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Comparative analysis of different-age vineyards in Fruska Gora National Park, in the Autonomous province of Vojvodina, Republic of Serbia, on the characteristics of lateral migration of mobile sulphur

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Abstract. Data on the content and lateral migration of mobile sulfur in brown forest soil of residual carbonate (Eutric Cambisols/ Haplic Cambisols) of autonomous and transit landscapes under vineyards in the Autonomous Province of Vojvodina, Republic of Serbia, are presented. The content of mobile sulfur in horizons 0-5 and 5-15 cm was highly contrasting from very low (less than 5 mg/kg) to high (more than 35 mg/kg) depending on the age of vineyards, landscape features of their location and applied cultivation systems. The content of mobile sulfur in the lateral structure of elemental landscapes under age (more than 200 years) vineyards with high slope steepness increased from trans-eluvial facies of upper parts of slopes to lower transaccumulative facies. In an industrial vineyard of intensive type 15 years old, the absence of inter-row sodding and the arrangement of rows along a long slope with a complex shape contributed to increased migration. Migration flows and accumulation of mobile sulfur in transaccumulative elemental landscapes can cause deterioration of quality characteristics of produced wine materials and contamination of adjacent environments.

1 Introduction

Since ancient times, sulfur has been used as a natural insecticide against parasites, plant fungicide, wine preservative, bactericide and antioxidant. Since about the middle of the 20th century, sulfur, along with copper compounds, has been used as an inorganic contact fungicide and low hazard class acaricide in plantation and horticultural agroecosystems. The advantages of sulfur over alternative organic fungicides include its low cost, availability, high efficiency, low risk of resistance development, and rather low toxicity [1]. Sulfur and sulfur-based preparations are widely used all over the world even in organic and biodynamic viticulture. Meanwhile, the widespread and long-term use of sulfur-containing pesticides, especially for the treatment of vine plantations, often leads to sulfur accumulation in the upper parts of the soil profile [2].

Sulfur entering the soil with pesticides and agrochemicals is accompanied by its active inclusion in biogeochemical migration flows with changes in the chemical form, nature and duration of element deposition, its mobility and bioavailability. Up to 98% of its gross sulfur content is located in the soil in organic form as part of plant residues and humus. Bioavailability of the element is provided by the processes of mineralization of its organic compounds to mobile sulfate forms with the participation of soil microorganisms. The biogeochemical cycle of sulfur in ampelocenoses is also significantly influenced by climatic factors and practiced agro-technologies. In case of growing grapes in arid conditions and without irrigation, the applied sulfur accumulates in the surface layer of soil until the onset of the rainy season [3]. At high soil humidity, sulfates saturate the soil solution and acquire the ability to migrate, which is especially important when vineyards are located on sloping landforms. In this case there are ecological risks of contamination of adjacent environments. Few studies indicate that sulfur in vine plantations is subject to leaching from the root layer, mainly in regions well supplied with moisture and when irrigation is used. Thus, intensive leaching of sulfate ion has been observed in the warm and humid climate of the Apulia region in southeastern Italy [4] and in irrigated vineyards in northern California [5].

The extremely insufficient number of works devoted to quantitative assessment of accumulation and migration of mobile sulfur in soils of ampelocenoses located on sloping lands predetermined the subject of the research presented in this work. The aim of the work was to ecological and geochemical assessment of lateral distribution of mobile sulfur in the transit landscape of slopes of different exposure and steepness under different-aged vineyards on the example of the historical wine-growing region around the Fruška Gora National

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Park in the Autonomous Province of Vojvodina, Republic of Serbia.

2 Material and method

The research was conducted in the vineyards of private wineries located in the southeastern and northeastern part of the Fruska Gora mountain range on the Middle Danube Foothills (Right Bank of the Danube) in the Autonomous Province of Vojvodina, Republic of Serbia (Figure 1). The climate of the study area is temperate continental with elements of subhumid and mesothermal in some locations. The average annual air temperature in the study area is 11.8°C, the average annual precipitation is 764 mm.

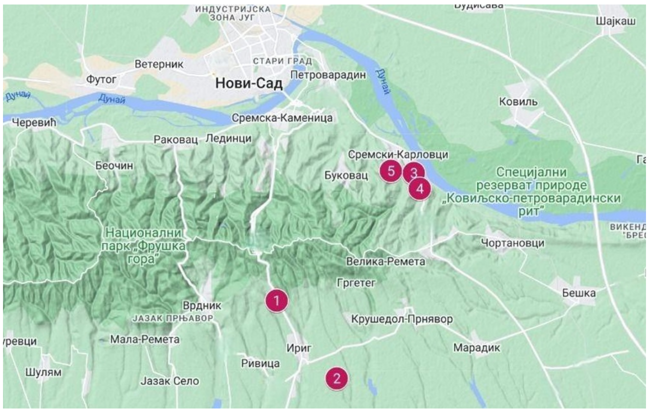

Fig. 1. Location of the study region and wineries around Fuska mountain (at rural settlements: 1 - Tursko Brdo; 2 - Plavulja; 3 - Čušilovo; 4 - Lipovac; 5 - Cerat).

The studied farms practice different systems of vine cultivation: farms near the rural settlements (villages) of Tursko Brdo, Plavulja, Čušilovo - traditional trellis-row system of bush cultivation with sodded inter-rows; industrial winery near the village of Lipovac - intensive, including full mechanization of labor-intensive processes of plant care and cultivation of inter-rows under black fallow; the farm near the village of Cerat - an archaic bush (bunched) system of grape growing, evenly distributed on the slope and cultivated entirely by hand.

Table 1. Characterization of the studied ampelocoenoses of the Frushka Gora region.

Vineyard		Slope		
Place	Cultivation period, years	Exposition	Steepness, deg.	Extent, m
Irig, Tursko Brdo municipality	> 300	Western	4	36
Irig,Plavulya village	> 300	Southern	5	55
Sremski Karlovci, mChushilovo village	> 100	Eastern	8	27
	15	Northern	3	41
Sremski Karlovci, Lipovac village	15	Eastern	12	287
Sremski Karlovci, Cherat village	> 200	Eastern	10	64

The objects of the study were brown forest residual carbonate (Eutric Cambisols, FAO (1988), Haplic Cambisols Calcaric, WRB (2006)) soils of five wineries located in the conditions of slope landscape of different length, steepness and exposure. Information on the location of ampelocenoses in the landscape, age and variety of cultivated plantations is presented in Table 1.

Soil sampling was carried out within adjacent autonomous and transit slope landscapes [6]: autonomous-eluvial (upper AE1, middle AE2, and lower AE3 parts of the gentle slope of the supra-floodplain terrace), trans-eluvial (upper Te1, middle Te2, downhill Te3 near Plavulya village), and trans-eluvial-accumulative (transaccumulative) (lower Tea part of the slope) according to the schemes presented in Fig. 2.

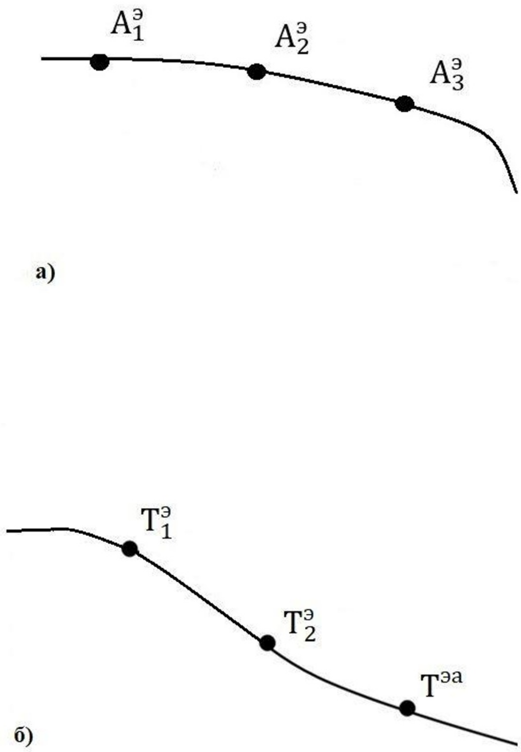

Fig. 2. Location schemes of soil sampling points in the autonomous (a) and transit (b) landscape under vineyards of the Fruska Gora region.

Point soil samples were taken with a soil borer from the depths of 0-5, 5-15 and 15-30 cm, a combined sample was obtained from six point samples. before analysis of soil samples its preparation were provided [7]. Determination of mobile sulfur content were provided [8].

The lateral differentiation coefficient L of mobile sulfur in the soil of conjugate elements of eluvial and trans-eluvial geochemical landscape was determined by the formula:

$$L = \frac{Lx(sub.)}{Lx(auth.)} \quad (1)$$

where Lx(sub.) - concentration of mobile sulfur in subordinate elementary geochemical landscape (middle part of slope A2e, T2e or lower part of slope\ A3e, Thea), Lx(auth.) - concentration of mobile sulfur in upper part of slope of eluvial A1e and trans-eluvial T1e geochemical landscape.

Statistical hypotheses were tested with a significance level of 0.05. Statistical analysis was performed with R Project for Statistical Computing [9].

3 Results and discussion

The content of mobile sulfur (S_{mob}) and the values of lateral differentiation coefficients in the soil of autonomous and transit landscapes under vineyards are presented in Table 2. In accordance with the Aristarkhov classification [10], the soils of the considered ampelocoenoses were characterized by a wide range of S_{mob} content from low (less than 5.0 mg/kg) to high (more than 35 mg/kg of soil).

Table 2. Mobile sulfur content (Smob mg/kg) and lateral differentiation coefficients (L) in the soil of autonomous and transit landscapes under vineyards of the Fruška Gora region.

Place	Elementary landscape type	Depth,cm					
		0-5		5-15		15-30	
		S_{mob}	L	S_{mob}	L	S_{mob}	L
Traditional cultivation system							
Irig, Tursko Brdo municipality	$A_1^{э}$	35,61	-	28,57	-	6,79	-
	$A_2^{э}$	3,77	0,11	9,74	0,34	6,25	0,92
	$A_3^{э}$	6,18	0,17	6,34	0,22	48,97	7,21
Irig, Plavulya village	$T_1^{э}$	3,21	-	3,77	-	3,14	-
	$T_2^{э}$	4,65	1,44	2,72	0,72	3,55	1,13
	$T_3^{э}$	3,57	1,11	3,04	0,81	2,21	0,70
Sremski Karlovci, Chushilovo village (eastern exposition)	$T_1^{э}$	0,09	-	0,09	-	0,06	-
	$T_2^{э}$	0,11	1,22	0,08	0,89	0,08	1,33
	$T^{эа}$	0,22	2,44	0,08	0,89	0,09	1,50
Sremski Karlovci, Chushilovo village (northern exposition.)	$T_1^{э}$	0,06	-	0,06	-	0,09	-
	$T_2^{э}$	0,09	1,50	0,09	1,50	0,09	1,00
	$T^{эа}$	0,08	1,33	0,07	1,17	1,07	11,89
Historical cultivation system							
Sremski Karlovci, Cherat village	$T_1^{э}$	2,25	-	4,15	-	6,47	-
	$T_2^{э}$	38,82	17,25	37,40	9,01	9,84	1,52
	$T^{эа}$	36,15	16,07	24,44	5,89	2,44	0,38
Intensive cultivation system							
Sremski Karlovci, Cherat village	$T_1^{э}$	23,80	-	6,29	-	1,83	-
	$T^{эа}$ I террасы	42,30	1,78	14,43	2,29	1,06	0,58
	$T^{эа}$ II террасы	53,76	2,26	2,03	0,32	1,70	0,93

The content of S_{mob} in the soil of farms practicing traditional cultivation technologies differed by three orders of magnitude. The highest values were recorded in a more than 300-year-old vineyard in the village of Tursko Brdo, which amounted to 35.61 and 28.57 mg/kg in horizons 0-5 and 5-15 cm, respectively, the lowest - in a 15-year-old vineyard in the village of Chushilovo on the slope of northern exposure, which amounted to 0.06-0.09 mg/kg depending on the landscape element and depth of sampling.

According to the data presented in Table 2, all the studied transit landscapes were covered by S_{mob} migration flows of different intensity from trans-eluvial facies of the upper parts of slopes to transaccumulative facies of the bottom of slopes. As a result, zones of mobile sulfur removal and accumulation were formed in geochemically conjugated elements of the landscape. Particularly evident accumulation of S_{mob} in the 0-5 cm horizon of the soil of the middle and lower part of the slopes was characterized by farms near the villages of Cerat and Lipovac, where S_{mob} content reached 36.15-38.82 and 42.30-53.76 mg/kg of soil, respectively, with migration involving not only the 0-5 cm surface horizon, but also the 5-15 cm horizon. According to some data, the increased sulfur content in the soil of ampelocenoses increases the availability of nitrogen to plants and its assimilation, which can adversely affect the organoleptic and physicochemical parameters of the obtained wine products by reducing the accumulation of phenolic compounds in grape berries that determine the quality of wine material and its belonging to a certain terroir [11].

The correlation, typical for certain soil horizons between the content of S_{mob}, cultivation system and vineyard age, was found. Thus, under the traditional system, significantly less mobile sulfur was accumulated in the upper soil horizons than in the historical and intensive systems (significance level p = 0.019 and 0.084 in horizons 0-5 and 5-15 cm, respectively), while the effect of the cultivation system on the S_{mob} content in the horizon 15-30 cm was not significant. On the opposite, a statistically significant ($p = 0.022$) increase of S_{mob} accumulation in the 15-30 cm horizon was observed in the soil of vineyards more than 200 years old compared to young plantations. Therefore, in the horizons 0-5 and 5-15 cm the cultivation system had a significant influence on the accumulation of S_{mob}, while in the horizon 15-30 cm the vineyard age had a significant influence on the accumulation of S_{mob}. The only exception was the high accumulation of S_{mob} in the surface soil layer of the young vineyard in Lipovac village, which was 2-3 orders of magnitude higher than that of similarly aged plantations in Chushilovo village, which was probably due to the specific conditions of slope processes in this location, as described below.

Correlations were also established between the intensity of lateral migration of S_{mob}, steepness ($p = 0.009$; 0.010 and 0.011 in horizons 0-5, 5-15 and 15-30 cm, respectively) and length ($p = 0.015$ in horizons 0-5, 5-15 cm and 0.009 in horizon 15-30 cm) of the slope. The high steepness and length of the slope, its curved shape, as well as the peculiarities of the applied technological processes in the young industrial vineyard near Lipovac village, such as the absence of vegetation in the inter-rows, the arrangement of rows along the slope and intensive mechanical treatment of the inter-rows, apparently increased the migration of mobile sulfur along the slope profile (L = 1.78 and 2.29 in 0-5 and 5-15 cm horizons, respectively), so that the level of its accumulation in the surface horizon of the transaccumulative facies soil was comparable and even exceeded that in the soil of the 200-year-old vineyard in the village of Cerat. Intensive accumulation of S_{mob} was also found in the soil of the lower part of the slope with a steepness of 8° under the vineyard near the Chushilovo village of eastern exposure (L=2.44 in the 0-5 cm horizon).

The maximum contrast of lateral differentiation of S_{mob} was characterized by transaccumulative facies in the farm near the village of Cerat (L = 16.1 and 5.89 for horizons 0-5 and 5-15 cm, respectively). Accumulation of S_{mob} in the soil of this age vineyard was observed not only in the lower, but also in the middle part of the slope, and the migration covered the whole studied part of the soil profile with a thickness of 30 cm, which was facilitated by the uniform bunched planting scheme throughout the slope, its natural soddenness and high steepness, and the absence of mechanical tillage. In weakly sloping, gentle and slightly sloping slope elements of the landscape with steepness up to 5° and with sodding of vine rows in farms near rural settlements Plavulya and Chushilovo, the transit of S_{mob} was also observed, but less intensive (L = 1.00-1.50).

The distribution of mobile sulfur in the autonomous eluvial landscape of a gentle slope of an upper floodplain terrace on which a vineyard more than 300 years old was cultivated near the village of Tursko Brdo is of great interest. In this ampelocenosis, the accumulation of S_{mob} in the soil of the upper, most flattened part of the gentle slope (Fig. 2a) in horizons 0-5 and 5-15 cm was observed at the level of 36.51 and 28.57 mg/kg, respectively, which may have been caused by additional sulfur intake into the surface soil layer of this location as a result of its location 10 m from a road with heavy motor vehicle traffic. Based on the low values of lateral differentiation coefficients at the level of 0.11-0.34 in the downslope eluvial geochemical landscape sampling points, there was a predominant removal of the element in consideration from the upper soil horizons with accumulation in the 15-30 cm horizon, where the value of the L coefficient was 0.92 and 7.21, respectively, in the middle A2e and lower A3e parts of the slope. In this connection, it can be assumed that in this type of landscape accumulation prevailed over emission, and radial migration of mobile sulfur deep into the soil profile over lateral migration.

4 Conclusion

Studies Eutric Cambisols, FAO (1988), of the slope landscape under vine plantations in the area of Fruška Gora National Park, Autonomous Province of Vojvodina, Republic of Serbia, have shown that the content of mobile sulfur in the lateral structure of elementary landscapes increased from trans-eluvial facies of the upper parts of slopes to the lower transaccumulative facies, which was promoted by the high steepness and length of slopes, as well as the lack of sodding of rows and the arrangement of rows along the slope in the industrial vineyard of intensive agriculture. As a consequence, such slopes acted not only as an area of transit but also of mobile sulfur accumulation at 23.8-53.76 and 24.44-37.40 mg/kg in 0-5 and 5-15 cm soil horizons, which is classified as medium and high accumulation levels. Migration flows and accumulation of mobile sulfur in transaccumulative elemental landscapes may cause deterioration of quality characteristics of produced wine materials and contamination of adjacent environments.

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