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Results of ecological research in the area of the National astronomical observatory "Rozhen"

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Abstract

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The aim is to present results of ecological research in the area of the National astronomical observatory "Rozhen", to evaluated the chemical status of soils and predict possible changes over time. The ecological research, conducted in the region of Rozhen – Central Rhodopes, near the National Astronomical Observatory "Rozhen", revealed a degradation process in the *dystric* Cambisols from the high mountain zone at an altitude of 1750 m. The soil-forming process occurred on a strongly rugged relief and acidic silicate rock – gneiss, at an average annual temperature of 3.50°C. The tree stands are of natural origin – *Picea abies* (L.) Karsten. The dominant soil-forming process was a progressive acidification – the pH_{CaCl2} values varied in the range from 3.98 to 4.83. The analysis showed that the vertical migration of basic cations exceeded the soil profile depth. Their values were high only in the forest litter, while in the surface 5 cm mineral layer the cations sharply decreased – 4 times for the exch. Ca and 2 times for the exch. Mg, respectively. The contents of exch. K and Na were also significantly decreased. The degradation process was also represented by changes in the cationic capacity. It was determined that the exch. Al occupied 26 % of the soil cationic capacity in the layer 0-5 cm, 73 % in the layer 5-10 cm, 85 % in the layer 10-20 cm, 81 % in the layer 20-40 cm, and 86 % in the layer 40-80 cm, respectively. The mobility of microelements was high, and the content of Cu in the forest litter was evaluated as increased above the toxicity level. The soil-forming processes led to soil depletion and the progressive acidification was defined as the main risk factor. It was assumed, that this is a naturally occurring process due to the lack of industrial sources of immissions in the area. The high acidity was assessed as a risk factor which should be monitored over time.

Keywords: ecological research; forest soil; spruce; landscape; cation exchange capacity

Introduction

Soils in forest territories are subject of long-term observations which allow the collection of information related to the evaluation of their status and changes occurring over time. At the European level, the observations are performed on key indicators, representing ongoing changes occurring due to changes in climate and environment (Cool N., & De Vos B., 2016; Seidling et al., 2017). Acidification is one of the most characteristic effects on soils in the conditions of atmospheric air pollution since the mid XX century. Studies carried out in many countries proved that process, and the increased deposition of acidic atmospheric depositions was determined as the main reason (Ulrich, 1983; Vitousek et al., 1997; Koptsik et al., 1998, Erisman, 2011; Winfried et al., 2012, etc.). A number of data connected with the forest ecosystem risk assessment were published (Stefan, K. et al. 1977; Vanmechelen et al.1997; Vries et al., 2000). These studies were aimed at investigating the combined effect of atmospheric pollutants and meteorological indicators, which lead to deterioration of soil conditions under the impact of processes such as acidification, buffer range changes, changes in the org.C/N ratios, deterioration of the nutritional status of woody plants, etc. According to some researchers of the forest territories (Kulhavý et al., 2009; Beck, 2009), the increase in temperatures leads to increased effect of acidic depositions. The acidification process also occurs in high-mountain soils, which are located away from industrial pollution sources. It was determined in soils developed on both carbonate and acidic rocks. In the presence of carbonate rocks, buffering was carried out by the calcium carbonate, and in acidic rocks – by weathering of silicate materials and the exchange of protons with basic cations (Ulrich, 1980; Ulrich, 1983; Rainer et al., 2021). The most common indicators of these changes are the pH values, loss of basic cations, decrease in base saturation, release of exchanged aluminum, mobilisaiton of heavy metals, inhibition of microbial activity, delayed decomposition of organic matter, etc. Due to the numerous factors causing these processes, the degradation can be specified and classified as ecological, chemical, physical and biological (Rainer, et al., 2021). The authors pointed out the loss of organic matter and nutrients, decreased pH, pollution, etc., as the main indicators of these processes.

In Bulgaria, information about these degradation processes is collected at permanent sample plots (PSP) for conducting ecological studies. Intensive monitoring has been carried out since 1989 (Kolarov et al. 2002; Pavlova, 2005 a; Pavlova, 2005; b etc.) as a part of the European network "International Co-operative Programme on Assessment and Monitoring of Air Pollution Effects on Forests". The observations are performed on a large set of soil parameters in a small number of PSP.

The aim is to present results of ecological research in the area of the National astronomical observatory "Rozhen", to evaluate the chemical status of soils and predict possible changes over time. It is assumed that the parameters that determine the sensitivity of soils in forest territories to acidification, i.e. altitude, soil-forming rock, precipitation, etc., are also an important indicator.

In the period 1989 – 2004, in Bulgaria were established three ecological field stations in the localities of Vitinya, Yundola and Staro Oryahovo. Results for the soils in them have been successively published over time by Malinova (2002), Malinova (2005), Malinova (2009), Malinova (2012), etc. In the period 2014-2019, another PSP was established in the Rozhen area, and this publication presents the results obtained so far from it.

Subject and Method

PSP Rozhen was established for the purpose of long-term monitoring of indicators which allow the assessment of changes in soil occurring under the effect of environmental pollution and climate changes. Harmonized sampling and comparable analytical assessment methods, used in the European countries, are applied (Cools N. & De Vos B., 2020).

PSP is located in the Central Rhodopes. According to the Physico-geographical landscape zoning of Bulgaria (Georgiev, 1982), the respective area is the Western Rhodope region of Osogovo within the Rhodope zone. The climate is typical high-mountainous with an average annual temperature of 3.50°C. The minimum temperature values from October till May are subzero. The coldest month is February with an average temperature of -7.10°C, and the warmest one is July with an average temperature of 13.30°C. The duration of the stable snow cover is approximately 140 days.

The highest point is the "Sveti duh" peak – 1759 m. The relief is strongly rugged, combining significantly elevated ridges in different directions with a deep and complex valley network (Georgiev 1977; 1979). The core of the crystalline base is composed of Hercynian granite and granodiorite batholith, and the mantle – of of pre-Paleozoic and Paleozoic metamorphites, represented by gneisses, mica shales and marbles (Galabov 1956; 1966). The diverse geomorphological activity and the complex geological structure are a prerequisite for the presence of contrasting ecological conditions and formation of different landscapes. For the purposes of the study, an area with acid silicate rocks – gneisses, which are a prerequisite for the natural acidification of the soils in the area, was selected.

The soil formation process occurred at an altitude of 1745 m. Climatic conditions at this altitude determine a short period of the year for the soil formation process. The exposure is west. The stand is of natural origin and is the typical representative species of the region – *Picea abies* (L.) Karsten.

The area is representative of the forest ecosystems, whose specific characteristics are determined by the spruce forests in the region. They are also the main receptor of solar energy.

There are no industrial sources of environmental pollution in the area and this is a reason to assume that the landscape structure is sustainable over time. The current state of the parameters, analyzed in the present study, are formed over a long period of time. Currently, no data regarding these parameters can be found in the scientific literature.

Laboratory analyses of the observed soil parameters were carried out by the Executive Agency for the Environment towards Ministry of Environment and Waters in connection with the implementation of the International Co-operative Programme on Assessment and Monitoring of Air Pollution Effects on Forests (ICP Forests) – Level II, within the framework of the Convention on Long-range Transboundary Air Pollution of the United Nations Economic Commission for Europe: organic carbon – ISO 10694, total nitrogen – ISO

13878, exchangeable cations – ISO 11260 and exchangeable acidity – ISO 14254.

Results and Discussion

The morphological description of the soil profile defines its structure as O-A-B-BC. The soil is developed on acidic silicate rocks – gneisses. In the morphological structure of the forest litter there is a clearly defined separate layer – L (litter). The transition to the mineral soil is gradual – through the F layer (fragmented). No separate H (humus) layer is determined. Forest litter can be classified as a moder type. Its mass is high – 2.10 kg.m^2 for the L layer and 3.55 kg.m^2 for the F layer, respectively, which indicates delayed decomposition processes of the organic matter. According to Ulrich et al., (1983) and Drábek et al., (2005) the forest litter depth and the amount of exch. Al are important indicators of adverse soil changes, hence, they should be subject to long-term monitoring and evaluation.

The surface soil horizon has a soil depth of 7 cm. It is coloured in dark brown – 10 YR3/2 (Munsell 10YR Soil Chart, 2010) in a wet state. The soil is loose, fine-grained and dusty. The transition from A to B horizons is clearly pronounced. The metamorphic horizon is located from 7 cm to 35 cm. It is coloured in light tones – 10 YR 3/6. The soil in it is slightly dense and dusty. There is also a transitional profile – BC, which occupies the depth below 35 cm to the rock ridge – 80 cm. The soil is deeply leached – no foaming of carbonates was determined during its treatment with hydrochloric acid.

Soil texture is assessed as sandy loam. The amount of sand is 46 – 59%, and the amount of clay 9-10%, respectively. The clay formation is weakly pronounced, due not only to the unfavourable climatic conditions at the altitude of the soil profile, but also to the advanced acidification.

The reaction of the forest litter (pH_{H2O}) is neutral (Table 1) and is due to the plant litter which is in a slightly decomposed form. In the surface 5 cm mineral soil layer the reaction is altered to acidic. The process takes place under the influence of acidic products released from the decomposition of the forest litter. Even stronger acidification is determined in the depth of the soil profile – the reaction is evaluated as a very strongly acidic one.

According to Ulrich et al. (1983) the values of pH_{CaCl2} can be used as an indicator to assess the predominant buffer processes in soil. The slight variation of the results obtained for the soil profile – pH_{CaCl2} of about 4.0_{CaCl2} is shown in Figure 1. An exception is observed only in the surface 5 cm soil layer – pH 4.4, which corresponds to buffering substances from proton exchange with base cations from exchange complexes – mainly clay minerals. This buffering process is evaluated as mostly low (on the scale by Ulrich et al., 1983). In soil profile depth the buffering is expressed by the dissolution of Mn-oxides, and the buffer capacity becomes low.

The amounts of exchangeable basic cations confirm the soil acidification. Their values are high only in the forest litter (Table 1). In the surface 5 cm layer their amounts sharply decreased – 4 times for the exch. Ca and 2 times for the exch. Mg, respectively. The decrease in the amounts of exchangeable K and Na is also clearly pronounced (Table 1). The vertical migration of basic cations crosses the soil profile depth,

Table 1. pH and content of exchange cations in the soil

Dept cm	pH	pH	Exch. Ca	Exch. Mg	Exch. K	Exch. Na	Exch. Fe	Exch. acidity	Base	CEC
	H_20	$CaCl_2$	cmol(+)/.kg^{-1}							
FH	6.06	5.32	29.88	4.32	0.95	0.13	<0.07*	4.47	35.28	39.75
	6.15	5.43	8.14	3.53	0.72	0.08	<0.07*	2.7	12.47	15.17
	6.28	5.65	34.35	4.6	1.11	0.11	<0.07*	3.69	40.17	43.86
	6.16±0.11	5.46±0.16	24.12±14	4.15±0.55	0.93±0.20	0.11±0.03		3.62±0.90	29.31±14	32.93±15
0–5	4.99	4.4	5.24	1.58	0.58	0.04	<0.07*	5.35	7.44	12.79
	5.04	4.4	6.76	1.89	0.51	0.04	<0.07*	5.31	9.2	14.51
	5.03	4.5	10.4	2.04	0.7	0.05	<0.07*	3.61	13.19	16.8
	4.99±0.05	4.38±0.13	7.47±2.65	1.84±0.23	0.60±0.10	0.04±0.01		4.8±1.0	9.94±2.99	14.70±3.98
5.oct.	4.85	3.95	1.54	0.67	0.27	0.03	0.11	9.61	2.51	12.12
	4.7	3.93	1.68	0.76	0.29	0.03	0.07	9.75	2.76	12.51
	4.67	4.06	1.62	0.71	0.29	0.05	0.18	10.05	2.67	12.72
	4.74±0.09	3.98±0.07	1.61±0.07	0.71±0.05	0.28±0.01	0.04±0.01	0.12±0.06	9.8±0.20	2.65±0.14	12.45±0.36
Oct.20	4.68	4.12	<0.89*	0.69	0.25	0.04	0.13	9.69	0.98	10.67
20-40	4.71	3.98	<0.89*	0.57	0.22	0.03	<0.07*	8.2	0.82	9.02
40-80	4.79	4.02	<0.89*	0.45	0.2	0.04	<0.07*	7.2	0.69	7.89

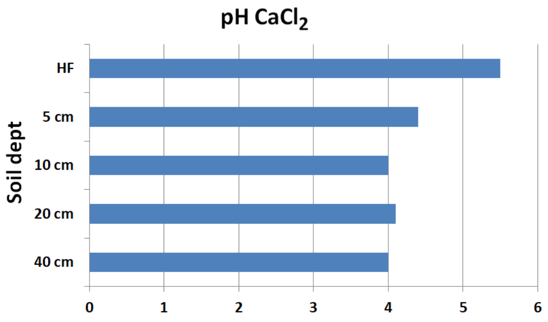

Fig. 1

which is most, pronounced in exch. Ca. At a depth between 10 cm and 80, and pH_{CaCl2} within the range of 4.0 – 4.1, its values are below the limit of determination by the analytical method.

The total exchangeable acidity is characterized by average values (in accordance with the scale by Vanmechelen et al., 1997) in the organic layer and in the surface 5 cm soil layer (Table 1). A sharp increase is observed in the profile depth (5-10 cm layer) – its amount is increased by 2 times, on average, and remains high within the whole profile. The soil is assessed as unsaturated with bases and with advanced acidification. It is determined by the amounts of exch. Al and exch. Mn. The role of the exch. Al is the most important one (Fig. 2). An important indicator for evaluating the acidification process is also the cationic capacity (Šantrůčková et al., 2019). In this case, the exch. Al takes 26% from it in the 0-5 cm layer, 73% in the 5-10 cm layer, 85% in the 10-20 cm layer, 81% in the 20-40 cm layer, and 86% in the 40-80 cm layer, respectively. According to Ulrich et al. (1983), the increased amount of exch. Al over 30% of the soil cationic capacity is the main reason for drying of spruce forests in Europe. It is also the reason for the decreased resistance of these forests to diseases and pests (Zołotajkin et al., 2014). According to the research carried out by De Wit et al. (2001), the increased amount of exch. Al is not as important as the acidity it produces in soil. Markedly, no drying of spruce forest in the studied area is determined, regardless of the high amount of exch. Al in the cation exchange capacity.

The profile behaviour of the exch. Mn is similar to the one of the exch. Al. Its highest values are determined in the surface soil layer, followed by a gradual decrease in depth (Fig. 2). The buffering processes in soil, i.e. the dissolution of manganese oxides contribute to its vertical migraton, which is outside the soil profile. Therefore, the participation of the exch. Mn in the cationic capacity is much lower compared with the exch. Al, and it is in the range of 3 – 5%.

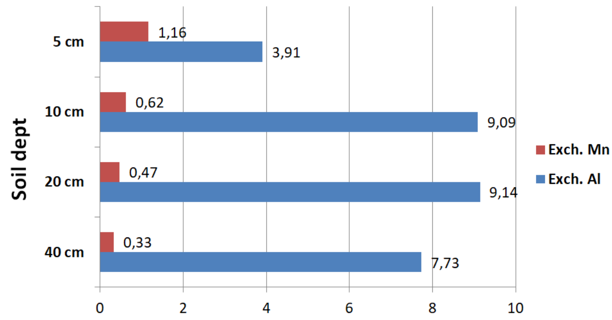

Fig. 2

The established strong soil acidification is considered to be a naturally occurring process due to the absence of industrial immission sources in the area.

The content of org. C is assessed as average in accordance to the scale by Vanmechelen et al. (1997). A high value is reported only at a depth up to 5 cm, which is affected by the organic products obtained from the transformation of the organic matter into forest litter. The amount of nitrogen in the forest litter is assessed as average. Nitrogen accumulation occurs in the surface mineral layer, and the nitrogen amount is high. According to some authors, this is might be attributed to the nitrogen uptake by microorganisms (Northup et al., 1998), resulting in very high values. The accumulation process gradually decreases in depth. According to Van Sundert et al. (2020), the amount of org. C and the ratios C/N are indicators for the presence of nutrients in spruce forests

Table 2. Content of macro and microelement in the soil

Soil dept (cm)	Org. C $g.kg^{-1}$	Tot. N	P mg.kg-1	Ca	Mg	K	Mn	Zn	Cu	Pb	Cd
FH	307	14.5	1293	16616	3611	4249	3725	193	31	86	0.11
0-5	114	6.5	981	5497	7322	6705	2428	184	40	86	0.15
0-10	36	2.6	804	2715	9056	7079	1926	176	34	51	0.05
окт.20	25	2.59	877	3145	10392	10449	1981	223	37	45	0.07
20-40	23	2.12	963	2930	10084	11933	1850	206	38	42	0.07
40-80	18	1.72	786	2569	8964	12080	1222	199	32	38	0,1

across temperate and boreal forests. The obtained rations of org. C/N (Fig. 3) are characterized as low, both in the organic F layer and in the mineral part of the profile, which indicates a relatively rapid release of nutrients from the organic matter. As seen in Figure 3, there is a clearly expressed trend of carbon loss and nitrogen retention in the processes of organic matter decomposition.

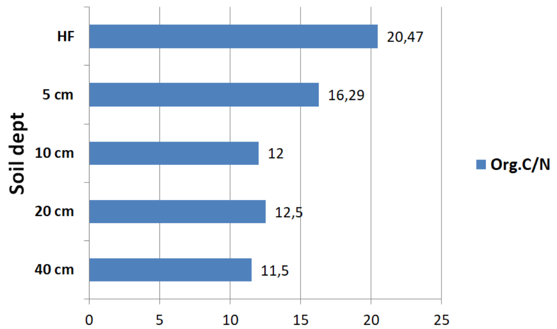

Fig. 3

The ratios of org.C/total N in the forest litter and in the surface soil layer have similar values (Fig. 3). This delayed decomposition of organic matter can be attributed to the high mountainous climatic conditions in the area. Processes, leading to decreased amounts of soluble substances and reduced values of the org. C/N ratio to relatively similar values, occur in the vertical direction of the forest litter. This process occurs at a depth below 5 cm.

The org. C/N ratios in the forest litter are considered as an important indicator showing the risk of nitrate leaching from it during the processes of its decomposition. According to Gundersen (1998) at a ratio of less than 25, as determined for the examined soil, the risk is high.

With regards to the macroelements, the content of total calcium is characterised by an active accumulation in the F layer (Tabl. 1). There is a slight increase of its amount in the layers 10-20 cm and 20-40 cm, resulting from its vertical migration due to the strongly acidic reaction. At a depth below 40 cm the amount of calcium decreases and has a low value. Magnesium is characterized by a similar behaviour. Its values are high throughout the soil, but its maximum value is determined in the layers 10-20 cm and 20-40 cm. Unlike calcium and magnesium, potassium has the lowest value in the forest litter. It washes off easily in depth due to the acidic environment, and its maximum value of 12080 mg.kg^{-1} is determined in depth below 40 cm.

The analysis of the database of the European soil monitoring (Vanmechelen et al., 1997) shows that the amounts of some macroelements in the forest litter are higher compared to the surface mineral soil layer. This is typical for manganese, copper, lead, cadmium, etc. The difference increases with the increased soil acidity. Manganese is characterized by the most active accumulation in the forest litter from all studied microelements. It is a strongly mobile metal in soil (Heinrichs et al., 1980), which easily migrates in depth (Utermann et al., 2019). Schulte et al. (1999) calculated that its content in the soil solution decreases 100 times with the increase of pH_{CaCl2} by 1 unit.

The high acidity of the studied soil, as well as its buffering capacity mentioned above – buffering substances from proton exchange with base cations from exchange complexes, reveal the presence of soluble forms of Mn. Their behaviour in soil is characterized by migration in depth, outside the soil profile. This buffering process is evaluated as mostly low (according to the scale by Ulrich et al., 1983). In depth of the soil profile the buffering is performed by the dissolution of Mn-oxides, and the buffer capacity becomes low.

In an acidic environment, Zn is also characterized by migration into the soil depth. According to Sheila (1994) its mobility decreases 100 times by increasing the pH with 1 unit. Its accumulation in the forest litter is very slightly pronounced. Its vertical movement is expressed by its profile distribution – its amount in the forest litter and the surface 10 cm is lower than the amount determined in the depth of the profile.

Cu is the only one of the studied elements with an increased amount in the forest litter. It is above the toxicity level (according to the scale by Wim de Vries et al., 2002). Its amount is high within the entire soil profile. There is a slight tendency of decreased Cu values in depth, which usually depends on the decrease in the amount of organic matter.

The behaviour of Pb differs from that of the other heavy metals. It is accumulated in the organic layer which is a typical characteristic (Dumoulin et al., 2017). Its accumulation in the studied site is clearly expressed both in the forest litter and in the surface soil layer.

The content of cadmium in the profile is low only in the forest litter (on the scale by Vanmechelen et al., 1997). Its values show active retention in the surface soil layer which is rich in organic matter. Its amount sharply decreases in the soil depth – 5 times, due to its mobility in acidic environment and vertical migration. There is a slightly expressed process of cadmium accumulation in the depth of soil, i.e. 40-80 cm layer.

Conclusions

The current state of the parameters, analysed in the present study, is formed over a long period of time. No data regarding these parameters was found in the scientific literature. The study determined the course of a degradation process in *dystric* Cambisols from the high-mountainous area of the Central Rhodopes – the Rozhen area. The process is characterized by a progressive acidification and depletion of soil due to loss of nutrients that migrate in depth. The strong acidification is considered as a naturally occurring process due to the absence of industrial sources of immissions in the region. Nevertheless, the high acidity is a risk factor and its development should be monitored over time. The presented results can be used for future comparisons and evaluations.

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