia and belong to the most fertile soils, practically used as arable land. Incidental occurrence of black soils is also visible also in other parts of Slovakia sometimes with phenomena of (paleo) hydro-morphism (Phaeozems). These soils are situated often in cooler and moist regions with inclination 3 – 5° and more, often with content of skeleton in soil profile (Kobza 2004). Based on the interpolation of evaluated soil profiles of black soils, these ones are situated on the area of 93,654.63 ha (4.68% of agricultural land of Slovakia). Selected soil profiles of black soils using the INBS criteria shows Figure 2.

Figure 2 Black soil (Chernozem) according to INBS criteria (Rišňovce)

Part of evaluated black soils in conditions of Slovakia is situated also with association with Luvisols (e.g. Luvic Chernozems, IUSS Working Group WRB 2015), where the depth of A horizon is not such deep (often less than 25 cm, what is outside of the INBS criteria of black soils). In addition, according to some micro-morphological studies in this case the brown diffusely dispersed forms of humus are visible (Čurlík 1975). It was confirmed also by detailed quaternary geological researches where such sediments are described as deluvial or proluvial ones (especially works from eastern part of Podunajská nížina lowland e.g. Vaškovský & Halouzka, 1976, Koštialik, 1974). Black soils with shallower A horizon (< 25 cm) are also situated in soil cover of Slovakia – Fig. 3 (Chernozem).

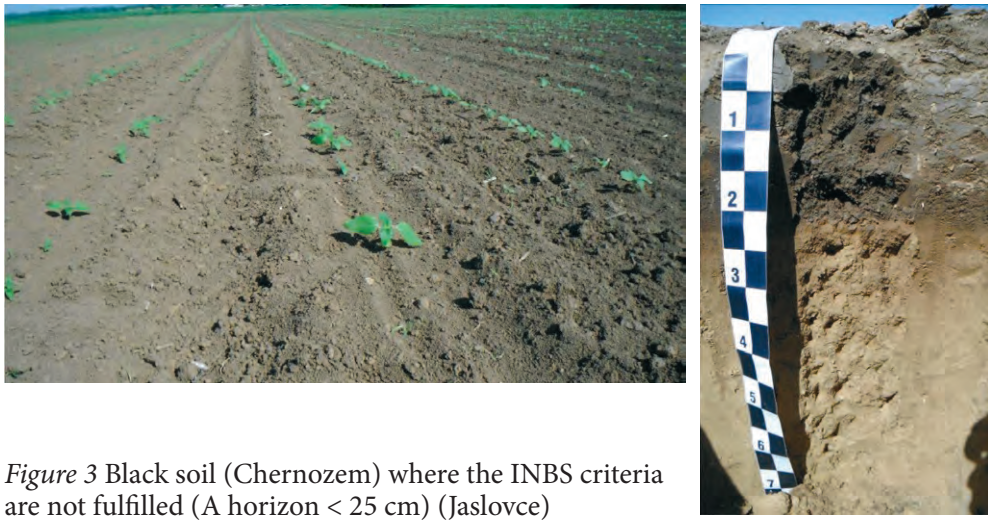

Figure 3 Black soil (Chernozem) where the INBS criteria are not fulfilled (A horizon < 25 cm) (Jaslovce)

This soil don`t meet the INBS criteria. Here is a question if the INBS criteria for black soils evaluation are reliably sufficient or not? Basic statistical characteristics of black soils in Slovakia according to the INBS are given in the Tab. 1.

Table 1
Basic statistical parameters of black soils in Slovakia according to the INBS criteria

Parameters	**X_{min}**	**X_{max}**	**X**	**Sd**	**Vc (%)**
Depth of A horizon (cm)	27	140	57	14.90	26
SOC (%)	2.01	9.68	2.66	0.86	32
BS (%)	54.34	100	96.65	7.60	8
Explanations: X_{min} – minimum value, X_{max} – maximum value, X – arithmetic mean, Sd – standard deviation, Vc – variable coefficient, SOC – soil organic carbon, BS – base saturation					

The depth of A horizon is running in wide range (27 – 140 cm), average value is 57 cm. Soil organic carbon content is also variable (2.01 – 9.68%), average value is 2.66%. Finally, base saturation is more than 50%, average value is 96.65%. The predominant pedological process is accumulation of soil organic matter which is more significant in (paleo) hydromorphic conditions. In the framework of complicated pedogenesis during the change of hydromorphic to automorphic conditions it is sometimes possible to observe the occurrence of old buried humus horizon covered by younger deposits (Fig. 4a, b).

Figure 4a Buried black soil (*Bátka in* Rimavská kotlina basin)

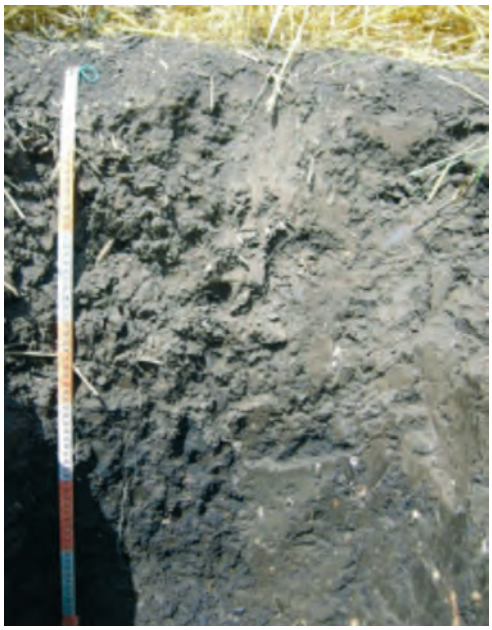

Figure 4b Buried black soil (*Žíp in* Rimavská kotlina basin)

In soil profile of Bátka (Figure 4a) the age of buried A horizon was determined on about 7,000 years – using the radioactive isotope of ^{14}C. As we mentioned before, also evaluation of qualitative parameters would be also useful for characteristics of black soils (Kobza 2017). According to obtained results of soil monitoring system in Slovakia, the important basic parameters of soil organic matter of black soils are given in the following the Table 2.

Table 2

Basic statistical parameters of qualitative parameters of black soils selected according to the INBS criteria in Slovakia

Qualitative parameters	**X_{min}**	**X_{max}**	**X**	**Sd**	**Vc (%)**
N_t (mg.kg^{-1})	1,541	4,140	2,281	4,95.9	22
C/N	8.08	11.57	9.79	0.89	9
C_{HA}/C_{FA}	0.60	2.75	1.28	0.56	44
Q^4_6	3.59	5.50	4.41	0.52	12
Explanations: Xmin – minimum value, Xmax – maximum value, X – arithmetic mean, Sd – standard deviation, Vc – variable coefficient, N_t – total nitrogen, HA - humic acids, FA – fulvoacids, Q^4_6 – colour quotient					

The average content of total nitrogen in black soils of Slovakia was calculated 2.281 mg.kg^{-1} what is medium content (Bielek 1998). Average values of C/N are one of the main indicators of humus quality (Sotáková 1982) and a good indicator of dynamics of soil quality (Franzluebbers 2002). The values of C/N ratio are even-tempered and are running in the range of 8.08 – 11.57, what confirms a medium supply of nitrogen with mull form (Šály 1978). Average value of C/N ratio is 9.79.

In addition, the basic qualitative indicator of soil humus is humic acid to fulvo-acids ratio (C_{HA}/C_{FA}). The values higher than 1 indicate well ripened and humificated soil organic matter. It also confirmed by colour quotient Q^4_6 with average value 4.41 what is the lowest value in soils of Slovakia and refers to soil organic matter with high quality (Kobza *et al.* 2014, Sotáková 1982).

A common feature of black soils is accumulation of soil organic matter (SOM) and its conversion. Composition of SOM depends on soil genesis and conditions in which the soils have been developed.

Originally, black soils have been developed in steppe conditions mostly on loess, resp. loess like loam soil forming substrates to more cold and moist conditions especially in volcanic rocks with fragments of volcanic glass (mostly in mountainous regions). Humus horizon of these soils is dark grey to black colour (mostly Munsell colour value of ≤ 3 moist and a chroma of ≤ 3 moist) what is in correlation with high to very high content of SOM but its quality is rather different (represented from mollic to umbric and melanic to fulvic humus horizons) in conditions of Slovakia. A substantial part of these soils does not meet the INBS criteria. Distribution of these soils is visible in Figure 5.

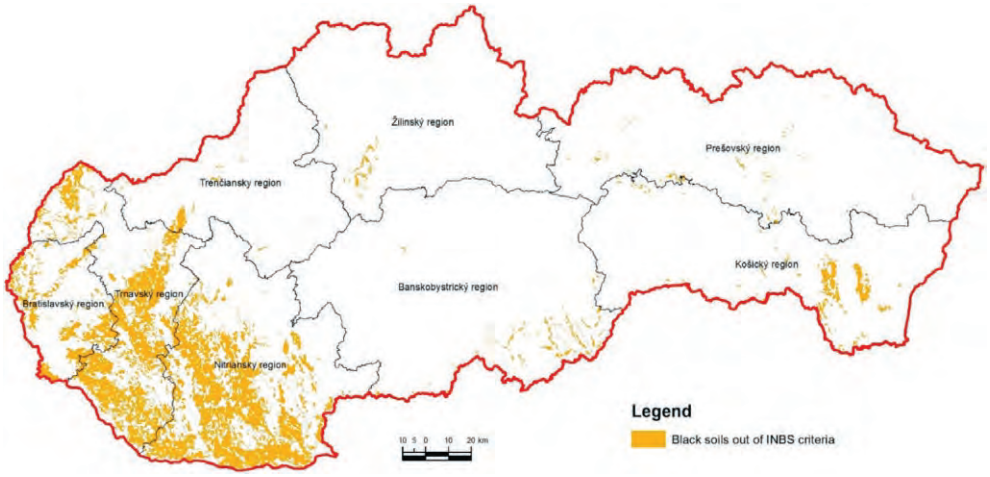

Figure 5 Distribution of black soils outside the INBS specified criteria in Slovakia

In the following map (Figure 6) is distribution of total black soils in Slovakia including and outside the INBS specified criteria.

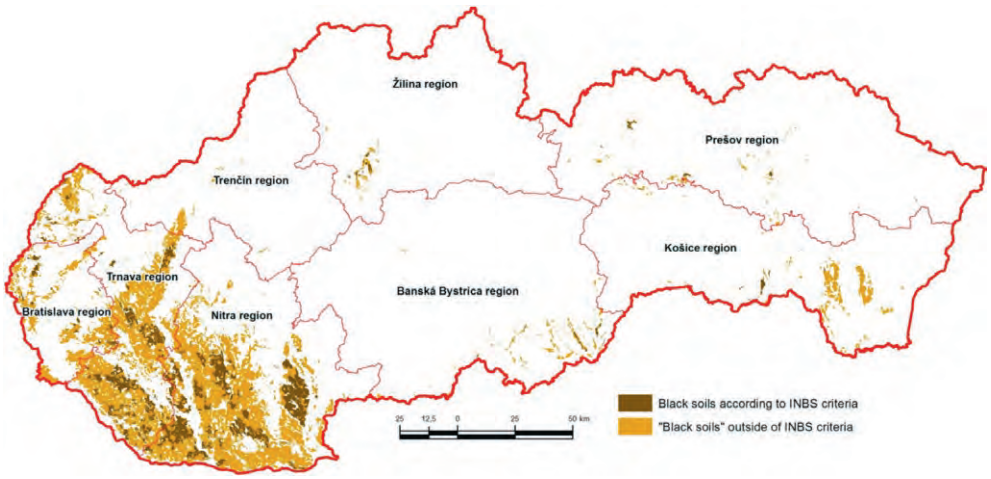

Figure 6 Distribution of total black soils in Slovakia

Black soils outside the INBS specified criteria are mostly situated in south-western part of Slovakia on the total area of 381,950 ha, what is about 8.7% of soil cover (agricultural and forest land together) in Slovakia. These soils belong to the most fertile soils with mollic horizon represented by Chernozems and Phaeozems soil types. In addition, only a small part of black soils occurs on more cold and moist regions (mostly in volcanic mountains on volcanic rocks – andesite and their pyroclastic) with fulvic humus horizon (Melanic index is > 1.7) (WRB 2015). These soils do not form continuous areas but occur locally in total area about 10,000 ha what is about 0.15% of soil cover in Slovakia (Kobza 1999).

Moreover, according to some micro-morphological studies in this case, the brown diffusely dispersed

forms of humus are often visible (Čurlík 1975). It was confirmed also by detailed quaternary geological researchers where such sediments are described as deluvial or proluvial ones (Vaškovský & Halouzka 1976, Koštialik 1974). After Würm period the origin relief by the planation has been created with a smooth relief of colourful mosaic of soils (in this case mosaic of black and bright soils – Phaeozems and Planosols) – Figure 7.

Figure 7 Heterogeneity of black and bright soils in small area (Turčianska kotlina basin) in central part of Slovakia

Soil cover in Slovakia is characteristic with different soil properties and their fertility, too. On the example of three localities of black soils out of the INBS criteria according to various land use (arable land, grassland and forest land) are evaluated in the next part of this contribution. Following Tab. 3 and 4 show the basic chemical and physical properties in humus horizons of black soils outside the INBS specified criteria.

Table 3
Basic chemical properties in A horizon of black soils outside the INBS specified criteria in selected localities

Localities	pH/ H_2O	pH/ KCl	BS [%]	SOC [%]	Nt [%]	C/N	C_{HA}/C_{FA}	Q^4_6	P $mg.kg^{-1}$	K $mg.kg^{-1}$	MI [%]
Jaslovce (arable land)	7.5	7.1	96.6	1.32	0.15	9.0	1.23	4.22	43.9	247.0	–
Dúbrava (arable land)	6.3	5.6	78.3	2.57	0.30	8.56	0.75	4.40	103.6	230.0	–

Explanations: BS – base saturation, SOC – soil organic carbon, Nt – total nitrogen, HA – humic acids, FA – fulvoacids, Q^4_6 – colour quotient, P – available phosphorus, K – available potassium, MI – melanic index

Table 4
Basic physical properties in A horizon of black soils outside the INBS specified criteria in selected localities

Localities	Fractional mechanical composition [%]			Bulk density $[g.cm^{-3}]$
	< 0.002 mm	0.002 – 0.05 mm	0.05 – 2 mm	
Jaslovce (arable land)	28.64	50.76	20.60	1.23
Dúbrava (arable land)	11.71	66.45	21.84	1.00

Jaslovce – the 1st of compared localities is situated in western part of Slovakia where black soils are predominated (Fig. 3). These soils are characteristic with neutral soil reaction and high base saturation. Soil humus is characteristic with a high quality ($C_{HA}/C_{FA} > 1$). In addition, C/N ratio belongs also to the main indicators of quality of soil organic matter (SOM) (Sotáková 1982) and parallel a good indicator of dynamics of soil quality (Franzluebbers 2002). According to our previous work (Kobza & Pálka 2020) concerning black soils in Slovakia the values of C/N ratio are even tempered and they are running in the range of 8.08 – 11.57, what confirms a medium supply of nitrogen. Locality Jaslovce (Fig. 3) meets this range of C/N ratio 9.0 (Ta.3). Similar value of C/N (8.56) has soil profile Dúbrava (Liptovská kotlina basin), but the humus is the worse quality in this case (C_{HA}/C_{FA} is less than 1, only 0.75) (Tab. 3, Fig. 8).

Figure 8 Luvic Phaeozem (Anthric, Loamic), locality: Dúbrava (Liptovská kotlina depression), central Slovakia

Figure 9 Skeletic Umbrisol (Andic, Loamic), locality: Poľana - Kalamárka (central Slovakia)

Since it is arable land the content of available potassium is good, but content of available phosphorus is mostly low (Kobza & Gáborík 2008). Finally, the content of available phosphorus is low to very low also in the next soil profiles – Poľana – Kalamárka (grassland) and Suchá hora in Kremnické vrchy Mountains (forest land), what is a result of natural supply without fertilization (Tab. 5, Fig. 9 – 12). These soil profiles are situated in central part of Slovakia – in volcanic mountains (Poľana, Kremnické vrchy – Suchá hora 1, 2 and Štiavnické vrchy – Sitno Mountains). These soils are acid to very acid, unsaturated with high

content of soil organic carbon (SOC) (6.1 – 21.2%) – Tab. 5. The highest value of SOC was determined logically under forest (Suchá hora localities in Kremnické vrchy Mountains). The high content of humus in these soils can be caused by the creation of „allophane-organic matter" complexes (Kobza 1999).

Figure 10 Dystric Umbric Andosol (Fulvic, Loamic, Thixotropic), locality: Suchá hora 1 in Kremnické vrchy Mountains (central Slovakia)

Figure 11 Suchá hora 2: Fulvic Andosol (Dystric, Thixotropic, Siltic, Skeletic)

Figure 12 Sitno: Fulvic Andosol (Skeletic, Siltic, Dystric, Thixotropic)

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Table 5
Quantitative and qualitative parameters of humus

Localities	Geomorphological units	Depth (cm)	SOC %	Nt %	C/N	C_{HA}/C_{FA}	Q^4_6	C_L (mg.kg^{-1})	N_L (mg.kg^{-1})	$C_L : N_L$
Kalamárka	Poľana Mts.	0 – 10	6.1	0.47	13.0	0.9		6775.25	218.25	31.04
		50 – 60	4.6	0.31	14.8	–	4.5	–	–	–
		90 – 100	4.7	0.25	18.8	–		–	–	–
Suchá hora 1	Kremnické vrchy Mts.	0 – 10	21.2	0.92	23.0	0.38	6.36	39897.90	218.75	182.39
		50 – 60	7.8	0.81	7.2	0.35	6.62	–	–	–
		90 – 100	5.9	0.57	10.3	0.32	6.40	–	–	–
Suchá hora 2	Kremnické vrchy Mts.	0 – 10	20.1	1.42	14.1	0.51	4.12	15680.95	300.25	52.23
		50 – 60	6.3	0.51	12.3	0.23	3.60	–	–	–
		90 – 100	5.9	0.81	7.3	0.18	3.40	–	–	–
Sitno	Štiavnické vrchy Mts.	0 – 10	10.5	0.87	12.1	0.9	4.8	20000.45		66.89
		50 – 60	7.8	0.80	9.6	–	–	–	299.00	–
		90 – 100	5.6	0.55	10.2	–	–	–		–

SOC – soil organic carbon, Nt – total nitrogen, HA – humic acids, FA – fulvo-acids, Q^4_6 – colour quotient, C_L – labile carbon, N_L – labile nitrogen

The total nitrogen content is in correlation to high content of humus. The total nitrogen content in evaluated soil profiles is running between 0.47 – 1.42% in A horizon. These values are the highest in comparison with the other soils of Slovakia (Bielek 1984). The C/N ratio is in the range of 12.1 – 23.0 what refers to moder humus form (Šály 1978). In spite of high content of humus, its quality is relatively low ($C_{HA}/C_{FA} < 1$, Q^4_6 in the range of 4.12 – 6.36). It refers to labile and slightly humificated soil organic matter in evaluated soils (also high content of raw organic matter and mostly non-decomposed organic components in the forest). It is in correlation with labile carbon (C_L) which value is practically the highest from among the soils of Slovakia (Zaujec & Kobza 2002). Very high content of labile carbon is a result of high to very high content of soil organic carbon and low degree of humification. For assessment of humus substances quality can be also used C_L: N_L ratio, when high values determined low quality of humus substances (Zaujec & Kobza 2002). It was indicated that more typical Andosols are characteristic with C_L: N_L ratio > 50 (Suchá hora 1 and 2 and Sitno) where C/N ratio is in the range of 12.1 – 23.0 (Tab. 5). The C_L: N_L ratio seems to be a better indicator for quality of humus in comparison with the C/N ratio. In addition, also very important is a fractional composition of humic acids which is given in the following the the Tab. 6.

Table 6
Fractional composition of humic acids (HA) in A horizon (depth of 0 – 10 cm)

Locality	Geomorphological units	C	H	H/C	O	N	COOH meq/1gHA	$E^{1\%}_6$	Car %	Calif %	α %
		atomic %									
Suchá hora 1	Kremnické vrchy Mts.	42.65	34.23	3.50	19.62	0.80	3.90	18.40	28.46	51.74	35.48
Sitno	Štiavnické vrchy Mts.	42.61	33.90	3.48	20.01	0.79	4.10	25.90	35.11	48.21	42.14

COOH – carboxylic groups, $E^{1\%}_6$ – optical parameter, Car – aromatic carbon, Calif – aliphatic carbon, α – degree of aromaticity of humic acids

The basic parameter of HA structure is elementary analysis C, H, N, O which reflects dominant characteristics of soil humification. H/C ratio clarifies stability and degree of HA condensation (Rossell et.

al. 1989). Values of H/C ratio in evaluated soils were determined in the narrow range of 3.48 – 3.50. It refers to more labile structure of HA opposite Chernozems, where the H/C ratio is much more-lower (0.55 – 0.65) in conditions of Slovakia (Kobza *et al.* 2014). The next important parameter concerning the quality of HA is the content of carboxylic groups (COOH). The process of humification is characterized by carboxylation of peripheral portions of HA (Ševcova & Sidorina 1988). The higher values of COOH refer to higher degree of humification and low values of COOH are characteristic for low humification degree of HA. Measured values of COOH for evaluated soils are in the range of 3.90 – 4.10 meq/1g HA (Tab. 6) which are lower in comparison with Chernozems (Kobza *et al.* 2014) where the COOH values are determined often in the range of 4.0 – 5.0 meq/1g HA.

In addition, significant parameter concerning evaluation of HA structure is ^{13}C NMR analysis (Novák & Hrabal 2011). Here is important distribution of aliphatic carbon (Calif) and aromatic carbon (Car) from which is degree of aromaticity (α) determined. . Based on obtained results (Tab. 6) aliphatic carbon (Calif) is predominated in Andic soils. Degree of aromaticity (α) was determined between 35.48 – 42.14%, what are lower values opposite fertile humous soils like Chernozems and Phaeozems (Kobza *et al.* 2014). The higher share of aliphatic carbon (Calif) in Andic soils could be a result of input of raw organic matter (forest) what is characteristic for incorporation of plant residues (Peréz *et al.* 2004).

The next important parameter of HA structure is an optical parameter $E^{1\%}_{6}$ which represents an extinction of HA solution measured at wave length of 600 nm. This parameter is named according to Kumada (1987) the degree of humification. If the optical parameter is higher, the degree of humification is also higher. In evaluated Andic soils the optical parameter $E^{1\%}_{6}$ was determined between 18.40 and 25.90 (Table 6) what are lower values opposite Chernozems and Phaeozems (also black soils but with Mollic horizon) where the values of optical parameter $E^{1\%}_{6}$ are often higher than 30 (Kobza *et al.* 2014).

Predominance of fulvo-acids and raw organic matter in various degree of decomposition (forest) is in relation to acid pH values of evaluated soils (Tab. 7).

Table 7

Soil profile distribution of pH values

Locality	Geomorphological units	Depth (cm)	pH/H_2O	pH/KCl	ΔpH	pH/$_{NaF}$
Kalamárka	Poľana Mts.	0 – 10	5.5	4.8	0.7	9.83
		20 – 30	5.3	4.6	0.7	10.65
		35 – 45	5.3	4.5	0.8	10.72
Suchá hora 1	Kremnické vrchy Mts.	0 – 10	4.3	4.0	0.3	9.95
		20 – 30	4.5	4.3	0.2	10.87
		35 – 45	4.6	4.5	0.1	11.20
Suchá hora 2	Kremnické vrchy Mts.	0 – 10	3.9	3.7	0.2	9.75
		20 – 30	4.2	4.1	0.1	11.12
		35 – 45	4.6	4.4	0.2	11.22
Sitno	Štiavnické vrchy Mts.	0 – 10	5.2	4.3	0.9	10.15
		20 – 30	5.2	4.3	0.9	10.55
		35 – 45	5.3	4.4	0.9	10.74

DpH – difference between pH/H_2O and pH/KCl

Based on obtained results it may be said that these soils are acid to very acid (pH/KCl ≤ 5.0). One of the characteristic properties of Andosols is the small difference between pH/H_2O and pH/KCl (DpH) (Šály 1982). This difference is the most significant in the 2nd and 3rd soil profiles (Suchá hora 1 and 2) with the range 0.2 – 0.3 caused by mineralogical composition (occurrence of allophanes), which is determined in the following Tab. 8.

Table 8
Mineral composition of Andosols

Locality	Geomorphological units	Depth (cm)	Allophane %	Ferrihydride %
Kalamárka	Poľana Mts.	0 – 10 20 – 30 35 – 45	2.0 3.5 5.4	2.0 2.0 1.9
Suchá hora 1	Kremnické vrchy Mts.	0 – 10 20 – 30 35 – 45	2.5 5.7 7.9	1.7 1.7 1.9
Suchá hora 2	Kremnické vrchy Mts.	0 – 10 20 – 30 35 – 45	2.4 6.1 8.2	2.2 1.9 0.4
Sitno	Štiavnické vrchy Mts.	0 – 10 20 – 30 35 – 45	1.8 2.7 4.3	1.9 2.0 2.1

Weathering of volcanic ashes commonly includes the formation of poorly crystalline minerals such as allophane and ferrihydrite. Detection of these minerals is rather difficult (Mizota & Van Reeuwijk 1989, Childs *et al.* 1990), because they may govern soil functions and processes, e.g. stabilization of soil organic matter and nutrient availability.

In addition, weathering of volcanic ashes, including the formation of allophanic compounds, typically leads to the formation of Andic properties/Andosols (IUSS Working Group WRB 2015). Content of allophane increases with depth of soil profile (Tab. 8), what was confirmed also by Balkovič *et al.* 2006. The highest values of allophane were determined in soil profiles of Suchá hora 1 and 2 (7.9 – 8.2% in deeper part of soil profile).

Presence of allophanes and existence of Andic properties were also identified using the sodium fluoride field test by Fieldes & Perrott (1966). Also the pH in NaF of 9.5 and more indicates allophane occurrence in all soil profiles, what was confirmed in all of evaluated soil profiles (Tab. 7).

Ferrihydrite is associated with the better crystalline Fe oxides (Stahr 1972; Campbell & Schwertmann 1984). Presence of silicates and organics such as humics, promote ferrihydrite formation, because these factors impede the formation of crystalline Fe oxides. The content of ferrihydride in all evaluated soil profiles is even-tempered, but the content of ferrihydride with the depth is slightly decreased (Tab. 8).

From soil genesis point of view, non-silicate forms of pedogenetic oxides – just iron and aluminium are significant. Their distribution in soil profiles of soils with andic properties/Andosols is given in the Tab. 9.

Table 9
Distribution of pedogenic oxides of Fe and Al in Andic soils (in %)

Locality	Depth (cm)	Fe_{ox}	Fe_d	Fe_d-Fe_{ox}	Fe_{ox}/Fe_d	Al_{ox}	Al_d	$Al_{ox}+{}^1/_2 Fe_{ox}$	Melanic Index (MI)
Kalamárka	0 – 10 20 – 30 35 – 45	1.16 1.16 1.12	2.04 2.10 2.20	0.88 0.94 1.08	0.57 0.55 0.51	2.92 2.50 2.62	0.06 0.05 0.05	3.50 3.08 3.18	1.75 – –
Sitno	0 – 10 20 – 30 35 – 45	1.12 1.20 1.26	2.09 2.29 2.40	0.97 1.09 1.14	0.53 0.52 0.52	3.00 2.45 2.23	0.14 0.19 0.16	3.58 3.05 2.86	1.98 – –

Locality	Depth (cm)	Fe_{ox}	Fe_d	Fe_d-Fe_{ox}	Fe_{ox}/Fe_d	Al_{ox}	Al_d	$Al_{ox}+{}^1/_2 Fe_{ox}$	Melanic Index (MI)
Suchá hora 1	0 – 10	1.01	1.81	0.80	0.53	3.15	2.73	3.65	2.63
	20 – 30	1.01	1.69	0.68	0.63	2.02	2.07	2.52	2.24
	35 – 45	1.14	1.94	0.80	0.62	3.02	3.02	3.59	2.31
Suchá hora 2	0 – 10	1.27	–	–	–	2.30	–	2.94	2.26
	20 – 30	1.13	–	–	–	3.34	–	3.90	2.13
	35 – 45	0.25	–	–	–	2.69	–	2.82	2.33

Fe_{ox} – oxalate iron, Fe_d – iron in dithionite extract, Al_{ox} – oxalate aluminium, Al_d – aluminium in dithionite extract

The content of Fe_{ox} and Fe_d in soil profiles is even-tempered with slight increase to the depth. The Fe_{ox}/Fe_d is often used for the approximate explanation of development status of soil as well as for the effort to differentiate old soil processes (Schlichting & Blume 1961). This ratio is very similar in all soil profiles and shows the degree of iron migration in soil profiles.

One of the main diagnostic criteria is $Al_{ox} + 1/2Fe_{ox} \geq 2$ (WRB 2015) which is on evaluated soil profile fulfilled (Tab. 7).

The object of wide discussions is the sequence of quality of humus horizons (umbric – melanic – fulvic). Based on our obtained results the criteria for fulvic horizon were determined (MI > 1.7). It was confirmed also by other sources (Balkovič *et al.* 2006, Kobza 2017) in Andosols of Slovakia.

Except chemical properties also important are physical properties (Tab. 10).

Table 10

Mechanical fraction composition (according to FAO 2006) and bulk density in Andosols

Localities	Depth (cm)	<0.002 mm %	0.002 – 0.05 mm %	0.05 – 2.00 mm %	ρ_d g.cm^{-3}
Kalamárka	0 – 10	10.45	65.73	23.82	0.88
	20 – 30	10.41	69.38	20.21	–
	35 – 45	11.18	69.30	19.52	–
Sitno	0 – 10	10.02	51.42	38.56	0.85
	20 – 30	11.10	62.00	26.90	–
	35 – 45	12.04	68.73	19.23	–
Suchá hora 1	0 – 10	8.53	31.91	59.56	0.42
	20 – 30	4.94	29.51	65.55	–
	35 – 45	5.77	25.27	68.96	–

ρ_d - bulk density

Based on obtained results fraction 0.002 – 0.05 mm is mostly predominated, resp. sandy fraction (0.05 – 2.00 mm) in the soil profile of Suchá hora 1. One of the most important indicators for Andosols is bulk density ($\rho d \leq 0.9$ g.cm^{-3}). This criterion is met in all evaluated soil profiles. In addition, Andosols have more or less different characteristics, depending on the type of the dominant weathering process acting upon the soil material. They may exhibit thixotropy, i.e. the soil material changes, under pressure or by rubbing. In per-humid climates (in conditions of Slovakia evaluated soil profiles are situated over 1,000 m about sea level), humus-rich Andosols may contain more than twice the water content of samples that have been oven-dried and rewetted (hydric characteristics).

CONCLUSION

Black soils in Slovakia could be divided into the two main groups. The 1st one is represented by black soils according to the INBS criteria with the total area of 93,655 ha (2.1% of soil cover). The 2nd group is

represented by black soils outside the INBS specified criteria with the total area of 381,950 ha (8.7% of soil cover). It may be said that soil properties of both groups are very similar (represented in conditions of Slovakia with occurrence of mollic horizon mostly in Chernozems and Phaeozems). Only in the 2nd group of black soils minimum one parameter is outside the INBS specified criteria (humus horizon – A is shallower than 25 cm and/or content of SOC is slightly lower than 2%, mostly acid to very acid). Black soils in conditions of Slovakia according to the INBS criteria are characteristic by deep mollic humus horizon (average depth 57 cm) with average content of soil organic carbon (SOC) 2.66% and average base saturation 96.65%. In addition, qualitative parameters of black soils are also significant. Total content of nitrogen is medium (average value 2281 mg. kg^{-1}) what is confirmed also by C/N ratio (average value is 9.79). Black soils according to the INBS criteria are characteristic with well humificated soil organic matter with C_{HA}/C_{FA} ratio > 1 and with low value of colour quotient (Q^4_6 = 4.41), the lowest value from among all agricultural soils in Slovakia.

A small part (less than 1%) of the 2nd group is particularly represented by Umbrisols and Andosols which are situated mostly under forest on volcanic deposits often with occurrence of volcanic glass. These soils with comparison of black soils according to INBS criteria are limited with low base saturation (< 50%), low soil reaction with predominated umbric and fulvic humus horizons in condition of Slovakia. This group of black soils can also include occurrence of mollic horizon if shallower than 25 cm (e.g. eroded forms of Chernozems and Phaeozems).

Finally, for the better characterization of black soils it would be more useful except recommended diagnostic criteria according to WRB 2015 to know also the other analytical characteristics in more details, especially concerning the fractional composition of humus and humic acids, as well.

Thereby, it is necessary to strongly protected and avoided soil sealing (one predominant part of black soils are the most fertile agricultural soils – Chernozems and Phaeozems) of all these black soils (evaluated according to the INBS criteria as well as outside of these criteria). The second part of them occur mostly in protected areas, resp. in national parks (Andosols).

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