Basic Properties of Calcocambisol from a Location on North Dalmatian Plain

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Summary

Calcocambisol is the most dominant soil type developed on Dinaric karst. It is formed by pedogenic processes acting on carbonate rocks, which include weathering, accumulation of insoluble residue, organic matter, and allogenic material and braunification. Further development of Calcocambisol includes leaching of clay from upper soil horizons and secondary accumulation in lower horizons. Calcocambisols are exclusively developed on carbonate rocks characterised by diverse relief forms resulting in variable soil depth over short distances and consequently different phases of soil development. Thus, the goal of this study was to analyse morphological, physical, and chemical properties of Calcocambisols in different stages of development from a location within the Krka National Park. Results of soil analysis showed similarities in morphological properties, soil field and air capacity, density and SOC content. On the other hand, differences in properties included different carbonate content and pH values of topsoil and difference in particle size distribution. These differences can be attributed to irregular rocky surface which plays important role in allogenic particles distribution and water percolation. Increased leaching of clay particles to deeper horizons results in diversification of Bt (argic) horizon, indicating more advanced stage of soil development towards Luvisol formation.

Key words

particle size distribution, soil density, field and air soil capacity, pH, SOC

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Introduction

Dinaric karst is one of the most important karst regions in the world, often called “classical” because of its diverse development of carbonate relief forms (Zupan Hajna, 2019). It is characterized by reddish soils (Pilaš et al., 2016) that include various types in different phases of soil development (Husnjak, 2014). Weathering of carbonate rocks (dominantly limestone) causes dissolution, disintegration, and accumulation of insoluble residue and organic matter, leading to formation of Calcomelanosol. Further development including process of braunification leads to formation of Calcocambisol, being the most dominant soil type on Dinaric karst and covering 40.55% of area (Pilaš et al., 2016).

Regional Calcocambisols are characterized by high rockiness and high degree of carbonate rock erosion, where relief plays a key role in creating favourable conditions for weathering of parent material and accumulation of insoluble residue (Husnjak, 2014). Furthermore, apart from accumulation of insoluble residue, input of allochthone material (predominantly loess) brought by different processes since the late Tertiary impacted development of these soils (Yallon, 1997; Muhs et al., 2012). Calcocambisols mostly develop on flat terrain and have variable soil depth over short distances (due to cracks in carbonate rocks formed by karstification process) and silty clayey and clayey texture (Škorić et al., 1985; Bogunović et al., 2009; Husnjak 2014). Due to stabile granular and angular blocky form of structural aggregates these soils have favourable soil-water relations (Gonzales Pelayo et al. 2006; Markoski et al. 2015). In general, these soils are non-calcareous, slightly acidic to neutral (Vrbek and Pilaš, 2007; Hamidović et al. 2013, Husnjak 2014) with variable soil organic matter (SOM) content (Bogunović et al., 2009; Durn et al. 2019).

Calcocambisols are typically relatively shallow soils, where with time and accumulation of particles, descending water movement causes leaching of clay from upper soil horizons and secondary accumulation in lower horizons, forming Luvisols, which are considered the oldest and most developed soils on carbonate sediment (e.g., Spaargaren, 2008; Pilaš et al., 2016).

It is well known that soils mostly result from the weathering of rocks (Chesworth, 2008) and although it is presumed that soil formation rate is closely related to weathering rate (e.g., Owens and Watson, 1979; Wakatsuki and Rasyidin, 1992; Stockmann et al., 2014), its quantification is still understudied topic. Understanding soil-forming processes and formation rate has gained its importance in recent decades due to global concern over soil degradation (Amundson et al., 2015; Hou et al., 2020) and its impact on global carbon cycle (e.g., Van Oost et al., 2007; Sanderman et al., 2017). Furthermore, due to global climate change Mediterranean climate is projected to become drier (Alessandri et al. 2014; Polade et al. 2017), resulting in decrease in annual rainfall, increase of rainfall intensity, and strong erosion (Capolongo et al. 2008), directly impacting soils of Dinaric karst.

Having that in mind, in order to better understand the complexity of soil systems and impact of rock weathering on soil formation in the area of the Dinaric karst KADEME project (Inter-comparison of karst denudation measurement methods) was launched in October 2018. It aims to evaluate the potential natural soil production rate based on weathering rate. To achieve this, it is necessary to understand characteristics of rock-soil-atmosphere system and its basic properties. Thus, the goal of this paper is to show the first results of soil properties investigation on a specific location within the Krka National Park. Data shown here will be later used to model processes in rock-soil-atmosphere system in this area.

Material and Methods

Study Site

The study site (43°47’39" N, 16°00'08" E; 200 m asl) is located in the Dalmatian region of Croatia (Fig. 1A), within southern part of the Krka National Park, in between villages Koštani, Tulići and Punčka draga dry valley. It is a part of Sjevernodalmatinska zaravan (North Dalmatian plateau), built up from Upper Cretaceous limestones and Eocene limestones and carbonate conglomerates (Mamužić, 1971; Ivanović et al., 1977; Brlek et al. 2014) that have been intensively faulted and folded forming structures having Dinaric orientation (i.e., NW–SE).

Eocene carbonate Promina beds that build up this study site are mostly composed of conglomerates, limestones, and marly limestones (Ivanović et al., 1978). The late Cretaceous limestones are unconformably overlain by the middle Eocene Foraminifera Limestones (Mrinjek et al., 2012). Conglomerates consist of fragments and pebbles of Cretaceous and Paleogene limestones, granular dolomites, dolomitized radiolarian cherts and fossil fragments. Pebbles are in average up to 2 cm in diameter, poorly sorted, of variable sphericity and clast supported. Limestones are mostly detrital, fine-grained, often alternate with marls or marly limestones with microcrystalline to cryptocrystalline structure (Ivanović et al., 1978).

Tectonic movements uplifted this region (Tari Kovačević and Mrinjek, 1994) that was later on levelled over a long period of denudation by corrosion planation in the level of the karst water, forming wide denudation plan. Finally, regional tectonics caused uplift to its present state and entrenchment of major allogenic through-rivers (Ford and Williams, 2007; Mihevc, 2010). Carbonate surface was dominated by denudation, while colluvial processes partly shaped (apart from entrenchment) slopes of the canyon. Karstification processes shaped flattened terrain, dominated by natural rock exposures and characteristic karst features such as karren and kamenitzas developed on the surface.

The region is characterized by the Mediterranean climate (Csa) with dry and hot summers and mild rainy winters (Filipčić, 1998) and dominated by winds from N to NE (Bura/Bora), W (Maestral) and SW to SE (Jugo/Sirocco) with speeds that can exceed 30 m s^{-1} (Zaninović, 2007; Vučetić and Bajić, 2008). Local meteorological conditions are recorded in a station installed in 2019 in proximity of the study site. Here the mean annual temperature recorded during 2019 was 14.97 °C, while annual amount of precipitation was 1222 mm. This data is in accordance with the data recorded during 1961-1990 period at nearby meteorological stations Drniš and Šibenik, where mean annual temperature was 12.9 °C and 15.1 °C, while average annual amount of precipitation was 1063.2 and 808.1 mm respectively (Milković and Trninić, 2007). According to meteorological data, precipitation in the region is more frequent in autumn and less during summer.

Soils developed in this area are characterized by high spatial variability (Vrbek and Pilaš, 2007a). Among different soil types developed, Calcocambisol on limestone is the most dominant soil type in this area (Čolak and Martinović, 1973). These silty clayey or clayey soils are characterized by high internal drainage, acid soil reaction and variable humus content depending on land use/vegetation. The depth of these soils varies greatly over small distances, but mostly are very shallow (< 15 cm) to shallow (15-35 cm) with large rock outcrops interrupting the continuity of the soil cover (Vrbek and Pilaš, 2007a). Surface rockiness of the study area expressed as cover percentage of exposed rock varies from 10 to 50%.

The study area is situated within the sub-Mediterranean zone of downy oak and oriental hornbeam forest (*Querco-Carpinetum orientalis H-ić* 1939) (Medak and Perić, 2005) fragmented and degraded due to intense exploitation (Fig. 1B, Fig. 2C and Fig. 2D). In the study area this type of vegetation is developed on levelled surfaces, and due to decline of agricultural activity is slowly progressing towards natural state. Apart from downy oak and oriental hornbeam, there are flowering ash (*Fraxinus ornus*), maple (*Acer monspessulanum*), sorbus (*Sorbus domestica*) and *Celtis australis* and different kinds of shrubs as well. The vegetation at the study site is as well dominated by *Juniperus oxycedrus*, characteristic for extremely degraded areas (Medak and Perić, 2005). Due to the reduction of biomass, vegetation does not have significant differential impact on soil morphology (Vrbek and Pilaš, 2007a).

Soil Sampling and Laboratory Analysis

In order to investigate soil properties on this particular location (one of the spot measurement sites within KADEME project), soil profiles were dug out. Due to high surface rockiness, large rock outcrops interrupting the continuity of the soil cover and dominantly very shallow soil depth (< 15 cm), we were able to investigate only two soil profiles, P-1 and P-2 (Fig. 1B). Soil profiles were investigated and described according to FAO recommendations (FAO, 2006), and a depth-based sampling was performed on each soil profile where disturbed and undisturbed (cores of 100 cm^3) soil samples were collected along the profile in 5 cm depth intervals.

The disturbed soil samples were air-dried, ground, and sieved using sieve with 2 mm mesh size (ISO 11464:2006). The soil pH was determined using combined glass electrode in a 1:5 (*v/v*) suspension of soil in water and soil in KCl solution (c=1M) according to ISO 10390:2005. Carbonate content was determined applying modified volumetric method (ISO 10693:1995), while humus content was analyzed by acid potassium-dichromate ($K_2Cr_2O_7$, c=0.4M) digestion, following the method of Tjurin (JDPZ, 1966). Soil C_{org} content was calculated by dividing the content of humus with the Van Bemmelen factor (1.724). Soil particle size distribution was analyzed by pipette-method, with wet sieving and sedimentation after dispersion with sodium-pyrophosphate ($Na_4P_2O_7$, c=0.4M) (ISO 11277:2009).

The field capacity (FC) was determined by gravimetric method using core samples (ISO 11461: 2001). The same samples were used for gravimetric determination of bulk density (BD) after drying the soil at 105 °C (ISO 11272: 2017). The particle density (PD) was measured in water, using 100 mL pycnometer after ISO 11508:2017. The total porosity (TP) and air-filled porosity (AP) were calculated according to Danielson and Sutherland (1986).

Results and Discussion

Soil Morphology

The very surface of the site where investigated soil profiles are located can be characterized as having many rock outcrops (15-40% with distance between rock outcrops 2-5 m; FAO, 2006) (Fig. 2C and 2D), in consistency with results of previous investigations (Čolak and Martinović, 1973).

Soil profile P-1 consists of the following mineral horizons: A-Bw-Bt-Bk-R (Fig. 2A, Table 1). The uppermost, A horizon, has a significant accumulation of humified organic matter entirely mixed with the mineral soil fraction.

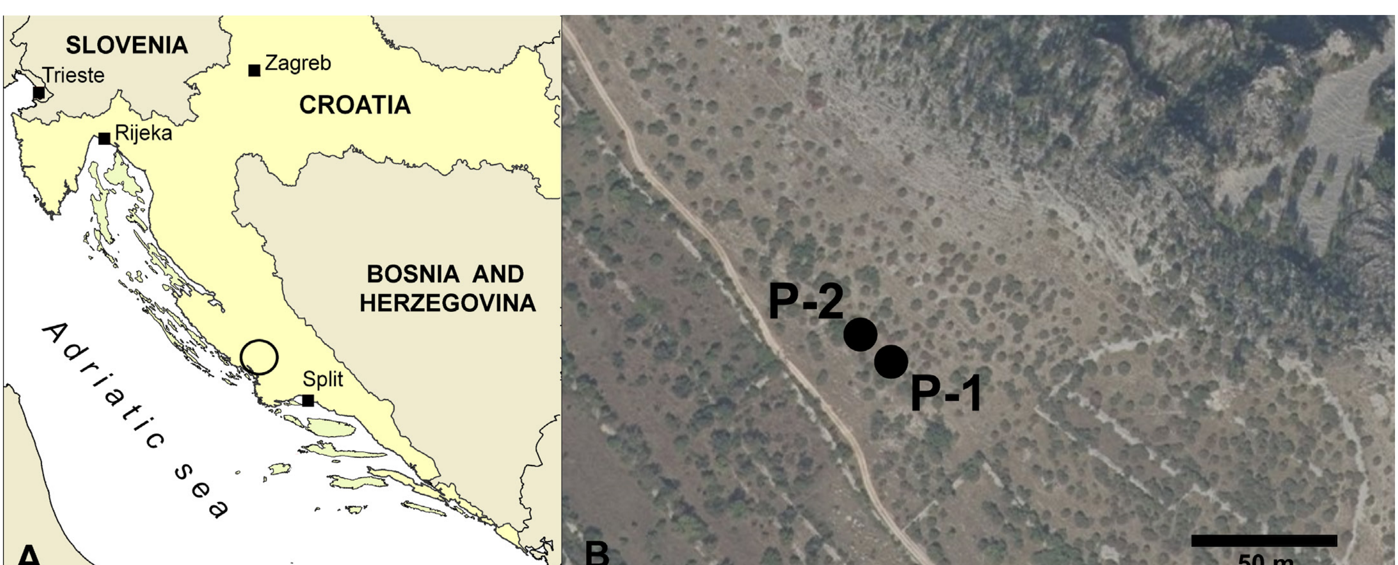

Figure 1. Location of study area (A) and studied soil profiles P-1 and P-2 (B)

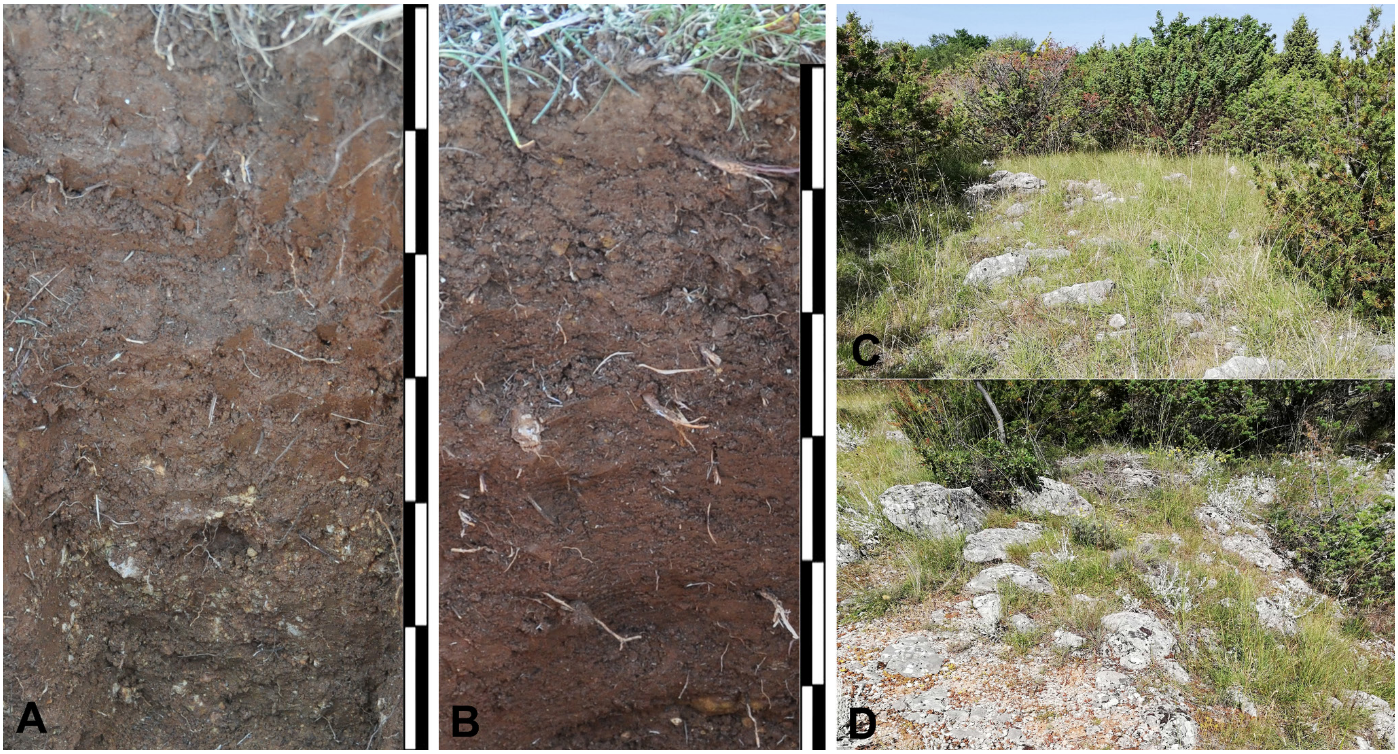

Figure 2. Investigated soil profiles P-1 (A) and P-2 (B). The thickness of P-1 profile is 60 cm, whereas P-2 is 55 cm thick. Scale division step is 10 cm. C and D panels show vegetation in study site

Table 1. Morphological features of the investigated soil profiles

Soil profile	Horizon designation (FAO, 2006)	Horizon depth (cm)	Dry soil colour	Texture	Rock Fragments[1]	Structure[2]	Roots Abundance[4]
P-1	A	0-7	7.5 YR 4/4	Silty clay	N	G	F
	Bw	7-22	5 YR 4/4	Clay	N	AB	VF
	Bt	22-44	5YR 4/6	Clay	N	MA	VF
	Bk	44-61	5 YR 5/6	Clay	F	SA	N
	R	>61	-	-	-	-	-
P-2	A	0-6	7.5 YR 4/4	Clay	N	G	F
	Bw1	6-19	7.5 YR 4/6	Clay	N	SA	VF
	Bw2	19-42	5 YR 4/6	Clay	N	SB	VF
	Bk	42-55	5 YR 4/6	Clay	F	SB	N
	R	>55	-	--	-	-	-

[1] F – few N – none, (FAO, 2006); [2] G- granular, MA - massive, AB - angular blocky, SA - subangular and angular blocky, SB - subangular blocky (FAO, 2006); [3] C – common, F - few, VF - very few, N – none (FAO, 2006). Dry soil colour was determined using Munsell Soil Colour Chart (Munsell Color, 2000).

The letter "B" designates cambic horizon which shows evidence of pedogenic alteration, while letter "w" indicates strong development of soil colour. Textural differentiation in terms of distinctly higher clay content than the overlying horizon is designated using suffix "t". The letter "k" implies appearance of calcite nodules. Hard rock which underlies the soil is designated by the letter "R". The soil colour ranges across horizons from brown in uppermost A horizon across reddish brown in the middle part of profile to yellowish red in lowermost Bk horizon indicating pedogenic processes (Table 1). The increase of clay content with depth was noted by feel from A to Bt horizon. The Bk horizon contains secondary carbonates in form of hard concretions/nodules and few carbonate rock fragments of variable size classified as fine gravel (2-6 mm) and gravel (6-20 mm) according to FAO (2006). The soil structure changes throughout the profile, from granular detected in A horizon to blocky and massive in the lower part of profile. A horizon has some roots (20-50 roots smaller than 2 mm in diameter per dm^2 i.e., 2-5 roots larger than 2 mm), while in underlying horizons the abundance of roots decreases with depth.

Soil profile P-2 consists of A-Bw1-Bw2-Bk-R horizons (Fig. 2B, Table 1) and shows some morphological properties similar to those described for P-1 profile (colour, appearance of calcite nodules and rock fragments, roots abundance through entire profile). However, the thickness of this profile (soil depth) is slightly smaller in comparison to P-1 profile (55 and 61 cm, respectively). Although shallow (<35 cm) Calcocambisol on limestone is a dominant soil type in this area (Čolak and Martinović, 1973), previous studies in this area identified some locations having medium deep (35-70 cm) Calcocambisol soil profiles (Čolak and Martinović, 1973; Vrbek and Pilaš, 2007a). Furthermore, Bogunović et al. (2009) found that the depth of this soil type in Dalmatia can reach up to 80 cm due to occurrence of rock fissures as a result of karstification process. The soil texture throughout entire P-2 profile is clayey, without noticeable differences in clay content, as was observed in profile P-1. Therefore, Bt horizon was not determined in this profile as it was in profile P-1. Furthermore, there are also differences in soil structure between P-1 and P-2 profile. Both profiles have granular structure of A horizon, but P-2 profile has blocky structure in the lower part of profile, while in P-1 profile massive structure was noticeable in Bt horizon.

Despite minor differences in soil morphology, both soils described in P-1 and P-2 profiles are characteristic for Calcocambisol soil type that can be usually found in Dinaric (Čolak and Martinović, 1973; Miloš and Maleš, 1998; Vrbek and Pilaš, 2007a; Bogunović et al., 2009, Miloš and Bensa 2014), as well as in the Mediterranean area (e.g., Torrent and Cabedo, 1986; Noulas et al., 2009; Fedoroff and Courty, 2013; Vingiani et al., 2018).

Soil Physical Properties

The analysis of particle size distribution showed that clay fraction dominated every single horizon within both analysed soil profiles (Table 2, Fig.3). The most prominent difference between studied soil profiles is observed in the increase of clay content with depth. In the profile P-1 clay content continuously increases from top of the soil profile (47.3%) to the depth of 35-40 cm (73.7%), and then decreases to the 41.7% in the lowermost part of the profile (Table 2). The average clay content in samples from Bw horizon (5-20 cm) is 58.4%, while in underlying horizon, which includes samples from 20-45 cm depth, has an average clay content of 71.1% (Fig. 3). Therefore, it meets criteria of WRB (2014) to be identified as argic horizon (20% more clay than overlying coarser textured horizon which has > 50% of clay). The clay content in Bw1 and Bw2 horizons of P-2 profile (64.1 and 69.5%, respectively) did not meet mentioned criteria (Fig. 4). A decrease of clay content in Bk horizon is noticeable in both profiles (Fig. 3 and Fig. 4).

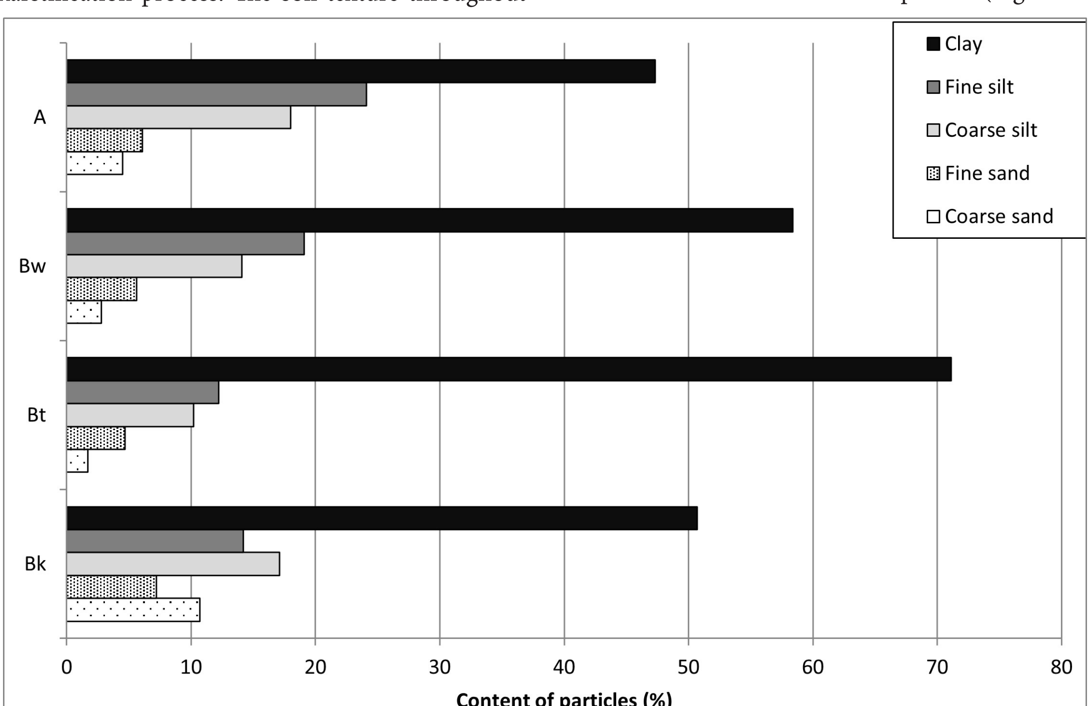

Figure 3. Particle size distribution of the investigated soil profile P-1

Table 2. Particle size distribution (%) and texture classes of the investigated soil profiles

Soil profile	Depth cm	Coarse sand 2.0-0.2 mm	Fine sand 0.2-0.063 mm	Coarse silt 0.063-0.02	Fine silt 0.02-0.002 mm	Clay < 0.002 mm	Texture class
P-1	0 -5	4.5	6.1	18.0	24.1	47.3	Clay silt
	5-10	2.7	6.1	16.3	21.3	53.6	Clay
	10-15	3.4	5.5	13.6	18.8	58.7	Clay
	15-20	2.2	5.2	12.5	17.3	62.8	Clay
	20-25	2.3	5.1	12.2	13.3	67.1	Clay
	25-30	1.5	4.8	9.7	13.4	70.6	Clay
	30-35	1.8	4.5	10.1	11.9	71.7	Clay
	35-40	1.2	4.6	9.9	11.0	73.3	Clay
	40-45	1.8	4.5	9.3	11.4	73.0.	Clay
	45-50	6.9	6.9	15.5	14.6	56.1	Clay
	50-55	7.6	7.4	16.9	13.7	54.4	Clay
	55-60	17.7	7.3	18.9	14.4	41.7	Clay
P-2	0 -5	4.9	6.0	14.0	24.6	50.5	Clay
	5-10	1.8	5.2	11.6	18.9	62.5	Clay
	10-15	1.5	4.8	10.7	16.5	66.5	Clay
	15-20	8.3	5.6	10.4	12.3	63.4	Clay
	20-25	2.0	6.1	10.9	12.9	68.1	Clay
	25-30	4.4.	4.3	10.0	11.9	69.4	Clay
	30-35	1.4	5.5	9.8	10.9	72.4	Clay
	35-40	1.9	5.2	11.3	13.5	68.1	Clay
	40-45	3.8	6.7	20.1	15.2	54.2	Clay
	45-50	7.0	8.4	18.4	14.8	51.4	Clay
	50-55	5.4	8.8	20.2	15.7	49.9	Clay

The content of fine and coarse silt fractions in both soil profiles decreased with depth up to 35/40 cm, but then increased towards the bottom of the profile (Table 2). The average values of fine and coarse silt fractions in A horizon of P-1 profile were 24.1 and 18.0%, respectively, while Bt horizon had significantly lower average values (12.2 and 10.2%; Fig. 3 and Fig. 4). The decrease of silt content from A to Bw2 horizon in profile P-2 is less pronounced, especially for coarse silt fraction (Fig. 4). The coarse silt fraction content slightly decreased from 14.0% (as determined in A horizon; 0-5 cm) to 10.5% in Bw2 horizon (20-40 cm) (Table 2). The increase of silt fractions in Bk horizon is noticeable in both profiles. In P-1 profile fine and coarse silt increased up to 14.2 and 17.1% respectively, while in the P-2 profile Bk horizon have 15.2 and 19.6%, respectively (Fig. 3 and Fig. 4).

Fine sand fraction is relatively homogenously distributed throughout both soil profiles ranging from 4.5 to 7.4% in profile P-1 and from 4.3 to 8.8% in profile P-2 (Table 2). Even so, the average values of fine sand content for particular horizon showed slight decrease from A (6.1%) to Bt horizon in P-1 profile (4.7%; Fig. 3) as well as from A (6.0%) to Bw2 horizon (5.3%) in P-2 profile (Fig. 4). Furthermore, Bk horizons in P-1 and P-2 profiles comprise the highest content of coarse sand fraction (7.2 and 8.0%, respectively). The studied profiles differ further when comparing coarse sand fraction content. In profile P-1 it ranged from 1.2% (at depth 35-40 cm) to 17.7% (at depth 55-60 cm), while in P-2 profile this range is significantly narrower (1.5-7.0%; Table 2). Nevertheless, both profiles showed a decrease of coarse sand fraction with depth up to 40/45 cm. In P-1 profile coarse sand fraction decreased from 4.5% (A horizon) to 1.7% (Bt horizon), while in P-2 profile from 4.9 (A horizon) to 2.4% (Bw2 horizon). Both studied profiles have the highest coarse sand content in Bk horizon (10.7 and 5.4%, respectively) (Fig. 3 and Fig. 4).

Soil texture of both profiles can be described as clayey throughout full profile, apart from uppermost, A horizon (depth 0-5 cm) of P-1 profile that is characterized by silty clayey texture. Textural classes of these soils reported in Table 2 are characteristic for Calcocambisol soil type (Škorić et al., 1985; Husnjak, 2014). Numerous studies reported clay fraction as dominant in Calcocambisols (i.e., Škorić et al. 1987; Miloš and Maleš 1998; Miloš and Bensa 2014), however other fractions (sand in particular) vary significantly due to variability of pedogenetic factors, dominantly parent material and relief. Thus, data reported here (Table 2) are comparable to those published in studies from the Dinaric region (Miloš and Maleš, 1998; Miloš and Bensa, 2014; Vrbek and Pilaš, 2007b). The observed textural difference between two profiles can be attributed to microtopography differences of the study site, since it is well known that microtopography influences soil properties over short distances (Kooijman et al., 2019, Pawlik and Kasprzak, 2015, Šamonil et al., 2016), affecting spatial variability of soil moisture on small scales (e.g., Biswas and Si 2011; Bowei et al., 2018). Therefore, rockiness and surface irregularities could have caused differences in percolation of water from the surface and consequently advanced the soil development (formation of Bt horizon in profile P-1).

Bulk density values of studied soils mostly increased with depth throughout both profiles, ranging from 1.11 to 1.44 g cm^{-3} in the P-1 profile and from 1.13 to 1.49 g cm^{-3} in the P-2 profile (Table 3). The lowest BD values measured in topsoil (0-10 cm) can be attributed to higher organic matter content in comparison to lower parts of profiles (Table 4). The observed increase of BD with depth indicates the process of soil compaction in Bw and Bt horizons of the P-1 profile, as well as in Bw1 and Bw2 horizon of the P-2 profile, related to the increase of clay proportion and less pronounced aggregation. However, measured BD values did not surpass 1.6 g cm^{-3} threshold that indicates a reduction of root growth and soil permeability (McKenzie et al., 2002). Soil particle density differed between profiles and varied between 2.46 and 2.62 g cm^{-3} in profile P-1 and 2.37 and 2.52 g cm^{-3} in profile P-2, indicating minor differences in mineralogical composition of mineral soil particles.

The highest field capacity (FC) values were measured in the first 5 cm of the P-1 and P-2 profiles (45.2 and 41.1%, respectively) due to accumulation of humified organic matter in topsoil increasing water holding soil capacity. The average values of FC in Bw and Bt horizons of P-1 profile (41.5 and 41.2%, respectively) were quite similar to those in Bw1 and Bw2 horizons of the profile P-2 (39.5 and 40.1%, respectively) (Fig. 5A and 5B). The lowest FC values were measured at the bottom of P-1 (55-60 cm) and P-2 profiles (50-55 cm) and were 36.9 and 35.2%, respectively (Table 3). This can be attributed to beforementioned high content of sand particles in these parts of the profile. In general, FC values across both soil profiles can be classified as medium, in consistency with previous soil investigations in this area (Čolak and Martinović, 1973). Total porosity (TP) values in P-1 and P-2 profiles varied in similar ranges (43.2-55.4% and 40.5 -54.4%; Table 3). The average values of TP for particular soil horizon showed decrease from A to Bk horizon in both studied profiles. In P-1 soil profile TP values decreased from 55.4% in A horizon to 44.3% as measured in samples form Bk horizon, while values measured in P-2 profile varied from 52.4% in A horizon to 43.5% as measured in Bk horizon (Fig. 5A and 5B). The air capacity values (AC) of P-1 ranged from 3.2 to 15.4%, having higher values in upper part of profile. The AC values in P-2 profile varied in narrower range (4.1 – 12.8%; Table 3). The decrease of average (within horizon) values of AC with depth is noticeable in both profiles (Table 3).

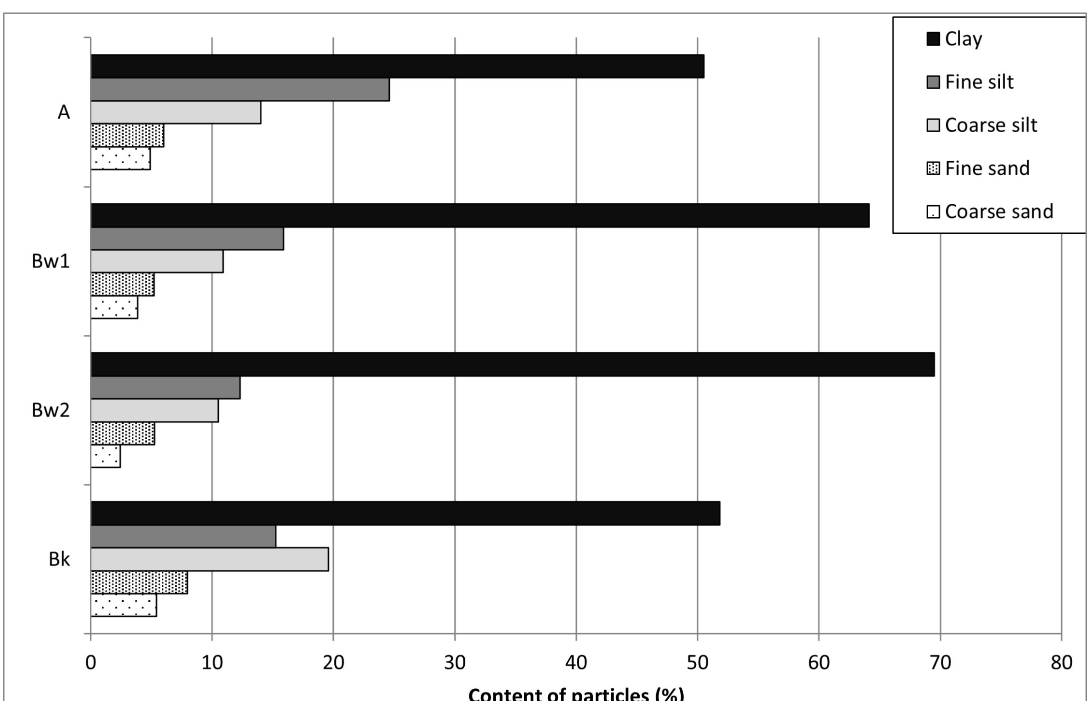

Figure 4. Particle size distribution of the investigated soil profile P-2

Table 3. Basic physical properties of the investigated soil profiles P-1 and P-2

Soil depth cm	Bulk density g cm^{-3}		Particle density g cm^{-3}		Field capacity %		Total porosity %		Air capacity %	
	P-1	P-2	P-1	P-2	P-1	P-2	P-1	P-2	P-1	P-2
0 -5	1.11	1.13	2.49	2.37	45.2	41.1	55.4	52.3	10.2	11.3
5-10	1.11	1.16	2.46	2.44	42.4	39.6	54.9	52.4	12.5	12.8
10-15	1.20	1.21	2.49	2.48	44.1	40.9	51.8	51.1	7.7	10.2
15-20	1.18	1.25	2.53	2.53	38.0	38.1	53.4	50.6	15.4	12.5
20-25	1.20	1.26	2.55	2.50	38.2	39.6	52.9	49.6	14.7	10.0
25-30	1.21	1.28	2.53	2.48	41.5	40.6	52.2	48.4	10.7	7.8
30-35	1.33	1.33	2.54	2.48	41.2	39.9	47.6	46.3	6.4	6.4
35-40	1.30	1.31	2.55	2.46	42.2	40.4	49.0	46.7	6.8	6.3
40-45	1.37	1.36	2.55	2.52	42.9	40.5	46.3	46.0	3.4	5.5
45-50	1.44	1.39	2.61	2.48	38.3	39.9	44.8	44.0	6.5	4.1
50-55	1.46	1.49	2.57	2.51	40.0	35.2	43.2	40.5	3.2	5.3
55-60	1.44	-	2.62	-	36.9	-	45.0	-	8.1	-

Table 4. Chemical properties of the investigated soil profiles P-1 and P-2

Soil depth cm	pH H_2O		pH KCl		$CaCO_3$ %		SOC %	
	P-1	P-2	P-1	P-2	P-1	P-2	P-1	P-2
0 -5	7.03	6.33	6.56	5.51	3.9	1.3	5.2	4.7
5-10	6.08	5.91	5.21	5.07	0.0	0.0	4.0	4.8
10-15	6.02	6.26	5.09	5.08	0.0	0.0	3.3	2.8
15-20	6.09	6.46	5.04	5.25	0.0	0.0	2.7	2.4
20-25	6.29	6.48	5.03	5.25	0.0	0.0	2.2	2.4
25-30	6.24	6.54	5.11	5.40	0.0	0.0	1.8	2.2
30-35	6.45	6.83	5.13	5.53	0.0	0.0	1.7	1.8
35-40	6.59	7.3	5.36	6.09	0.0	0.0	1.7	1.8
40-45	7.00	7.92	5.87	7.05	0.0	8.7	1.3	1.5
45-50	7.89	8.06	7.07	7.02	20.9	18.2	0.5	0.8
50-55	7.96	8.06	7.14	7.12	20.3	27.5	1.2	0.8
55-60	8.02	-	7.26	-	37.6	-	0.7	-

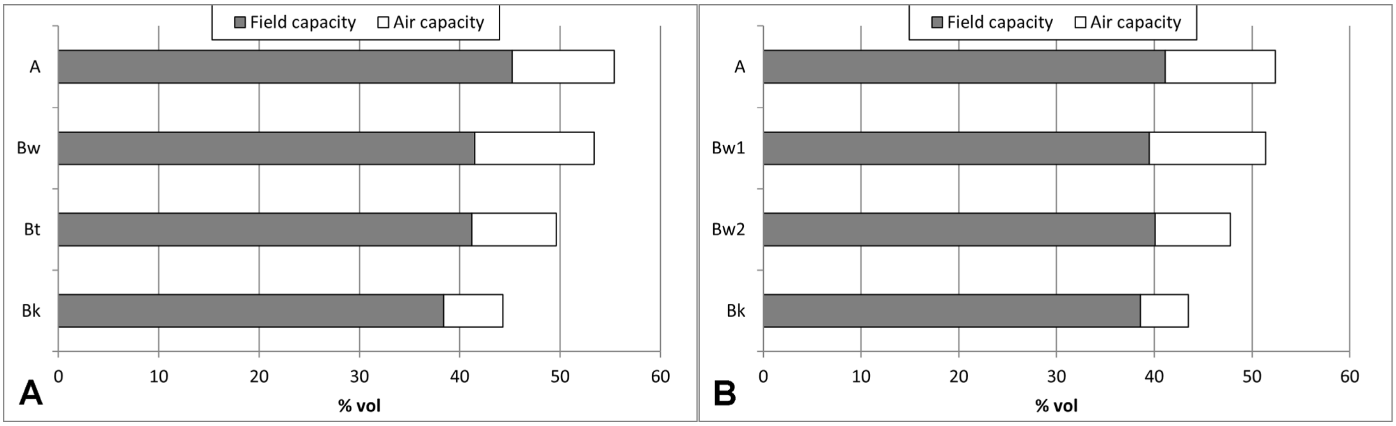

Figure 5. Total porosity, field capacity and air capacity of P-1 (A) and P-2 (B) profile

Soil Chemical Properties

In both soil profiles pH generally increased with depth, with exception of topsoil 0-10/15 cm of profiles in which decrease is noticeable (Table 4). A higher pH value in the top 0-5 cm of A horizon in the P-1 profile (7.03 in H_2O and 6.56 in KCl) can be attributed to the presence of $CaCO_3$ (3.89%), while at the depths of 5-10 and 10-15 cm soil is non-calcareous and consequently the pH is lower. The A horizon in P-2 profile had lower pH values in comparison to P-1 profile (6.33 in H_2O and 5.51 in KCl) due to lower values of carbonate content (1.3%). Wind-blown particles sedimented on irregular surface (microtopography) could have caused increase of $CaCO_3$ content in top 5 cm of P-1 profile and consequently increased of pH value. Thus fine-scale spatial variation of topsoil pH could be attributed to variations in microtopography as previously showed by Baltensweiler et al. (2017; 2020).

From Bw across Bt to Bk horizon of P-1 profile mean pH values measured in H_2O increased from 6.06 to 8.00, as well as those measured in KCl (from 5.11 to 7.20; Fig. 6). In P-2 profile the increase of pH values with depth is notable as well (throughout horizons Bw1, Bw2 to Bk horizon). Both, measured in H_2O (from 6.21 to 8.01) and KCl (from 5.13 to 7.06; Fig. 6).

The highest pH values in P-1 profile were determined in Bk horizon, where they increase with depth within it, ranging from 7.89 to 8.02 (measured in H_2O) and 7.07 to 7.26 (measured in KCl; Table 4). This increase is result of increase of carbonate content from 20.9 to 30.6%. Analysis soil samples from P-2 profile also showed increase of pH(H_2O) and pH(KCl) values with depth within Bk horizon (7.92-8.06 and 7.05-7.12, respectively) due to increase of amount of carbonates from 8.7 to 27.5%.

The soil reaction in P-1 profile is neutral in A horizon, acid in Bw and Bt horizon and alkaline in Bk horizon whereas P-2 profile has weak acid reaction in A and Bw2 horizon, acid in Bw horizon and alkaline in Bk horizon. Weak acid and acid reaction in the most part of studied soil profiles is typical for this soil type as highlighted by Čolak and Martinović (1973), Škorić et al. (1985) and Husnjak (2014), although alkaline reaction in particular parts of Calcocambisols profiles has been reported by Škorić et al. (1987), Miloš and Maleš (1998) and Miloš and Bensa (2014). Both profiles are dominantly non-calcareous, which agrees with the theory of development of this soil type, as a result of decalcification of carbonate parent material and accumulation of insoluble residue. Although typical Calcocambisol formed "in situ" is characterized by absence of carbonates in soil profile (Čolak and Martinović, 1973; Škorić et al. 1987; Miloš and Maleš

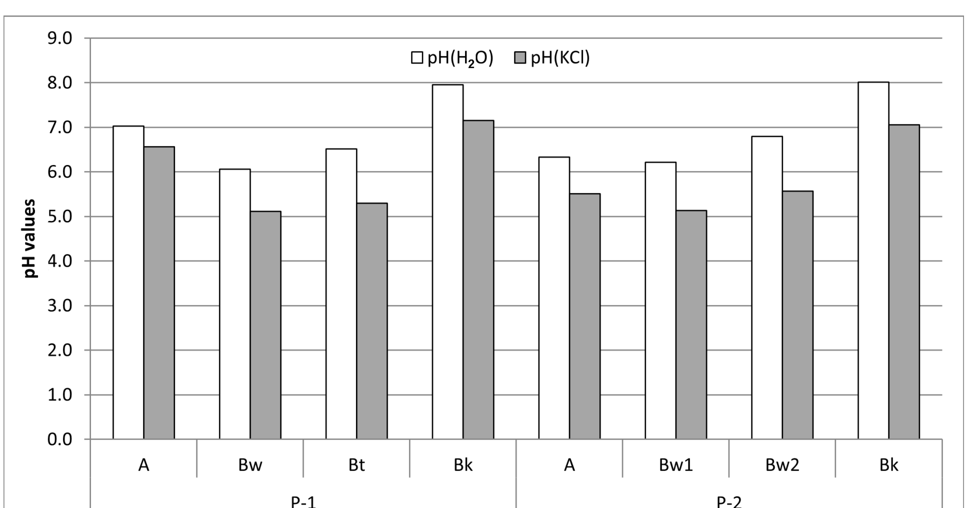

Figure 6. Values of pH measured in H_2O and KCl in P-1 and P-2 profiles

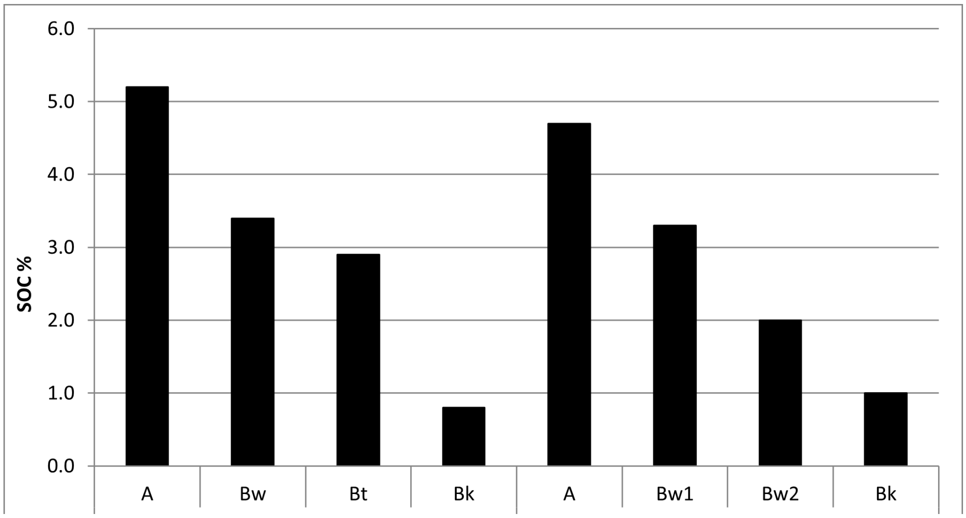

Figure 7. Soil organic carbon (SOC) content in studied soil profiles

1998), it is well known that colluvial subtype of Calcomabisol contains carbonates due to carbonate skelet present in particular parts of the profile (Vrbek and Pilaš, 2007; Bogunović et al., 2009; Hamidović et al. 2013). However, in those studies of colluvial Calcocambisol carbonates are evenly distributed throughout soil profile as a result of colluvial process, while in the current study carbonates are present in the lowermost part of profile. This can be the result of re-precipitation od dissolved $CaCO_3$ from underlying carbonate parent material. Also, small fragments of physically weathered carbonate rock which are present in this horizon contribute to higher concentration of soil solution. Therefore, secondary carbonates in form of spheroidal nodules size of few millimetres are formed in Bk horizon.

The soil organic carbon (SOC) content varied from 0.5 to 5.2 in samples form P-1 profile, while in P-2 profile values varied between 0.8 and 4.8% (Table 4). The highest SOC values were determined in the topsoil horizon of each profile due to accumulation of humified organic matter, and with increasing depth SOC values decreased. Even so, minor differences in SOC content between studied soils were observed (Fig. 7).

The upper three horizons of studied profiles had medium SOC content, while the lowermost Bk horizon in both profiles contained low SOC content. Values reported here are in agreement with those from regional studies (e.g., Miloš and Maleš, 1998). It is well known that SOC content is directly related to vegetation. Therefore, as expected, values reported here are lower in comparison to Cambisols of Gorski kotar and Velebit under forest vegetation (Bakšić et al. 2008) and are higher compared to anthropogenized Cambisols under vineyards (Vitanović et al. 2010) where increased mineralization of organic matter is a result of applied agrotechnical measures.

Conclusions

The properties of Calcocambisol soils were investigated on a particular location within the Krka National Park and results of investigations showed similarities in properties of investigated soil profiles, although some differences were observed.

The highest field capacity values were measured in topsoil horizons due to high organic matter content, while the lowest values were recorded at the bottom due to increase of sand fraction proportion. At the same time, air capacity values decrease with depth, due to increase of clay content. The pH values generally increased with depth approaching interface soil-bedrock containing carbonate rock fragments and calcite nodules. The SOC content decreased from top down having medium values in the upper part of profiles and the low ones in the bottom.

Differences in properties of studied profiles include an increase of $CaCO_3$ content and higher pH values of topsoil (first 5 cm) in profile P-1 and difference in particle size distribution (increase of clay fraction at the depth 20-45 cm in profile P-1). Higher carbonate content and consequently higher pH in topsoil of P-1 can be attributed to higher amount of wind-blown material, sedimented on an irregular rocky surface, which prevents uniform distribution of sedimented material. On the other hand, rockiness and surface irregularities could have caused differences in percolation of water from the surface, triggering more intense lesivation process, resulting in increase of clay fraction at the depth 20-45 cm in profile P-1. This resulted in diversification of Bt (argic) horizon of P-1, indicating more advanced stage of soil development towards Luvisol formation. This long-term process is difficult (or almost impossible) to quantify, but if a weathering rate is known, the duration of this process (and soil production rate) could be estimated.

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References

Amundson R., Berhe A. A., Hopmans J. W., Olson C., Sztein A. E., Sparks D. L. (2015). Soil and Human Security in the 21st Century. Science 348 (6235): 1261071

Alessandri, A., De Felice M., Zeng N., Mariotti A., Pan Y., Cherchi A., Lee J., Wang B., Ha K., Ruti P., Artale V. (2014). Robust Assessment of the Expansion and Retreat of Mediterranean Climate in the 21st Century. Sci Rep 4: 4–11

Bakšić B., Pernar N., Vukelić J., Baričević D. (2008). Properties of Cambisol in Beech-Fir Forests of Velebit and Gorski Kotar. Period Biol 110 (2): 119-125

Baltensweiler A., Heuvelink G.B.M., Hanewinkel M., Walthert L. (2020). Microtopography Shapes Soil pH in Flysch Regions across Switzerland. Geoderma 380: 114663

Baltensweiler A., Walthert L., Ginzler C., Sutter F., Purves R.S., Hanewinkel M. (2017). Terrestrial Laser Scanning Improves Digital Elevation Models and Topsoil pH Modelling in Regions with Complex Topography and Dense Vegetation. Environ Model Softw 95: 13-21

Biswas A., Si B.C. (2011) Revealing the Controls of Soil Water Storage at Different Scales in a Hummocky Landscape. Soil Sci Soc Am J 75: 1295–1306.

Bogunović M., Bensa A., Husnjak S., Miloš B. (2009). Suitability of Dalmatian Soils for Olive Tree Cultivation. Agronomski glasnik 5-6: 367-404

Bowei Y., Gaohuan L., Qingsheng L., Jiuliang F., Xiaoping W., Guozhong H., Chong H. (2018). Effects of Micro-Topography and Vegetation Type on Soil Moisture in a Large Gully on the Loess Plateau of China. Hydrol Res 49 (4): 1255–1270

Brlek M., Korbar T., Košir A., Glumac B., Grizelj A., Otoničar B. (2014). Discontinuity Surfaces in Upper Cretaceous to Paleogene Carbonates of Central Dalmatia (Croatia): Glossifungites Ichnofacies, Biogenic Calcretes and Stratigraphic Implications. Facies 60: 467–487

Capolongo D., Diodato N., Mannaerts C.M., Piccarreta M., Strobl R. O. (2008). Analyzing Temporal Changes in Climate Erosivity Using a Simplified Rainfall Erosivity Model in Basilicata (Southern Italy). J. Hydrol 356: 119–130

Čolak A., Martinović J. (1973). Basic Soil Map of Croatia 1: 50 000 section Šibenik 1, Projektni savjet za izradu pedološke karte SRH, Split

Danielson R. E., Sutherland P. L. (1986). Porosity. In: Methods of Soil Analysis: Part 1—Physical and Mineralogical Methods (Klute A., ed.). Willey, pp. 443-461

Durn G., Škapin S., D., Vdović N., Rennert T., Ottnerr F., Ružičić S., Cukrov N., Sondi I. (2019). Impact of Iron Oxides and Soil Organic Matter on the Surface Physicochemical Properties and Aggregation of Terra Rossa and Calcocambisol Subsoil Horizons from Istria (Croatia). Catena 183: 104184

FAO (2006). Guidelines for Soil Description, fourth ed., FAO, Rome

Fedoroff N., Courty M. A. (2013). Revisiting the Genesis of Red Mediterranean Soils. Turkish J Earth Sci 22: 359-375

Filipčić A. (1998). Climatic Regionalization of Croatia according to W. Köppen for the Standard Period 1961–1990 in Relation to the Period 1931–1960. Acta Geogr Croat 34:1–15

Ford D., Williams P. (2007). Karst Hydrogeology and Geomorphology. John Wiley & Sons, pp. 1-562.

González-Pelayo O., Andreu V., Campo J., Gimeno-García E., Rubio J. L. (2006). Hydrological Properties of a Mediterranean Soil Burned with Different Fire Intensities. Catena 68 (2-23): 186-193

Hamidović S., Čolo J., Delić M., Jurković M., Lalević B., Raičević L., Talaie A. R. (2013). Seasonal Dynamic and Vertical Distribution of Microorganisms and Nutrients in Soils of Mostar Pit (Bosnia and Herzegovina). Agric Conspec Sci 78 (2): 107-111

Hou D., Bolan N. S., Tsang D. C. W., Kirkham M. B., O'Connor, D. (2020). Sustainable Soil Use and Management: An Interdisciplinary and Systematic Approach. Sci Total Environ 138961. doi: 10.1016/j.scitotenv.2020.138961

Husnjak S. (2014). Sistematika tala Hrvatske, Hrvatska sveučilišna naklada. Zagreb, Croatia, pp. 1-371 (*in Croatian*)

ISO 10693:1995 (1995) Soil Quality - Determination of Carbonate Content, Volumetric Method, Geneva: International Organization for Standardization.

ISO 11461: 2001 (2001). Soil Quality - Determination of Soil Water Content as a Volume Fraction Using Coring Sleeves – Gravimetric Method, Geneva: International Organization for Standardization

ISO 10390:2005 (2005) Soil Quality - Determination of pH, Geneva: International Organization for Standardization.

ISO 11464:2006 (2006). Soil Quality - Pretreatment of Samples for Physico-Chemical Analysis, Geneva: International Organization for Standardization

ISO 11277:2009 (2009). Soil Quality - Determination of Particle Size Distribution in Mineral Soil Material. Method by Sieving and Sedimentation, Geneva: International Organization for Standardization

ISO 11272: 2017 (2017). Soil Quality – Determination of Dry Bulk Density, Geneva: International Organization for Standardization

ISO 11508:2017 (2017). Soil Quality – Determination of Particle Density, Geneva: International Organization for Standardization

Ivanović A., Sikirica V., Marković S., Sakač K. (1977). Osnovna geološka karta SFRJ 1:100 000, list Drniš K 33-9, Institut za geološka istraživanja, Zagreb, Savezni geološki zavod, Beograd. (*in Croatian*)

Ivanović A., Sikirica V., Sakač K. (1978). Osnovna geološka karta SFRJ 1:100 000, Tumač za list Drniš K 33-9, Institut za geološka istraživanja, Zagreb, Savezni geološki zavod, Beograd, pp. 1-59. (*in Croatian*)

JDPZ (1966). Priručnik za ispitivanje zemljišta. Knjiga I. Kemijske metode ispitivanja zemljišta, Beograd (*in Croatian*)

Kooijman A. M., Weiler H. A., Cusell C., Anders N., Meng X., Seijmonsbergen A. C., Cammeraat L. H. (2019). Litter Quality and Microtopography as Key Drivers to Topsoil Properties and Understorey Plant Diversity in Ancient Broadleaved Forests on Decalcified Marl. Sci Total Environ 684: 113-125

Markoski M., Mitkova T., Vasilevski K., Tomić Z., Tanskovik V. (2015). Moisture Retention Caracteristics in the Soil Formed upon Limestones and Dolomites in the Republic of Macedonia, Agric Conspec Sci 80 (1): 31-37

Mamužić P. (1971). Osnovna geološka karta SFRJ 1:100 000, list Šibenik, K 33-8. Institut za geološka istraživanja, Zagreb, Savezni geološki zavod, Beograd. (*in Croatian*)

McKenzie N., Coughlan K., Cresswell H. (2002). Soil Physical Measurement and Interpretation for Land Evaluation. Australian Soil and Land Survey Handbook Series, CSIRO Publishing, Australia, pp. 1-387

Medak J., Perić, S. (2007). Vegetation Characteristics of Krka National Park. In: Book of Abstracts of the Symposium Krka River and Krka National Park: Natural and Cultural Heritage, Protection and Sustainable Development (Marguš D., ed), Krka National Park, Šibenik, Croatia, pp. 917-932

Mihevc A., Prelovšek M., Zupan Hajna N. (2010). Introduction to the Dinaric Karst. Karst Research Institute at ZRC FSAZU, Postojna, pp. 1-72

Milković J., Trninić D. (2007). Meteorological and Hydrological Properties of the Krka River Basin. In: Book of Abstracts of the Symposium Krka River and Krka National Park: Natural and Cultural Heritage, Protection and Sustainable Development (Marguš D., ed). Krka National Park, Šibenik, Croatia, pp. 67–78 (*in Croatian*)

Munsell Color (2000). Munsell Soil Color Charts. Baltimore: Munsell Color Company.

Miloš B., Maleš P. (1998). Soils of Kaštela Bay and Problems of Their Protection. Agronomski glasnik 4: 185-204

Miloš B., Bensa A. (2014). A GIS Based Assessment of Agricultural Resources for Karstic Areas of the Adriatic Coastal Region. Agriculture and Forestry 60 (4): 135-141

Mrinjek E., Nemec W., Pencinger V., Mikša G., Vlahović I., Ćosović V., Velić I, Bergant S., Matičec, D. (2012). The Eocene-Oligocene Promina Beds of the Dinaric Foreland Basin in Northern Dalmatia. In: Marine to Continental Depositional Systems of Outer Dinarides Foreland and Intra-Montane Basins (Eocene-Miocene, Croatia and Bosnia and Herzegovina). 29th IAS Meeting of Sedimentology. Field Trip Guide, Topic Two: Promina Beds. (Vlahović, I. et al., Eds.). J Alp Geol 54: 413–455

Muhs D.R., Budhan J.R., Prospero J.M., Skipp G., Herwitz S.R. (2012). Soil Genesis of the Island of Bermuda in the Quaternary: The Importance of African Dust Transport and Deposition. J Geophys Res 117: F03025

Noulas C., Karyotis T., Charoulis A., Massas I. (2009). Red Mediterranean Soils: Nature, Properties, and Management of Rhodoxeralfs in Northern Greece. Commun Soil Sci 40 (1-6): 633-648

Pawlik Ł., Kasprzak M. (2015). Electrical Resistivity Tomography (ERT) of Pit and Mound Microrelief, Mt Rogowa Kopa Case Study, the Stołowe Mountains, SW Poland. Landf Anal 29: 41-47

Owens L. B., Watson J. P. (1979). Rate of Weathering and Soil Formation on Granite in Rhodesia. Soil Sci Soc Am J 43: 160-166

Pilaš I., Medak J., Vrbek B., Medved I., Cindrić K., Gajić-Čapka M., Perčec Tadić M., Patarčić M., Branković Č., Güttler I. (2016). Climate Variability, Soil, and Forest Ecosystem Diversity of the Dinaric Mountains. In: Sustainable Development in Mountain Regions (Zhelezov G., ed.). Springer, Cham, pp. 113-139

Polade S. D., Gershunov A., Cayan D. R., Dettinger M. D., Pierce D. W. (2017). Precipitation in a Warming World: Assessing Projected Hydro-Climate Changes in California and Other Mediterranean Climate Regions. Sci Rep 7: 1–10

Sanderman J., Hengl, T., Fiske G. J. (2017). Soil Carbon Debt of 12,000 Years of Human Land Use. Proceedings of the National Academy of Sciences of the United States of America 114 (36): 9575-958

Spaargaren O. (2008). Luvisols. In: Encyclopedia of Soil Science (Chesworth W., ed.). Springer, pp. 440-443

Šamonil P., Valtera M., Schaetzl R.J., Adam D., Vašíčková I., Daněk P., Janík D., Tejnecký V. (2016). Impacts of Old, Comparatively Stable, Treethrow Microtopography on Soils and Forest Dynamics in the Northern Hardwoods of Michigan, USA. Catena 140: 55-65

Stockmann U., Minasny B., McBratney A. B. (2014). How Fast Does Soil Grow? Geoderma, 216: 48–61.

Škorić A., Filipovski G., Ćirić M., (1985). Soil Classification of Yugoslavia", Akademija nauka i umjetnosti Bosne i Hercegovine, Sarajevo (*in Croatian*)

Škorić A., Adam M., Bašić F., Bogunović M., Cestar D., Martinović J., Mayer B., Miloš B., Vidaček Ž. (1987). Pedosphere of Istria. Projektni savjet Pedološke karte Hrvatske, Zagreb

Van Oost K., Quine T.A., Govers G., De Gryze S., Six J., Harden J.W., Ritchie J.C., McCarty G.W., Heckrath G., Kosmas C., Giraldez J.W., Marques da Silva J.R., Merckx R. (2007). The Impact of Agricultural Soil Erosion on the Global Carbon Cycle. Science 318 (5850): 626–629

Tari Kovačević V., Mrinjek E. (1994). The Role of Palaeogene Clastics in the Tectonic Interpretation of Northern Dalmatia (Southern Croatia). Geol Croat 47 (1): 127-138

Torrent J., Cabedo A. (1986). Sources of Iron Oxides in Reddish Brown Soil Profiles from Calcarenites in Southern Spain. Geoderma 37 (1): 57–66

Vingiani S., Di Iorio E., Colombo C., Terribile F. (2018). Integrated Study of Red Mediterranean Soils from Southern Italy. Catena 168: 129-140

Vitanović E. Vidaček Ž., Katalinić M., Kačić S. Miloš B. (2010). Journal of Food, Agriculture & Environment 8 (1): 268-274

Vrbek B., Pilaš I. (2007a). Soils of Krka National Park. In: Book of Abstracts of the Symposium Krka River and Krka National Park: Natural and Cultural heritage, Protection and Sustainable Development (Marguš D., ed). Krka National Park, Šibenik, Croatia, pp. 949-977

Vrbek B., Pilaš I. (2007b). Contribution on Knowledge of Štirovača Soils on Velebit, Radovi –Šumarski institut Jastrebarsko 42 (2): 155-166

Vučetić V, Bajić A (2008). Wind. In: Climate Atlas of Croatia 1961–1990, 1971–2000 (Zaninović K., ed). Državni Hidrometeorloški Zavod, Zagreb, Croatia, pp. 111–116)

Wakatsuki T. Rasyidin A. (1992). Rates of Weathering and Soil Formation. Geoderma 52(3-4): 251-263

Weil R. R., Brady C. N. (2017). The Nature and Properties of Soils, Pearson, Boston, USA, pp. 1-1104

Yallon, D. H. (1997). Soils in the Mediterranean Region: What Makes Them Different? Catena 28 (3-4): 157-169

Zaninović K. (2007). Climate and Bioclimate of the Krka National Park. In: Book of Abstracts of the Symposium Krka River and Krka National Park: Natural and Cultural Heritage, Protection and Sustainable Development (Marguš D., ed). Krka National Park, Šibenik, Croatia, pp. 67–78

Zupan Hajna N. (2012). Dinaric Karst—Geography and Geology. In: Encyclopedia of Caves (White W.B., Culver D.C., Pipan T., eds.). Academic Press, pp. 353-362

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