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Soil properties in beech-fir forests on Mt. Medvednica (NW Croatia)*

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Abstract

Background and Purpose: *Beech-fir forests in Croatia have very broad edaphic amplitude. On Mt. Medvednica they are predominantly developed on dystric cambisol, but also, to a smaller extent, on several other soil types. The purpose of this paper was to investigate soil properties in these forests and establish relations with pedogenetic factors, and especially with the bedrock and the relief.*

Materials and Methods: *Research was based on the study of 14 soil profiles and soil samples from the horizons, and on the analysis of 39 composite samples from the surface 5 cm of soil. The following parameters were assessed from the samples: pH in water and 0.01 M $CaCl_2$, the carbonate content, and the content of biogenic elements Org C., Total N, P, K, Ca and Mg, as well as the texture of profile samples.*

Results: *Dominant soils in beech-fir forests on Medvednica are dystric cambisol and eutric cambisol. Most of the profiles are situated on moderately steep and steep slopes, so their A-horizon is colluvially influenced. All profiles were shallower than 100 cm, except for the stagnosol profile. The most variable parameter in the surface 5 cm was organic carbon, ranging from 40.9 to 367.2 g kg^{-1}, whereas the pH value measured in water suspension oscillated between 3.69 and 7.21 and corresponded with the calcium content in the soil, with carbonate substrates in the central part of the range and with carbonate quantity in the soil.*

Conclusions: *The distribution range of beech-fir forests on Mt. Medvednica is highly complex both from the pedogenetic and pedophysiographic aspect. It provides a good basis for the application of more complex models of spatial prediction of soil properties, but also for phytocoenological and ecological management profiling of beech-fir forests.*

INTRODUCTION

Beech-fir forests in Croatia have very broad edaphic amplitude. They are distributed on leptosols, regosols, cambisols, luvisols and podzols *(19, 20)*. The specific population of these forests, in the sense of vegetation, phytocoenology and pedology, are Pannonian beech-fir for-

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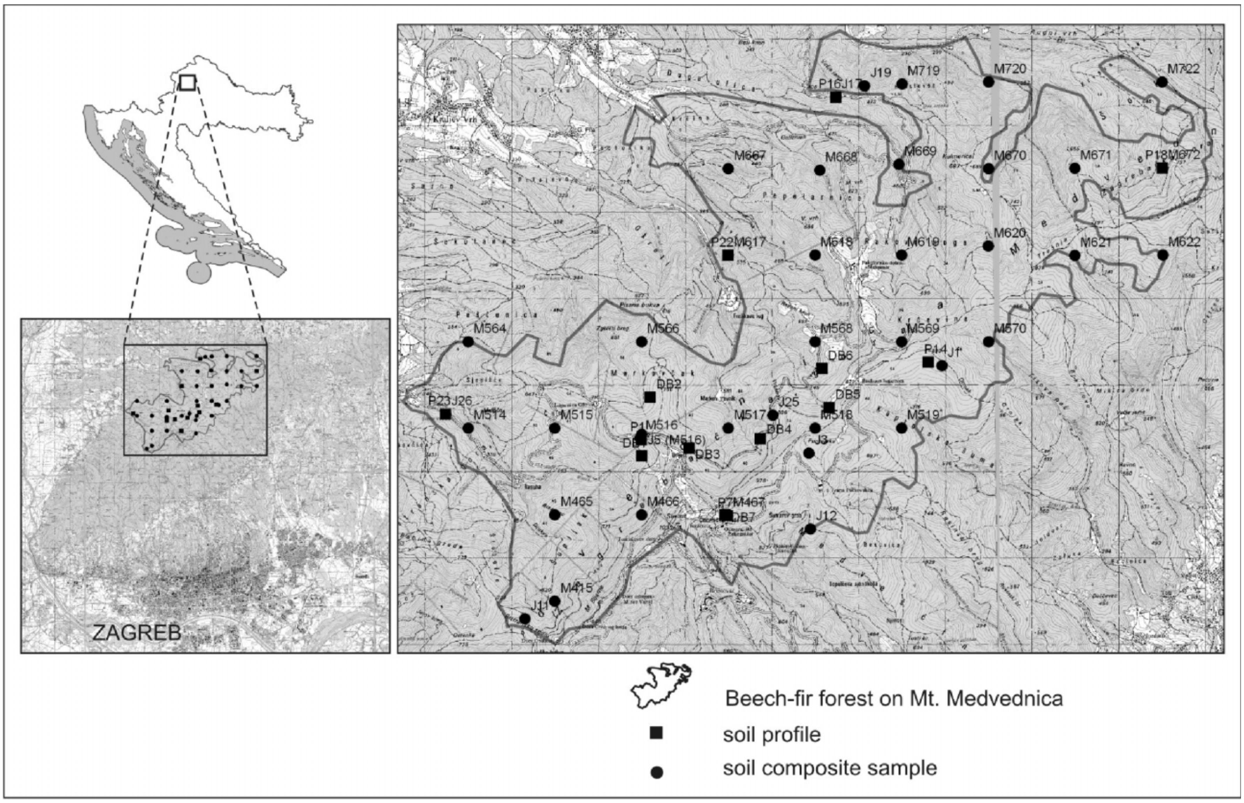

Figure 1. *Position of Medvednica and research points.*

ests, and particularly beech-fir forests growing on Mt. Medvednica. In addition to their commercial function, the latter also have numerous non-commercial functions.

Medvednica is a mountain situated in the north-western part of Croatia, north of Zagreb (Figure 1). It is a predominantly wooded complex with about 22,000 ha of forests. Forests extend from 150 m above the sea to the very top (Sljeme – 1,035 m) in the central part of the massif. Beech-fir forests cover the north-facing slopes of Medvednica, whereas on the south-facing slopes they only grow on the ridge of the main crest. Phytocoenologically, they are defined as beech-fir forests with roadside fescue (*Festuco drymeiae-Abietetum*) with two subassociations: lunarietosum redivivae and festucetosum drymeiae *(28)*. They are mainly distributed at altitudes between 650 and 1,000 m, but on northern slopes they grow down to as low as 200 m above the sea. According to *(23, 26)*, this is probably the lowest point in Croatia in which fir occurs naturally. Within the distribution range of these forests there are numerous edaphically conditioned enclaves in which fir is absent due to specific ecological relationships *(22)*. Although they are floristically relatively well investigated *(5, 10, 11, 12, 13, 14)*, their plant-sociological profile was only established in some recent research *(5, 28)*. The diversity of climatic, relief and edaphic factors is responsible for relatively complex ecological relationships *(5, 17, 18)*. This situation corresponds with the complexity of pedogenetic processes and consequential soil properties.

RESEARCH AREA

Mt Medvednica has a very complex tectonic, geological and lithological structure. Šikić *(24)* and Herak *(9)* gave a detailed illustration of its investigated status. From the mining aspect, this mountain has aroused interest since the middle ages *(4, 25)*, as indicated by numerous traces of raw mineral mining. More recently, a comprehensive insight into lithological basis and its role in the geochemistry of Medvednica has been provided by geochemical research *(6, 8)*. The lithological composition of beech-fir forest range on Medvednica is characterized by 4 lithological complexes: parametamorphites, orthometamorphites, magmatites and clastic sediments. The top ridge is predominantly composed of orthometamorphites, among which the most represented is greenschist related to gabbroic-dioritic rocks (basic to neutral rocks). The northern slopes are basically characterized by interbeds of carbonate sediments, and in the bottom part by the significant participation of basic magmatities. In the limestone complex, the most frequent lithological member are different varieties of recrystallized limestones (breccias) and marbles, alternating with cretaceous sandstones and siltities with shales *(7)*. Magmatic complex contains quartz diorites, diorites and quartz keratophires (Upper Paleozoic), and gabbro, basalt, diabase and spilites (the Mesozoic Era). Medvednica is an elongated mountain with relatively steep side slopes which extends in the SW-NE direction. The main ridge is also the starting point for a number of vertically positioned lateral

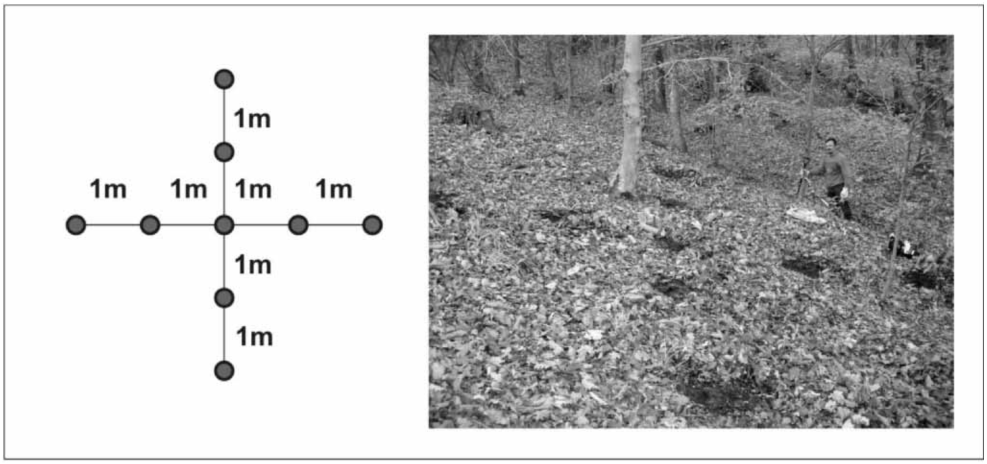

Figure 2. *Pattern of forming the composite sample of the surface 0–5 cm soil layer.*

ridges, formed by deep incisions of numerous stream beds. Apart from tectonics, such orographic features were also caused by exodynamic processes related to specific weathering patterns of some rocks (impermeability and moderate weathering of magmatites and metamorphites).

Medvednica is characterized by a temperate continental climate. In the beech-fir area it is humid to perhumid, with the average precipitation quantity of 900–1,000 mm in the lowest parts of the range and 1,200–1,250 mm in the top part. Precipitation maximums fall in the second part of spring and in the second part of summer. Mean annual temperature is the lowest in the top part of Medvednica (6.5 °C), while in the bottom part of the range it is ~ 9 °C.

Research to date by Kovačević *et al. (15, 16),* Vrbek *(27)* and Bakšić *(1)* have shown that the most represented soil in beech-fir forests of Medvednica is dystric cambisol. It is loamy soil, with very acid to acid reaction, predominantly medium deep and skeletal (10–30% skeleton). Based on field research and analyses of relations between pedogenetic factors, Pernar *(19)* also lists regosol, luvisol and eutric cambisol. Related to the lithological diversity of the beech-fir forest range on Mt. Medvednica, we set up a goal of obtaining a better insight into the soil physiography of the area, with special emphasis on the surface 5 cm of soil and, on the other hand, of studying and identifying the role and participation of vegetation and relief in soil pedogenesis and physiography.

MATERIAL AND METHODS

Seven pedological profiles were opened in the distribution range of beech-fir forests within pedological research in the Medvednica area. The research included soil physiography and geochemical relationships in the function of parent material, relief, vegetation and soil physiography itself. The profiles were opened for the purpose of investigating the morphology and pedogenetic relationships, as well as for sampling the soil by horizons. The samples were prepared according to the prescribed HRN norms, and the following elements were determined: texture, the pH value in water and 0.01 M $CaCl_2$, the carbonate content, and the content of biogenic elements Org. C., Total N, P, K, Ca and Mg. The sites of 39 locations were simultaneously described and the surface 5 cm soil layer was sampled. To sample the surface mineral soil layer (beneath the forest floor), a composite sample was formed from 9 individual samples distributed in vertical directions 1 m apart from each other (there were 5 points in each direction, of which the central point was joint – Figure 2). Sampling was done with a probe with an internal diameter of 8 cm. The pH value in water and 0.01 M $CaCl_2$, the carbonate content, and the content of biogenic elements Corg., N, P, K, Ca and Mg were determined in samples.

Laboratory data of soil sample analyses were processed at the level of descriptive statistics, linear correlation and spatial interpolation (soft. Statistica 7.1 and ArcMap 9.3). Data from 7 previously analyzed pedological profiles were also processed *(1)*.

RESULTS AND DISCUSSION

In the overall sample of 14 pedological profiles (Figure. 1 – research area, Table 1) in the range of beech-fir forests on Medvednica, 8 profiles represented dystric cambisol, 5 profiles represented eutric cambisol and 1 profile represented stagnosol. On steeper slopes, the profiles in the surface part are regularly contaminated by material from the upper parts of a slope which is responsible for varying degrees of colluvial character. Evidently, such numerical soil ratios in the sample do not fully correspond to the actual participation of soils in the entire range (the soils on limestones and limestone breccias are missing, and so are the soils at the bottom of very steep slopes – regosol, as well as illimerized deep soils of flat or mildly sloping positions – luvisol). However, the fact that eutric cambisol also participates amply in the pedosphere of these forests is striking. Actually, literary sources primarily mention brown forest soil *(15, 16),* dystric cambisol *(1, 2, 28)* while eutric cambisol is only mentioned

TABLE 1

Results of analyses of soil samples from soil profiles.

Pro-file	Soil type	Horizon	Horizon thickness	Particle size distribution * 2.0–0.2mm	0.2–0.02mm	0.02–0.002mm	<0.002 mm	pH (H_2O)	pH ($CaCl_2$)	Org C g kg^{-1}	Total N g kg^{-1}	$CaCO_3$ g kg^{-1}	Ca g kg^{-1}	Mg g kg^{-1}	K g kg^{-1}	P g kg^{-1}
P1	CM(dy)	Aoh	17.5	7.5	30.6	60.7	1.1	4.64	4.08	89.7	7.2		1.6	4.0	0.9	1.2
		(B)v	30.5	10.0	26.8	59.1	4.0	4.92	4.15	46.4	3.2		0.7	5.8	0.7	0.8
P7	CM(eu)	Aoh	8	14.2	35.1	47.3	3.5	4.16	3.52	76.8	6.8		1.0	6.1	0.6	0.6
		(B)v	72	11.0	32.3	55.6	1.0	5.82	4.80	22.5	2.0		1.0	8.8	0.5	0.5
P14	CM(eu)	Aoh	4	12.0	21.3	59.7	7.0	3.83	3.24	162.0	9.9		0.5	6.0	0.6	0.9
		(B)v	31	16.5	22.3	57.5	3.6	6.30	4.95	39.5	3.1	43	0.2	8.6	0.5	0.7
P16	CM(eu)	Aoh	4	2.2	57.2	20.0	20.6	5.87	4.92	88.9	5.5		2.8	5.9	0.8	0.5
		(B)v1	31	3.4	33.6	61.9	1.1	5.33	4.80	2.9	0.6		0.6	6.2	0.4	0.2
	CM(eu)	(B)v2	55	2.2	51.2	46.6	0.0	5.53	5.21	0.0	0.4		0.2	6.8	0.7	0.2
		(B)v3,g	25	9.4	23.4	63.4	3.8	5.60	4.75	0.0	0.3		0.1	7.1	0.9	0.3
P18	CM(eu)	Aoh	13.5	14.0	21.0	59.2	5.8	6.63	5.93	60.8	5.3	39	5.1	3.4	0.6	0.4
		(B)v	71.5	22.4	17.2	54.0	6.4	7.42	7.00	0.0	0.7	30	2.6	4.4	0.5	0.2
P22	CM(eu)	Aoh	10	21.7	24.2	49.0	5.1	5.69	5.12	112.8	6.5		13.0	11.9	0.6	0.4
		(B)v	45	5.6	31.2	53.5	9.7	6.72	5.50	17.6	1.1	44	11.0	19.5	0.3	0.3
	ST	Aoh	6	19.0	29.6	50.5	1.0	6.88	6.53	19.4	1.4	48	2.4	4.3	0.8	0.3
P23		E	21.5	23.4	28.4	46.3	1.9	6.99	6.66	13.5	0.9	39	2.8	4.7	0.9	0.3
		Bg1	31	10.6	29.2	60.0	0.2	6.56	5.66	0.0	0.1	44	1.1	5.4	0.8	0.2
		Bg2	61.5	8.8	33.4	57.7	0.1	6.72	6.17	0.0	–	65	1.7	5.4	1.1	0.3

Pro-file	Soil type	Hori-zon	Horizon thickness	Particle size distribution ** 2,0–0,2 mm	0,2–0,02 mm	0,02–0,002 mm	<0,002 mm	pH (H_2O)	pH ($CaCl_2$)	Org C g kg^{-1}	Total N g kg^{-1}	Ca^{2+} cmol(+) kg^{-1}	Mg^{2+} cmol(+) kg^{-1}	K^+ cmol(+) kg^{-1}	Na^+ cmol(+) kg^{-1}	CEC cmol(+) kg^{-1}	BS %
DB1	CM(dy)	Aoh	12	24.2	27.0	32.0	16.8	4.27	3.75	80.3	6.9	0.75	0.05	0.76	0.35	9.49	20
		(B)v	28	21.8	15.1	39.9	23.2	4.54	4.09	48.1	2.1	0.29	0.02	0.60	0.37	7.15	18
DB2	CM(dy)	Aoh	10	9.1	39.5	34.5	16.9	4.43	3.95	87.2	2.4	0.84	0.05	0.99	0.35	8.57	26
		(B)v	40	8.6	30.0	38.4	23.0	4.48	3.95	27.2	1.2	0.17	0.01	0.61	0.36	7.75	15
DB3	CM(dy)	Aoh	12	32.9	31.1	23.7	12.3	4.41	3.73	95.9	4.9	0.96	0.04	0.84	0.31	8.42	26
		(B)v	38	24.2	21.5	33.4	20.9	5.02	4.29	18.9	1.4	0.21	0.01	0.65	0.30	4.21	28
DB4	CM(dy)	Aoh	10	14.3	39.0	30.5	16.2	4.45	3.80	149.1	11.5	0.66	0.05	0.94	0.33	6.92	29
		(B)v	35	22.4	24.4	37.3	15.9	4.72	4.08	57.6	3.4	0.14	0.02	0.44	0.35	6.56	14
DB5	CM(dy)	Aoh	8	23.8	38.8	25.6	11.8	4.10	3.53	117.9	8.5	0.47	0.04	0.94	0.50	7.16	27
		(B)v	28	20.8	22.0	38.8	18.4	4.78	4.15	20.1	2.8	0.16	0.01	0.59	0.38	4.58	25
DB6	CM(eu)	Aoh	12	12.0	36.6	35.0	16.4	4.72	4.05	104.3	4.9	6.05	0.05	0.88	0.40	11.46	64
		(B)v	38	11.7	23.0	34.6	30.7	6.96	6.28	10.8	1.2	9.24	0.05	0.64	0.42	11.00	94
DB7	CM(dy)	Aoh	10	12.0	50.6	23.5	13.9	4.17	3.65	107.6	5.5	2.81	0.05	0.88	0.38	12.78	32
		(B)v	55	10.0	34.3	38.8	16.9	5.05	4.24	23.5	2.6	0.95	0.03	0.60	0.43	6.29	32

* Particle size distribution – ISO 11277
** Particle size distribution – International B method
Exchangeable Cations – extraction with $BaCl_2$ – (ISO 11260)

CM(dy) – cambisol dystric
CM(eu) – cambisol eutric
ST – stagnosol

Org C – organic carbon
Total N – total nitrogen

sporadically *(1, 19)*. Such participation of eutric cambisol in the pedosphere of these forests is more easily understood in view of the fact that, apart from carbonate substrates, there are predominantly substrates which are either derivatives of basic magmatites or are originally basic magmatites (gabbro, diabase). It is interesting that the pH value of the A horizon of both dystric and eutric cambisol is very acid to acid (Table 1). In this respect there are almost no differences between these soils. This phenomenon is associated with bioclimatic impacts on the surface part of the soil which compensates for original lithological differences, whereas properties which show better correspondence with mineralogical and chemical features of the rock have been retained in the deeper parts of the soil. The exception is eutric cambisol on a very steep slope, which is evidently contaminated with carbonate detritus from the top part of the slope (profile 18), is of colluvial character and therefore has some essential characteristics of regosol. As a rule, such bioclimatic effects in beech-fir forests are marked by eluvial-illuvial processes that lead to leaching and acidification of surface soil. The resulting consequence is a base-poor humus-accumulative horizon, usually occurring in the ochric modification, of acid to very acid reaction, with a frequently underlying B horizon rich in base cations in the adsorption complex and the pH value in water higher than 6.

In terms of texture, the soil in all profiles was predominantly silty to fine-sandy loam. This property does not necessarily reflect ecological diversity in the range of beech-fir forests. Stagnosol, represented in the lowest, flat to mildly sloping concave positions in the northern part of the range, does not differ much texturally from the majority of cambisol profiles, except for being significantly deeper. It should be pointed out that the majority of profiles are of skeletoidal character. Some have a higher skeleton content from the very surface downward, or surface horizon and soil surface are enriched with transported detritus.

In view of distinct phytodiversity of beech-fir forests on Medvednica, it is evident that soil chemism, particularly that of the humus-accumulative horizon, and hydrothermal properties of the soil play a decisive role in clarifying synecological relations in beech-fir forests on Medvednica. High variability of A horizon depths, combined with different anthropogenic influences, are responsible for exceptional complexity of these relations *(21)*.

Pedogenetic and pedophysiographic features in the range of beech-fir forests on Medvednica reflect the intricate complexity of ecological relations in these forests. One of the most important factors of such complex relations is relief which, in synergy with lithological substrate (especially rock weathering), has a decisive role in matter redistribution in the surface part of soil, particularly on steeper slopes. In such a complex area in terms of lithology, the impact of relief strongly contributes to general geochemical complexity of the area *(6, 7)*. This is best seen in the transport of mineral materials to lower positions, »contaminating« in the process the soil mainly developed from a profoundly different substrate (e.g contamination of soil on schists with detritus of limestone breccias and vice versa – a good example is profile P18).

Research of Jelaska *(10)* and Jelaska *et al. (11)* provided a very significant contribution to the study of soil – vegetation relationship on Medvednica. Their investigations were based on the MTB network of 0–10 cm soil samples and floristic parameters. Our research was limited to the shallower (5 cm deep) surface soil part and was aimed at determining the spatial distribution of trace elements in the entire Medvednica area, as well as determining the anthropogenic, relief and vegetational influence on this distribution.

The analysis of soil samples from 39 localities (Figure 1) showed that the pH value was highest in the Mélišće – Markov Travnik – Kulmerica – Bukovje direction (Figure 3). Here, the pH of the surface 5 cm of soil ranged between 5.1 and 7, and occasionally even exceeded 7.2. This is the area of spreading of carbonate sediments, from limestones and limestone breccias in the western and central part of the range, to marls in the north-easternmost part. In the easternmost part of the range, in the area of the Medvednica transversal, the values of pH also exceeded 6.1. This is a narrow area in which carbonate sediments with their weathering on the Medvednica ridge enrich the soil on northern slopes with carbonate detritus. These sediments further extend toward the south-east of Medvednica.

The lowest pH values of the surface part of the soil were found in the peak part of Medvednica, i.e. along the south-eastern part of the beech-fir range. Here, the pH in water rangeed from 3.7 and 5.0 (except for the already mentioned deviation in the easternmost part). The lowest measured pH value of the surface 5 cm of soil was 3.69 (3.05 in 0.01 M $CaCl_2$), and the highest was 7.21 (6.76 in 0.01 M $CaCl_2$). The organic carbon content in the surface part of the soil manifested exceptionally high variability (Table 2).

It ranges between 40.9 and as much as 367.2 g kg^{-1}. The arithmetic means was 105 g kg^{-1}, with 80 to 120 g kg^{-1} in most of the range. The highest values are associated with colluvial effect on the accumulation of organic matter or with moder humus in localities with a low pH value. It is this phenomenon that is responsible for relatively low correlation between pH values and organic C content (r 0.36).

The phosphorus content of the surface 5 cm of soil was between 0.29 and 1.37 g kg^{-1}, and the arithmetic mean was 0.6 g kg^{-1}. Its highest values were in the top ridge area (between Sljeme and Rauhova Lugarnica), where they predominantly ranged between 0.4 and 1.2 g kg^{-1}.

The potassium content of the surface 5 cm of soil oscillated between 0.2 and 1.9 g kg^{-1}, and its arithmetic mean was 0.7 g kg^{-1}. The highest concentrations were recorded in the western part of the range up to Markov Travnik. P and K concentrations showed relatively low variability in the research area, lower than those of C, Ca and Mg.

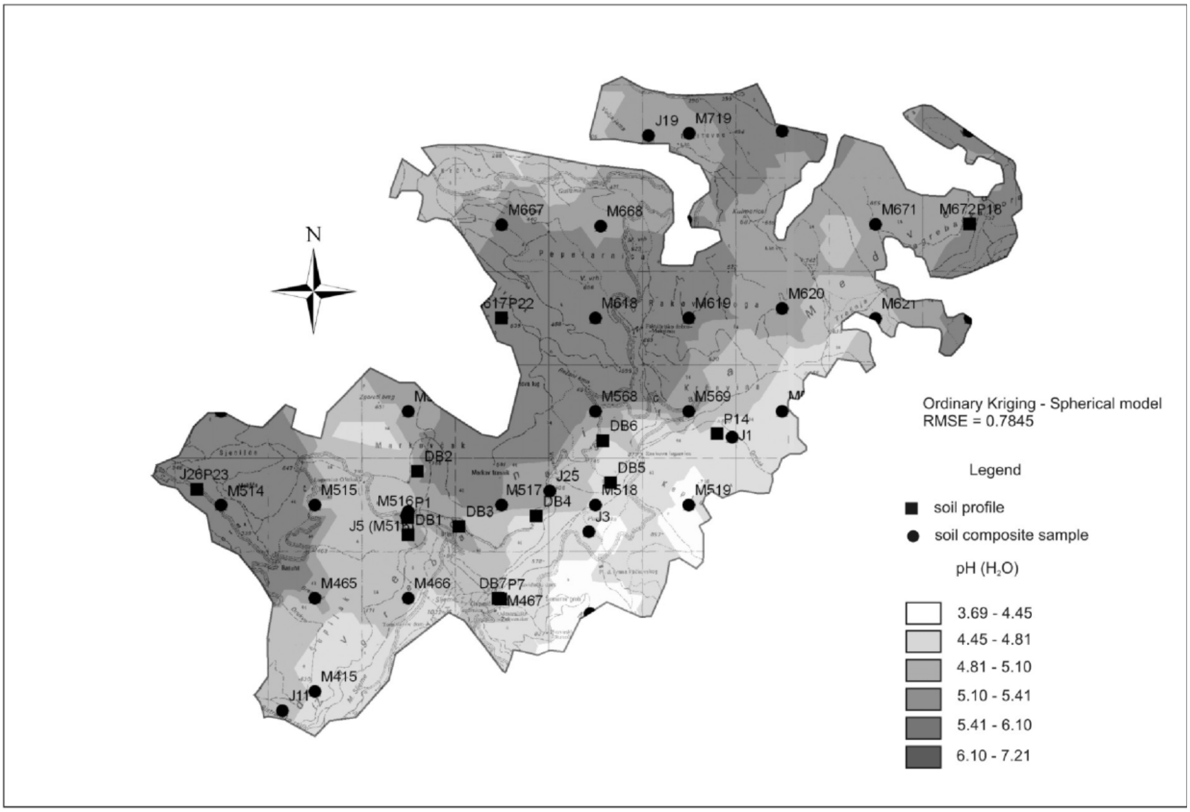

Figure 3. *Spatial distribution prediction map of pH value in soil surface layer (5 cm depth) on beech-fir forests on Mt. Medvednica.*

TABLE 2

Descriptive statistics of the soil surface layer (5 cm depth).

Variable	Unit	Valid N	Mean	Minimum	Maximum	Std. Dev.
pH (H_2O)		39	5.13	3.69	7.21	0.78362
pH ($CaCl_2$)		39	4.49	3.05	6.76	0.78070
CaCO	g kg^{-1}	6	32	16.90	39.29	9.95940
Org C	g kg^{-1}	39	104.6	40.90	367.20	61.88607
Total N	g kg^{-1}	19	6.3	1.30	14.90	3.09444
Ca	g kg^{-1}	39	3.6	0.30	13.00	3.29051
Mg	g kg^{-1}	39	6.2	0.60	14.90	3.80216
K	g kg^{-1}	39	0.7	0.20	1.90	0.32321
P	g kg^{-1}	39	0.6	0.29	1.37	0.29286

The calcium content in the surface soil part was distinctly variable and ranged between 0.3 and 13.0 g kg^{-1}. Increased Ca concentrations in the soil were linked with carbonate substrate and relatively well corresponded with the pH value (r=0.57, and 0.61, respectively). The Ca content corresponds with the spreading of carbonate substrates on the NW slopes of Medvednica. Its highest values correspond with the highest pH values in the area of Markov Travnik and Faculty Estate (Figure 4).

The magnesium content also shows very high variability. It ranged between 0.6 and 14.9 g kg^{-1}. Its arithmetic mean was 6.2 g kg^{-1}, and it achieved the highest values in the central part of the range. The Mg content does not show almost any association with other measured parameters, except with calcium.

In general, the distribution of the analyzed elements (P, K, Ca and Mg) in the surface part of the soil reflects to a certain extent the chemical composition of bedrock. The only exception is phosphorus whose concentration in the soil is primarily determined by biogeochemical processes in pedogenesis.

These investigations confirmed the complexity of ecological relations in the distribution range of beech-fir for-

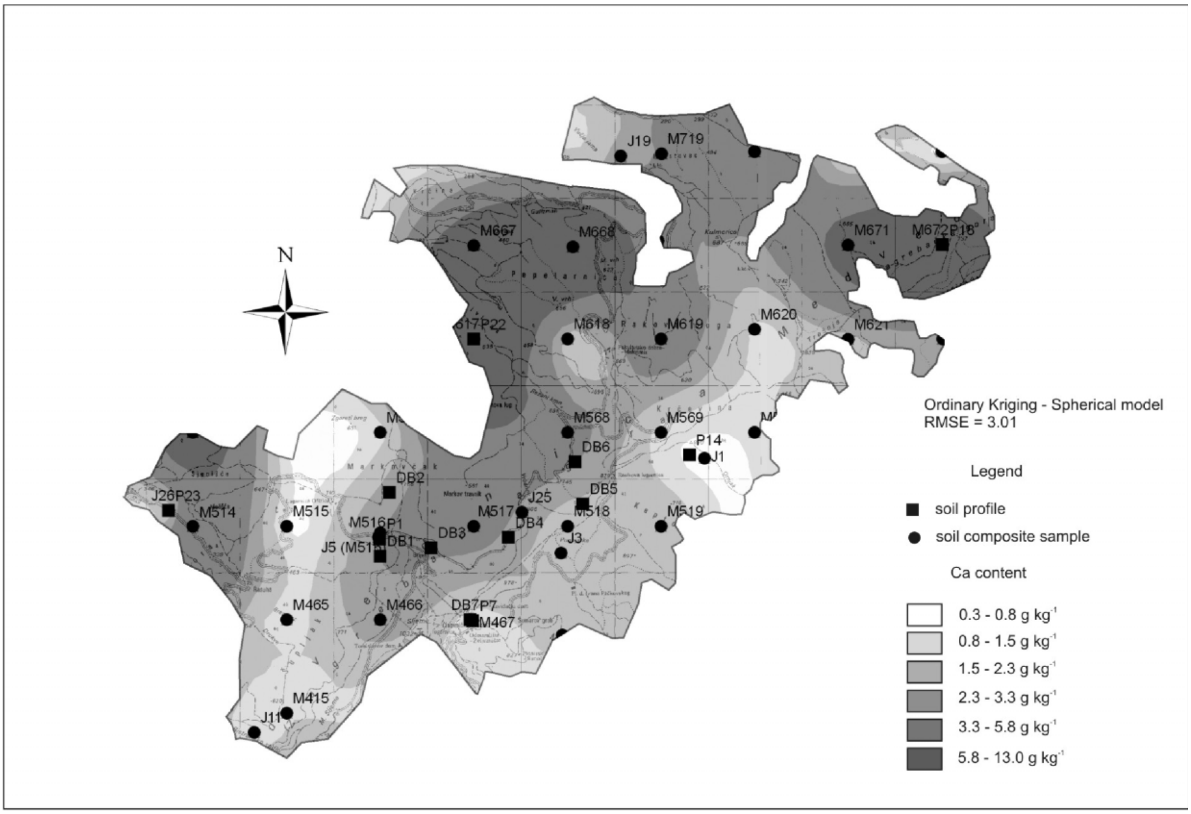

Figure 4. *Spatial distribution prediction map of Ca content in soil surface layer (5 cm depth) on beech-fir forests on Mt. Medvednica.*

ests on Medvednica. Clearly, these relations are directly reflected on the physiognomy of the forest and especially on the layer of ground vegetation *(5, 11, 13)*. This will allow further taxonomic profiling of these forests, but also the application of model *(3)* which will enable better spatial prediction of soil properties.

CONCLUSIONS

With regard to the physiographic diversity of soil in the entire range of beech-fir forests on Medvednica, the following should be taken into account:

1.Apart from dystric cambisol, eutric cambisol also participates significantly in the pedosphere of beech-fir forests on Medvednica;

2.Taking into account entire soil profile, diversity in the surface part of soil mostly does not correspond with the diversity of features in the deeper parts of soil. The reasons are bioclimatic and relief impacts which counterbalance very complex lithological relations in the structure of Medvednica and their dominant role in soil formation and development; this is why the soil profile frequently manifests colluvial character;

3.The lowest pH values in the surface part of soil are characteristic for the peak ridge of Medvednica, while the highest values correspond relatively well with increased soil Ca contents in the central and northern part of the range on north-western slopes of the mountain. The highest diversity in the surface soil part was shown by organic carbon content, and the lowest by potassium content; the high diversity of organic carbon is connected with the surface matter redistribution, with the forest floor receiving the strongest impacts;

4.The distribution range of beech-fir forests on Medvednica is highly complex both from pedogenetic and pedophysiographic aspect. It is ideal for the application of complex models of spatial prediction of soil properties, but also for phytocoenological and ecological-management profiling of beech-fir forests.

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