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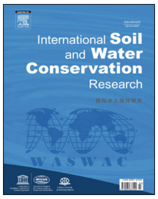

Original Research Article

Features of selected benchmark soils along an elevational transect of the northeastern part of the Moldavian Plateau (Romania)

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ABSTRACT

Soil morphological, physical and chemical properties are described at four locations along an elevational transect in the northeastern part of the Moldavian Plateau (Romania). These data contribute to the knowledge of the soils of this area and to their classification according to the USDA-Soil Taxonomy, FAO-WRB and the SRTS-Romanian System. The soils were classified as Inceptisols, Alfisols and Mollisols, according to the USDA-Soil Taxonomy; Gleysol, Chernozem and Luvisol, according to the FAO-WRB and Gleiosol, Cernoziom, Preluvosol, Luvosol, according to the SRTS-Romanian System. The selected soils have a range of properties that represent the soilscape of the Moldavian subcarpathian plateau, characterised by a natural forest with oak as the dominant species. The selected soil parameters decreased with increasing elevation; calcium carbonate and clay leaching and accumulation are the main soil formation processes.

1. Introduction

Soils are non-renewable natural and economic resources producing goods and services that are of paramount importance for human life. Soils produce food, timber, fibre and fuel. They filter and clean large amounts of water and, as a major storehouse for carbon, also help in lowering the emissions of carbon dioxide and other greenhouse gases, which is fundamental for regulating the climate (Blum, 2013; Dazzi, 2008; FAO, 2017). However, evidence recently provided in the Status of the World's Soil Resources (FAO & ITPS, 2015) shows that about 33% of global soils are moderately or highly degraded, which is mainly due to unsustainable management practices.

At the global level, the political momentum to tackle the adverse impacts of land degradation due to unsustainable management practices is particularly favourable due to an increase of the awareness of the importance of the role of the soil in the environmental equilibria (Keesstra et al., 2016). Such awareness is supported by a strong global acknowledgement that land degradation can have a large negative impact not only on the climate and on biodiversity (Reed & Stringer, 2016), but also impacts food security and ecosystem services (Lal, 2003; Richardson, 2010).

The growing concerns about the state of global soils resulted, amongst others, in the establishment of the Global Soil Partnership (GSP Technical Working Group, 2017), in the proclamation of the International Year of Soils by the United Nations General Assembly (Vittori Antisari et al., 2014), in the proclamation of the International Decade of Soils (2015–2024) by the International Union of Soil Sciences (IUSS, 2015) and in the adoption of the revised World Soil Charter by the FAO Conference (FAO, 2015).

The largest political boost for addressing land degradation came from the United Nations General Assembly's adoption of the Sustainable Development Goals (SDGs). In a broader context, the 2030 Agenda for Sustainable Development adopted a number of related targets in 2015, i.e. those aimed at restoring degraded soil, striving to achieve a land degradation-neutral world and implementing resilient agricultural practices that progressively improve soil quality and minimise soil contamination (FAO, 2017). To reach the SDGs and the related targets, it is imperative to have a perfect knowledge of the soils and of their features. Such knowledge allows also for: the sustainable management of the soilscapes (Dazzi, 2007; Schafer & Kirchhof, 2000; Smith, Halvorson, Bolton, & Jr, 2002); updating soil classifications in anthropogenically disturbed areas (Dazzi, Lo Papa, & Palermo, 2009; Vittori Antisari et al., 2014); highlighting the relationship between soil quality and human heath (Goedert et al., 2010); compiling inventories of the soil features and distribution (Dahlgren, Boettinger, Huntington, & Amundson, 1997; Plekhanova, 2017; Poch, Simó, & Boixadera, 2013).

This last case is of paramount importance for those areas where information on soils is scarce, which is the case for the part of the

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Moldavian plateau in northeastern Romania. In such areas, soils along transects allow for the assessment of both the types and rates of change in soil processes and properties (Dahlgren et al., 1997). In this context, the objective of this study was to investigate the main features of selected benchmark soils of a climosequence in the northern part of the Moldavian plateau, with the overall aim to broaden our knowledge of the soils of this area.

2. Study area

The Moldavian Plateau is a geographic area spanning north-eastern and eastern Romania, most of Moldova and parts of the Ukraine (Romanescu, Cotiuga, Asandulesei, & Stoleriu, 2012). In Romania, the Moldavian plateau that lies in between the Prut River (East) and the Nistru Valley (West) accounts for over 2,480,000 ha, with elevations ranging between 5 and 794 m a.s.l. (Mărgărint & Niculiţă, 2017) (Fig. 1).

The relief of the plateau was modelled on a monoclinal sedimentary structure, with a mean inclination of 7–8 m/km from north-west to south-east, contrasting with the crystalline basement of the East-European Platform, which sinks toward west, under the Carpathian Orogene (Ionesi, Ionesi, Roşca, Lungu, & Ionesi, 2005). For the purpose of this survey, we considered four benchmark soils, selected according to an elevational transect that encompasses the Iasi County and the Neamţ County (Fig. 2).

From a geological point of view, the Moldavian plateau belongs to the Moldavian Platform constituted by Precambrian crystalline formations overlaid by Ordovician-Silurian formations. Alternations of consolidated rocks such as sandstones, limestones, tuffs and fewer micro-conglomerates and unconsolidated rocks, such as clays, silts, and sands represent the lithology (Mărgărint & Niculiţă, 2017). These rocks allowed for the genesis of deep soils with low skeleton contents, mainly Luvisols intermixed with Cambisols, Phaeozems and Chernozems. Hills and plateaus characterise the morphology of the landscape, which is undulated for the most part (91%), with an elevation mostly ranging between 100 and 500 m.

The climate is influenced by an air circulation of polar origin, which determines frosts, hoarfrosts and snowfalls at the beginning of the cold season. It is defined humid continental (Dfb according to Köppen, 1936) and is typified by large seasonal temperature differences, with warm and humid summers and cold winters. Rainfall is usually well distributed through the year and ranges between average values of 517 and 650 mm/year. Average annual temperature ranges from 8.2° to 9.8°C. Air temperature ranges from 19° to 20°C in the warm period (July/August) and from −2.5 to −4.0 °C in the cold period (January/February). These climatic features allow for a mesic (border to frigid) soil temperature regime and for an udic soil moisture regime. The dominating lands use type is forest, with oak (*Quercus petraea*) and beech (*Fagus silvatica*) being the main species. There are also a few scattered areas with shrubs and meadows.

3. Material and methods

In the context of our study aims, we considered the four most important forestry ecosystems of the Iasi and Neamt Counties, namely i) the oak forest from Ezăreni; ii) the ash forest from Probota; iii) the oak forest from Barnova; and iv) the mixed forest with beech, ash, hornbeam and oak from Vânători-Neamţ. In each of these forest ecosystems and in a place chosen as being the most representative of the ecological condition of each of them, one soil profile was opened (Table 1).

Soil samples were air-dried and sieved through 2 mm for laboratory analysis. Particle-size distribution was determined by the pipette method; soil pH was measured in a 1:2.5$_{(w/v)}$ soil to water mixture. Total carbonate was measured by the gas volumetric method after HCl treatment. Total organic carbon (TOC) was analysed according to Walkley and Black method (Nelson & Sommers,

Fig. 1. Location of the Moldavian plateau (from Bizbilla.com).

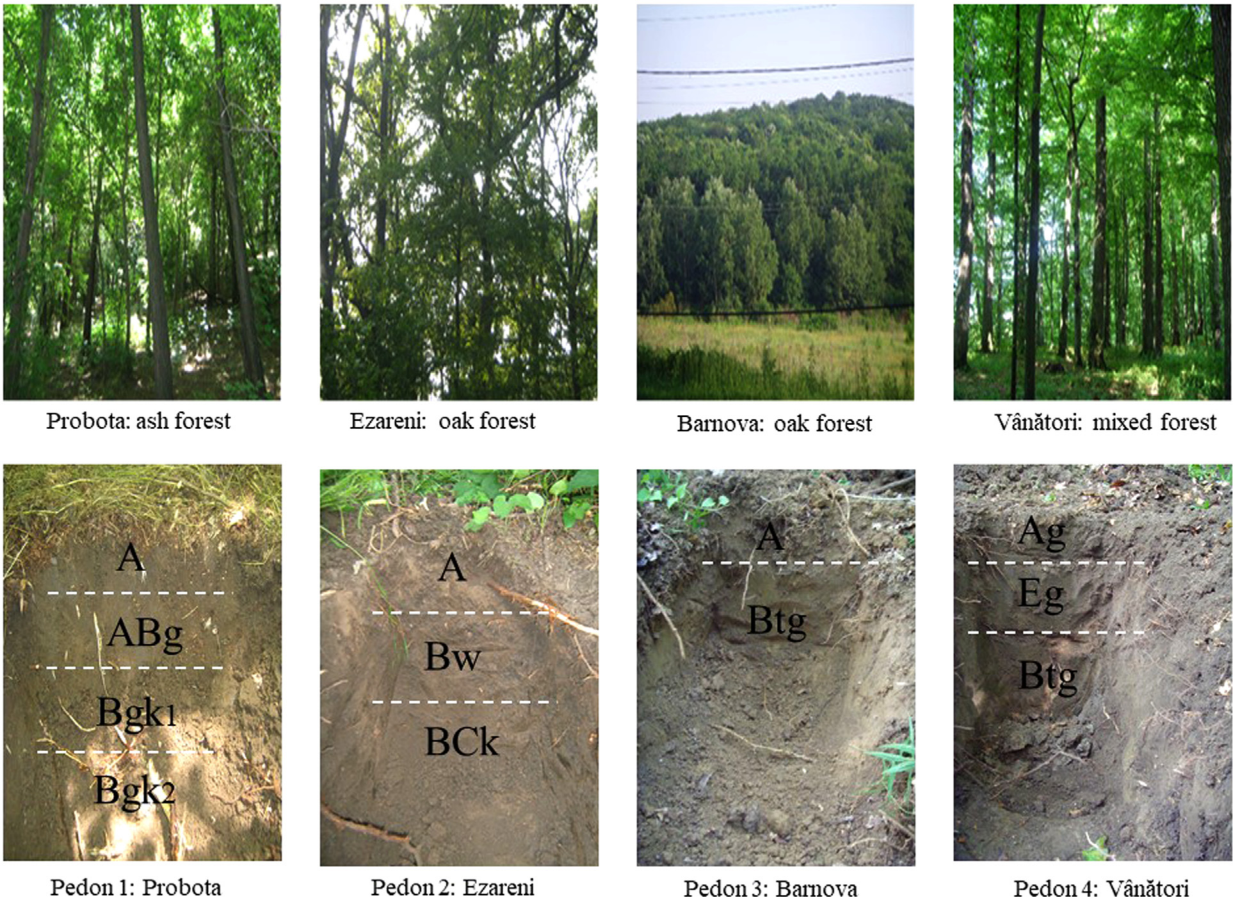

Fig. 2. Location of the four benchmark soils.

Table 1
Main features of the sampling area of the surveyed pedons.

Pedon	**Sampling point**	**Elevation** (m asl)	**Landform**	**Parent material**	**Slope** (degree)	**Rainfall** (mm)	**Temp** (^{0}C)	**Dominant vegetation at sampling site**
1 Probota (Iasi)	47° 23' 11" N; 27° 30' 11" E	60–70	Undulating plain	clayey deposits	6	517	9.6	Ash forest
2 Ezăreni (Iasi)	47° 6' 52" N 27° 32' 3" E	110–120	Undulating plain	loessoid deposits	30	557	9.8	Oak forest
3 Barnova (Iasi)	47° 4' 42" N; 27° 39' 12" E	290–300	Undulating plateau	loamy deposits	20	587	9.4	Oak forest
4 Vânători (Neamt)	47° 12' 40" N; 26° 11' 36 E	530–540	Hilly	loamy clayey deposits	15	650	8.2	Beech, ash, hornbeam and oak forest

Table 2
Classification of the surveyed pedons according to ST, WRB and SRTS.

Pedon	**Location**	**S T**	**WRB**	**SRTS**
1	Probota	Mollic Endoaquept	Mollic Gleysol	Gleiosol cernic
2	Ezăreni	Typic Calciudoll	Haplic Chernozem	Cernoziom cambic
3	Barnova	Typic Hapludalf	Gleyic Luvisol	Preluvosol tipic
4	Vânători	Typic Kanhapludalfs	Stagnic Luvisol	Luvosol stagnic distric

1982). Organic matter (OM) content was calculated by multiplying TOC by the conversion factor 1.724 (Pribyl, 2010). Cation exchange capacity (CEC) was determined with NH4OAc at pH 7 (Soil Survey Staff, 2011). Total nitrogen (Nt), assimilable phosphorus (Pas) and assimilable potassium (Kas) were determined according to the methodology developed by the Research Institute of Soil Science and Agrochemistry (ICPA Bucharest, 1987). Dehydrogenase activity (DA) (mg TPF/100 g dry soil) was determined by incubation at 280 °C over 24 h with 2,3,5-triphenyl tetrazolium chloride (TTC), according to the Casida, Klein, and Santoro (1964) modified by Kiss and Boaru (1965). To classify the soils, we referred to the Soil Taxonomy (ST) system (Soil Survey Staff, 2014), the World Reference Base for Soil Resources (WRB) system (IUSS Working Group, 2015) and the Romanian Soil Taxonomy (SRTS) System (Florea & Munteanu, 2012).

4. Results and discussion

The results of the soil classification of the four pedons are reported in Table 2, while the main morpho-descriptive and analytical features are reported in Tables 3 and 4.

Table 3
Main morpho-descriptive features of the surveyed soils.

Pedon	Horizon	Horizon	Depth	[a]B	[b]T	[c]S	[d]C	[e]R	[f]$CaCO_3$	[g]D
N°	ST & WRB	SRST	(cm)							
1 Probota	A	Am	0–25	gr, s	CL	gr / f / 3	eh	1, fi	0	md
	ABg	Asz	25–35	cl, s	C	sbk / m / 3	eh	1, fi	1 / a	pd
	Bgk1	Bglsz	35–45	gr, s	C	abk / m / 3	eh	1, fi	2 / a-b	pd
	Bgk2	Bkglsz	45–85	un	C	abk / m / 1	eh	0	2 / b	vp
2 Ezăreni	A	Au	0–25	gr, s	SL	gr / f / 2	vh	1, fi	0	mw
	Bw	Bv	25–48	gr, s	CL	sbk / m / 3	vh	1, fi	2 / a-b	pd
	BCk	BCkm	48–118	un	CL	sbk / m / 1	vh	0	2 / b	pd
3 Barnova	A	Au	0–25	ab, s	SL	sbk / f / 1–2	vh	1, fi	0	md
	Btg	Btvr	25–95	un	SCL	pr / m / 3	vh	1, fi	0	pd
4 Vânători	Ag	Aw	0–25	cl, s	SL	gr - sbk / f / 2	mc	1, fi	0	md
	Eg	Ew	25–35	cl, s	SL	sbk / m / 3	mc	1, fi	0	pd
	Btg	BtW	35–115	un	CL	pr / m / 3	mc	0	0	vp

[a] B (boundary): ab = abrupt; cl = clear; gr = gradual; un = unknown; s = smooth.
[b] T (texture): C = clay; CL = clay loam; SL = sandy loam; SCL = sandy clay loam.
[c] S (structure): gr = granular; sbk = subangular blocky; abk = angular blocky; pr = prismatic; f = fine; m = medium; 1 = weak; 2 = moderate; 3 = strong.
[d] C (consistence (dry)): vh = very hard; eh = extremely hard; mc = moderate cohesive.
[e] R (roots): 0 = absent; 1 = few; fi = fine.
[f] Calcium carbonate concretions: 0 = absent; 1 = few; 2 = common; a = small; b = medium.
[g] D (internal drainage): md = moderately drained; pd = poorly drained; vp = very poorly drained.

Table 4
Main physical, chemical and biological features of the surveyed soils.

Pedon	Horizon		Depth	pH	Clay	$CaCO_3$	Corg	OM	CEC	BS	Nt	Pas	Kas	DA
N°	ST & WRB	SRST	(cm)	H_2O	(g kg^{-1})			(%)	(cmol)	(%)	‰	ppm		(mg TPF)
1 Probota	A	Am	0–25	7.9	401	0	51.5	8.8	30.5	92	3.42	27	193	40.1
	ABg	Asz	25–35	8.4	466	25	39.9	6.8	35.6	100	3.05	30	161	nd
	Bgk1	Bglsz	35–45	8.6	561	85	18.5	3.2	26.5	100	1.66	24	144	nd
	Bgk2	Bkglsz	45–85	8.8	570	118	nd	nd	19.4	100	nd	15	150	nd
2 Ezăreni	A	Au	0–25	6.0	367	0	36.0	6.2	31.6	80	2.84	38	147	36.5
	Bw	Bv	25–48	7.4	401	96	16.6	2.8	30.4	100	2.26	40	126	Nd
	BCk	BCkm	48–118	7.6	404	134	nd	nd	13.0	100	nd	21	123	Nd
3 Barnova	A	Au	0–25	6.1	161	0	22.1	3.8	14.2	71	2.84	25	133	32.0
	Btg	Btvr	25–95	6.7	350	0	15.9	2.7	17.8	79	0.50	17	103	nd
4 Vânători	Ag	Aw	0–25	5.7	251	0	23.7	4.1	13.1	61	1.92	34	157	10.3
	Eg	Ew	25–35	4.3	204	0	11.1	1.9	10.5	53	0.84	12	103	nd
	Btg	BtW	35–115	6.4	390	0	10.8	1.8	9.4	66	nd	14	115	nd

4.1. Pedon n. 1 (Probota)

4.1.1. Mollic Endoaquept (ST); Mollic Gleysol (WRB); Gleiosol cernic (SRTS)

The first benchmark soil developed in a lowland area (60–70 m asl) characterised by undulated plains and clayey deposits. Its main characteristics are due to a moderate process of leaching: clay as well as carbonate increase with depth, while air porosity decreases, contributing to the formation of evident “gleyic” features in the subsoil. Dry soil consistency is a restrictive ecological indicator, being extremely hard on the entire soil profile due to high clay content (from 401 to 570 g kg^{-1}). The OM content is high, both in the topsoil (8.8%) and in the argillic horizon (6.8%), due to a high content of grass and forest debris, showing a high biological significance for several soil functions and processes (Carter, 2002). Reaction is sub-alkaline in the whole profile. Cation exchange capacity and dehydrogenases show high values due to the OM and clay contents.

4.2. Pedon n. 2 (Ezăreni)

4.2.1. Typic Calciudoll (ST); Haplic Chernozem (WRB); Cernoziom cambic (SRTS)

This soil developed in a plain area characterised by a slightly undulating morphology with gentle slopes and a natural oak forestry vegetation. The main features of this soil profile point to a moderate leaching process: carbonates are present below a depth of 25 cm and increase in the carbonato-illuvial horizon (BCk) below a depth of 48 cm. The same was observed for the pH (from 6.0 to 7.4) and for the clay content (from 367 to 404 g kg^{-1}). The latter value justifies the low drainage in the subsoil. The OM content of the topsoil is relatively high (6.2%) due to the microbial decomposition of the organic debris in the forest floor. Cation exchange capacity (CEC) as well as macro-element values decreased with soil depth. The dehydrogenase value (36.51 mg TPF/100 g dry soil) is possibly related with the acid soil reaction, which ensures a positive trend for anaerobic conditions and the development of the fungal microflora (Wolińska & Stępniewska, 2012).

4.3. Pedon n. 3 (Barnova)

4.3.1. Typic Hapludalf (ST); Gleyic Luvisol (WRB); Preluvosol tipic (SRTS)

Pedon n. 3 was formed on loamy deposits and on a morphology caused by an undulated plateau, higher in elevation (260–350 m asl) and in rainfall than the above described benchmark soil. These environmental conditions allowed for the development of oak forests. All these features led to a more advanced process of alteration of minerals and organic matter, which favoured the formation of a Btg genetic horizon (Btvr according to the SRST system). The soil structure is sub-angular in the topsoil and prismatic in the Btg horizon; it is related with the clay content, determining low drainage intensity in the subsoil. The soil reaction is acid (pH 6.1–6.7), the OM content is moderately high (3.8–2.7%), CEC values are low (14.2–17.8 cmol/Kg^{-1}). Dehydrogenase activity is 32.06 mg TPF/100 g dry soil.

4.4. Pedon n. 4 (Vânători)

4.4.1. Typic Kanhapludalfs (ST); Stagnic Luvisol (WRB); Luvosol stagnic distric (SRTS)

The fourth benchmark soil developed on loamy clayey deposits in a gently sloping hilly area with the highest elevation (520–550 m asl), the highest precipitation and the lowest temperature compared to the other three benchmark soils. Such morpho-climatic features allow for the presence of a mixed deciduous forest (with beech, ash, hornbeam and oak), reflected in the clear visible redoximorphic figure in the whole soil profile and in the presence of an argillic horizon. The soil structure changes from granular to sub-angular in the topsoil, sub-angular in the Eg horizon and prismatic in the Btg horizon. The soil does not contain $CaCO_3$. The soil reaction is acid or moderately acid (pH 4.3–6.4). Values of CEC and OM decrease with depth. Dehydrogenase activity (10.3 mg TPF/100 g dry soil) is much lower than Pedon n. 1, 2 and 3. This fact can be related to the restrictive ecological conditions of moisture and aeration in this Pedon. Soil air-water conditions are important for the regulation of the activity of soil microorganisms (Stepniewski et al., 2000). Indeed, lower values of dehydrogenase activity can be explained with the prevalence of reduction processes under anaerobic conditions, a phenomenon that characterises these kinds of soils.

We observed decreasing trends (Fig. 3) for pH values ($R = 0.75$), OM values ($R = 0.91$) CEC values ($R = 0.84$), BS values ($R = 0.99$), Nt values ($R = 0.87$) and DA values ($R = 0.82$), with increasing

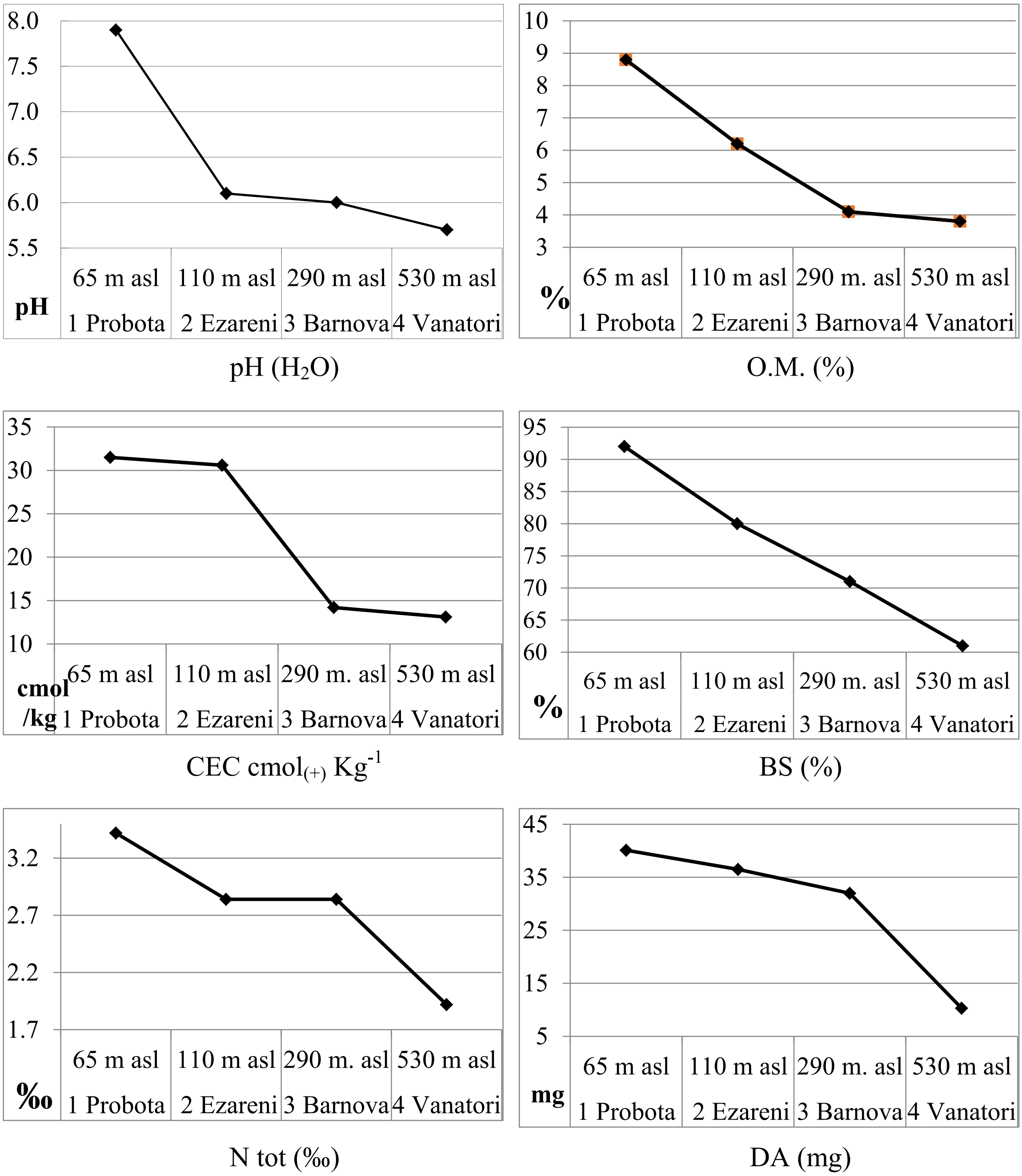

Fig. 3. Values of pH, OM, CEC, BS, Nt, and DA decrease with the increase of the altitude of the locations of the soils surveyed.

elevations of the surveyed benchmark soils. The environmental features of the study area, mainly temperature, rainfall and the natural vegetation, could explain these trends and confirm the findings reported by Dahlgren et al. (1997) in a soil survey along an elevational transect in the western Sierra Nevada (California).

5. Conclusions

In the benchmark soils we surveyed, calcium carbonate and clay leaching and accumulation are the main soil formation processes. In soils located at higher elevations (Barnova and Vânători), calcium carbonate is leached out from the soil profile, clay illuviation is strong and coupled with the presence of redoximorphic features. In soils located at lower elevations (Probota and Ezăreni), the coexistence of clay coatings and secondary carbonates can be explained by recarbonation or by spatial differentiation of soil environments in the profile, as evidenced for other environments (Poch et al., 2013).

It should be noted that specific soil parameters (pH, OM, CEC, BS, Nt, DA) decreased with increasing elevation, possibly due to leaching underneath the forest litter as well as to the temperate continental climate regime of forest steppes on the Moldavian Plain, a subunit of the Moldavian Plateau (Florea, Munteanu, Rapaport, Chiţu, & Opriş, 1968; Ielenicz, 1999). Indeed, the main soil chemical features and the pedoclimatic conditions are favourable for the development and sustaining of a natural forest with oak as the dominant species. The dehydrogenase values and trends with elevation are probably linked to the acid soil reaction, facilitating anaerobic conditions and the development of the fungal microflora (Wolińska & Stępniewska, 2012). In addition, the forest vegetation, particularly oak, could play a role in determining the dehydrogenase activity trends (Błońska, Lasota, & Gruba, 2016) highlighted in this research.

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