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IMPACT OF THE SOIL EROSION ON SOIL PROPERTIES ALONG A SLOPE CATENA - CASE STUDY HORNÝ OHAJ VINEYARDS, SLOVAKIA

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Abstract: Long term erosion processes affect soil significantly, especially on vineyards that represent one of the most erosion prone types of cultivated lands. The aim of this paper is to assess the impact of erosion processes on soil properties in the vineyards of Vráble viticultural district in Slovakia. The spatial and profile changes of selected soil properties have been measured along the slope transects on summit, backslope and footslope position. Transects were located on same slope under two different types of soil cultivation: ploughing and hoeing. The erosion and deposition rates were estimated using the levelling method based on successive measurement of the soil surface variability against vineyard. We found a significant difference between erosion and deposition rates on different part of the slope as well as in use of different management practices. Some selected soil properties (pH, organic carbon content - Cox, bulk density -BD, porosity - POR, erodibility - K, Cu content) were compared both for the severe eroded ploughed and the slightly eroded hoed vineyard in summit, footslope and backslope. In case of hoed vineyard the parameters reached values of: Summit – Ph = 7.54; Cox= 1.30 %; BD = 1.38 $g.cm^3$; POR = 48.10 %; K = 0.42; Cu = 213 $mg.kg^{-1}$, Backslope – Ph = 7.59; Cox= 1.33 %; BD = 1.36 $g.cm^3$; POR = 49.30 %; K = 0.46; Cu = 194 $mg.kg^{-1}$, Footslope – Ph = 7.60; Cox= 1.34 %; BD = 1.26 $g.cm^3$; POR = 52.30 %; K = 0.39; Cu = 215 $mg.kg^{-1}$. In case of ploughed vineyard parameters reached values of: summit – Ph = 7.72; Cox= 1.76 %; BD = 1.50 $g.cm^3$; POR = 43.10 %; K = 0.36; Cu = 188 $mg.kg^{-1}$, backslope – Ph = 7.42; Cox= 1.08 %; BD = 1.38 $g.cm^3$; POR = 48.20 %; K = 0.48; Cu = 124 $mg.kg^{-1}$, footslope – Ph = 7.36; Cox= 1.44 %; BD = 1.60 $g.cm^3$; POR = 39.30 %; K = 0.44; Cu = 144 $mg.kg^{-1}$.The higher variability of soil properties and more intensive transformation of soil profile related to more accelerated erosion processes on ploughed vineyard have been noticed. Values of pH, organic carbon content and Cu content were considerable lower in the eroded part of the ploughed vineyard if compared with the slightly eroded hoed vineyard.

Keywords: sediments; deposition; erosion measurement; soil properties; slope catena

1. INTRODUCTION

Vineyards have been reported as one of the most erosion prone types of cultivated land in Europe (Cerdan et al., 2010). Soil degradation in vineyards caused by erosion represents a serious threat especially in Mediterranean region (Augustinus & Nieuwenhuyse, 1986, Blavet, et al., 2009, Cots-Folch et al., 2009, Hooke, 2006, Kosmas, et al., 1997). In contrast to a number of studies from the Mediterranean regions, there are only a few reflecting this problem in vineyard regions of Central Europe (Jordan et al., 2005, Vrsic et al., 2011, Nagy et al., 2012). Vineyards are considered as one of the most eroded type of cultivated lands in Slovakia. It is because they are usually planted on steep slopes, parallel to the slope gradient, and under low vegetation cover in between the vine rows. The study of Zachar (1982) described a huge erosion event in Myslenice, southwest Low Carpathians vineyard region, where the soil erosion on newly planted vineyards, located on higher slopes (8-10°), reached 300 – 500 $m^3.ha^{-1}$. Šúri et al., (2002), they assessed the consequences of land cover changes on soil erosion distribution at the national level including vineyard regions. Dlapa et al., (2011) investigated the impact of various land use practices on soil properties, in particular, the issue of the soil aggregate stability was addressed with respect to the existing risk of soil erosion and runoff formation. The study of Lieskovský & Kenderessy (2012) focused on assessing of the various management practices on soil losses and accumulation in vineyards.

The sloping regions of Slovakia with suitable exposure were most likely devoted to viticulture from as early as the 5th century (Slavkovský, 2002). Since Slovakia occupies a marginal position within the European winegrowing regions, increasing effort to find the most suitable locations has led to deforestation and the use of relatively steep slopes. Another effect of viticulture arises from change of the soil profile by the deep-ploughing prior to vineyard establishment. According to Kolény (2001) this practice involves overturning the soil horizons and moving the humus horizon to depth of 40-60 cm where grapevines develop their best root system. This planting system together with the orientation of the plant rows along the gradient line resulted in the increase of the surface runoff after heavy rainfall.

Erosion triggers numerous effects on soil properties, including textural coarsening, depletion of soil organic matter and loss of nutrients (Andreu et al., 1994; Bauer & Black, 1994; Frye et al., 1982; Guerra, 1994; Farsang et al., 2012). There is a great amount of studies referring to soil properties transformation resulting from erosion processes. Sobocká (2002) have used an erosion-accumulation catena method to identify the impact of erosion processes on Luvisols in Trnava loess hilly land in Slovakia. The results confirmed enormous water sheet erosion influence on morphology and horizontation of soil profiles. The impact on physical and chemical properties was also registered, mainly changes in carbonate content. Styk (2002) have related the Caesium^{-137} derived soil erosion rates and spatial and profile variation of soil properties on transects of experimental plots in Slovakia. The results showed that best indicator of erosion processes among all observed characteristics (texture, pH, organic carbon content, porosity) was represented by organic carbon content due to fact that this parameter is most stable in the soils. The impact of soil erosion on organic carbon content and soil fertility has been also studied by Fullen et al., (1998, 2006), Su et al., (2010), Martinez-Mena et al., (2008), Papiernik et al., (2007). According to these authors the organic carbon content tends to decrease with increasing soil loss by erosion. Comparison of the particle size distributions of the pre and post-eroded samples analyzed by Fullen & Brandsma (1995) showed that erosion selectively removed the fines, leaving behind a coarser soil. It was notable that fine soil material, that were selectively transported from upslope, were accumulated at the downslope position (Ge et al., 2007). Owing to easy movement of the fine materials through runoff, chemical elements like nutrients, phosphorus or soil organic matter captured by fine particles exhibited a similar spatial distribution pattern. The thinning and possible topsoil removal often result in the exposure of calcareous subsoil at the shoulder positions and relatively deep A horizon (with low carbonate content) at footslopes. In middle slope position, an inverted soil profile may be present, where high-carbonate soil translocated from higher slope positions buries a carbonate-free horizon (De Alba et al., 2004). Eroded soil profiles are then impacted by a shallow C parent material horizon that has high inorganic carbon content and pH value and low aggregate stability, while profiles in areas of soil accumulation are characterized by Bw or Bt horizons at depths >50 cm with low carbonate and high aggregate stability (Papiernik et al., 2007).

Our study relates erosion/deposition rates to spatial variation of soil properties along slope catena in vineyards. The specific objectives of our study are as following: 1) to apply simple leveling method in order to compare soil erosion and deposition rates along slope catena on heavy eroded ploughed vineyard and less eroded hoed vineyard; 2) to investigate the spatial variation in surface soil properties and profile stratification; 3) to analyze the relationship between the contemporary soil redistribution patterns and selected soil properties.

2. MATERIALS AND METHODS

2.1. Study Site

The research was carried out in Horný Ohaj vineyards (48º16'11''N, 18º18'05''W) located in southwestern Slovakia in the Vráble viticultural district (Fig. 1). The vineyards have a total area of 65.68 hectares and comprise of small fields with private rows of wire-trained vines. Each field contains 2 - 4 rows of 120 - 160 vine stocks planted and cultivated along a slope of < 11°. Soils in the area are represented by luvisols and regosols formed on Aeolian loess deposits. The soils were classified as silt loamy according to textural analysis of soil samples taken in the study area. According to Lapin et al., (2002) the climate is classified as warm, dry with mild winter. The average annual temperature is 9.5°C. The average annual precipitation is about 552 mm. Most of the monthly precipitation falls in May (63 mm on average), the main erosive rainfall events caused by heavy rainstorms occur in July and August.

The erosion was measured on two differently cultivated fields located within the similar slope profile (Fig. 1) and within the same soil and climate zone. The first field was planted in 1983, and since then it has been ploughed by a garden tractor annually. The field consists of two rows of 33 poles and one row of 30 poles. The spacing of poles is 8.2 m. Medium ploughing (15 - 18 cm) is applied before and after the vegetation season, and shallow ploughing (9 - 11 cm) is applied a few times per season to controll weeds. The second field has been manually hoed since 1975. The vines are hoed three to five times per vegetation season depending on the prevalence of weeds. The soil is disturbed up to 3 - 5 cm. There are two rows of 33 poles and one row of 30 poles. The distance between the poles is 7.8 m.

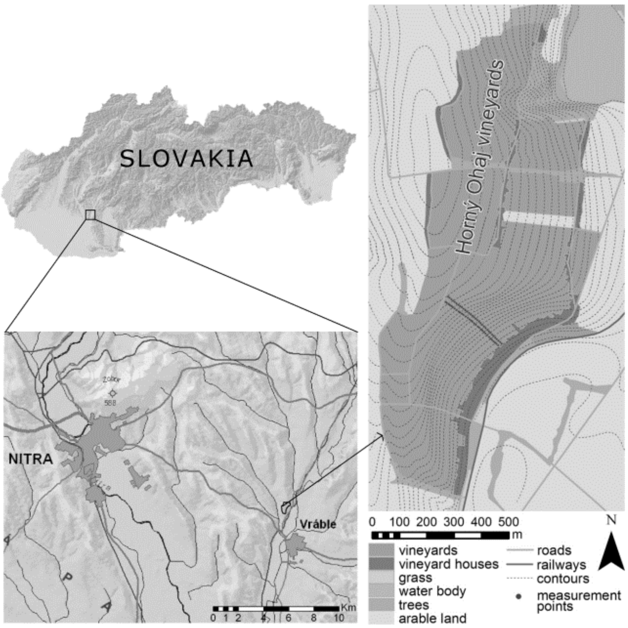

Figure 1. Location of the study area and measurement transects. Dots on detailed pictures (above and right) represent measured points (right: ploughed field, centre: hoed field, left: rotavated field.

2.2. Erosion Measurement

Erosion/deposition rates were estimated using levelling method according to Zachar (1982). The estimation of erosion/deposition rates was based on a variation of the exposed vineyard pole heights at the year of vineyard plantation and the year of measurement. The exposed pole heights have increased in the erosion areas, where the soil has been washed away, and have decreased in the deposition areas, where the poles have been covered by the deposited soil. The annual erosion or deposition in $mm.yr^{-1}$ was calculated as a difference between the initial and measured exposed pole length divided by difference between year of measurement and year of the poles insertion. The obtained values in $mm.yr^{-1}$ were transformed to the annual erosion or deposition rates in $t.ha^{-1}.yr^{-1}$ using the soil bulk density (Lieskovský & Kenderessy, 2012). The information about initial poles length and year of the poles insertion was provided by the vineyards owners.

Measurements were carried out on 14 October 2008, 26 October 2009 and 25 October 2010. In 2008 a total amount of 102 poles in the ploughed vineyard and 81 poles in the hoed vineyard were measured. In 2009 and 2010, the measurements were repeated. The erosion/deposition rates were calculated as an average value of the poles located within the same position on the slope. As control plot the ploughed vineyard located on flat surface was chosen. This vineyard consists of 81 poles. The measurements were undertaken on May, 2011.

2.3. Analysis of soil properties

The samples for soil analyses were collected in three topographical positions: summit, backslope and footslope (Fig. 2), located on similar slopes where erosion measurements were undertaken. Sampling was replicated on slopes in two types of cultivated fields: ploughed and hoed. Control sample was taken from flat position not affected by erosion. Given the conditions mentioned above, samples were collected from total number of 7 sample points. The undisturbed soil samples were collected using the Eikelkamp 250 cm^3 sample ring kit, from the surface soil level 5-10 cm deep. They were analyzed by the certified laboratory of Soil Science and Research Institute in Bratislava. The following properties were determined: organic carbon content (Cox, %), pH, Cu content ($mg.kg^{-1}$), porosity (%), bulk density ($g.cm^{-3}$), textural classes (%). The determination of soil organic carbon, pH, particle size distribution, porosity and bulk density were made by standardized methods of soil survey according to Fiala (1999). Particle size distribution was determined by measuring the amount of soil particles remaining in suspension following varying settling time, the percentage of each size fraction was determined by the pipette method. Soil pH values were determined using a soil/solution ratio 1:2:5, while soil organic carbon content was determined by oxidation with $K_2Cr_2O_7$-H_2SO_4 and titration of non-reduced dichromate. Cu content was estimated using the flame and electrothermal atomic absorption spectrometric methods. The Cu content has been selected as an indicator of erosion processes, since the copper substances are widely used in vineyards to protect grapevines against fungus diseases. The undisturbed soil samples were used to determine the bulk density and porosity. The soil samples were weighted before and after drying in an oven at 105°C for 24 hours. These values were then used to calculate the values of bulk density and total porosity. K factor was computed as function of soil texture, organic matter content, structure, and permeability according to Wischmeier & Smith (1978) modified by Fulajtár & Janský (2001) using the following equation:

$$K = 2.1*10^{-6} [p(100-i)]^{1.14} (12-a) + 3.25*10^{-2} (b-2) + 2.5*10^{-2} (c-3) \quad (1)$$

where:

a - Soil carbon content (%).

b - Parameter of soil structure based on scale 1 to 4.

c - Parameter of soil permeability based on scale 1 to 6.

p - Silt and fine sand content (%).

i - Clay content (%).

Furthermore, in the same positions where soil samples were collected, the hand auger drill with length of 160 cm was used in order to investigate the stratification of soil profiles and measurement of the thickness of diagnostic soil horizons (cm).

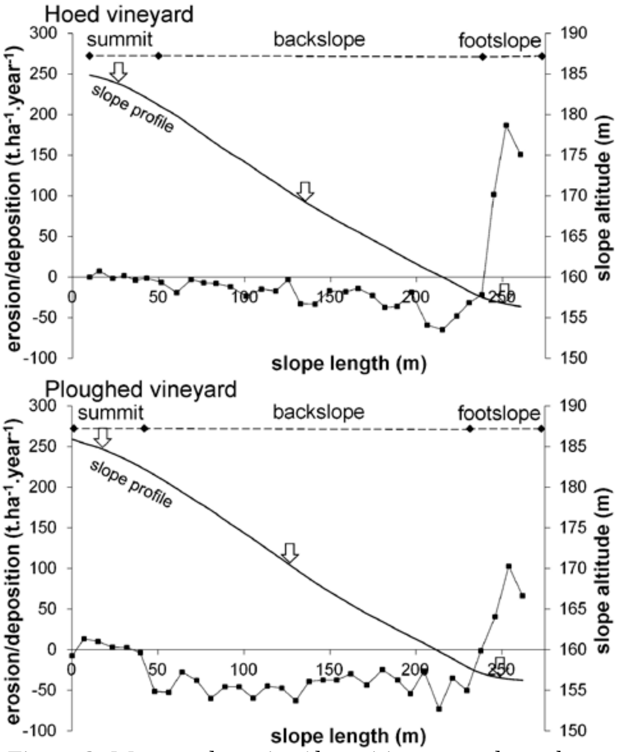

Figure 2. Measured erosion/deposition rates along the slope catena (arrows shows the soil sampling locations).

3. RESULTS

3.1. Erosion measurement

The obtained results show three situations on slope in both vineyards. On the summit of the slope, erosion and deposition are in equilibrium and the difference in erosion/deposition rates in between the vineyards is not significant (Fig. 2). Prevailing deposition could be caused by amount of material delivered by unpaved road located along the ridge of the hill. The backslope is characterized by the prevailing erosion process, which slightly increases with slope length and steepness. There is a significant difference in erosion rates ($P<0.001$) between the vineyards (Fig. 3). Average erosion on hoed vineyard is 22.97 $t.ha^{-1}.year^{-1}$ and on ploughed vineyard is 44.67 $t.ha^{-1}.year^{-1}$. On the footslope, where the slope gradient decreases, soil is deposited at an increasing rate. Surprisingly, the amount of deposited material is higher in hoed vineyard with average deposition 146.35 $t.ha^{-1}.year^{-1}$, comparing to 46.20 $t.ha^{-1}.year^{-1}$ for ploughed vineyard. The part of eroded material from both vineyards is transported out to the lower part of the slope. The more intensive transportation in ploughed vineyard could be caused by the difference in topography on the lower parts of the slope.

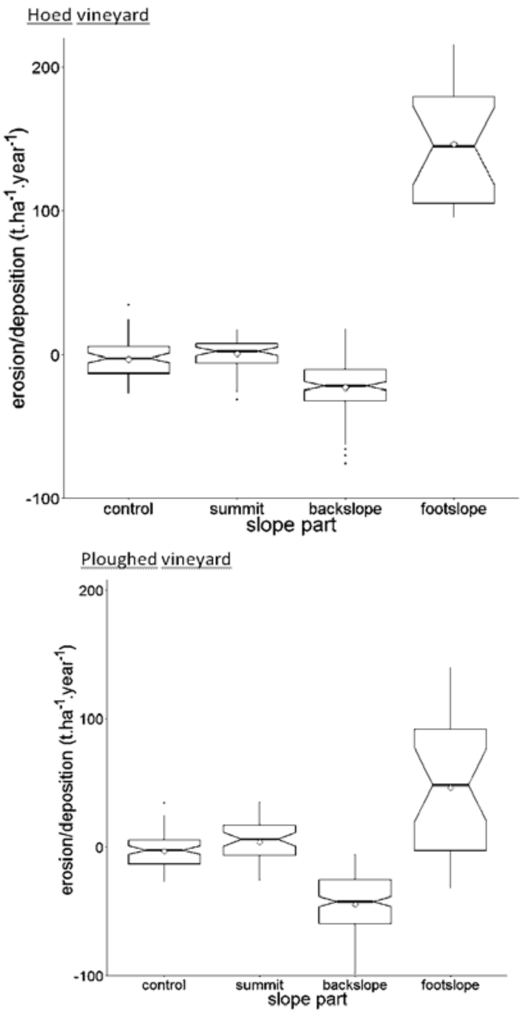

Figure 3. Erosion/deposition rates in the different part of the slope.

3.2. Analysis of soil properties

Soil properties in the most (ploughed) and less (hoed) eroded vineyards have been compared (Fig. 4). For the hoed vineyard the variability of soil properties along the slope was lower than the ploughed vineyard. The values of pH were positively correlated with erosion in the hoed vineyard and negatively correlated in the ploughed vineyard. In case of hoed vineyard the Cox was almost constant in case of ploughed vineyard it was negatively correlated with erosion, and the lowest values were recorded on most eroded

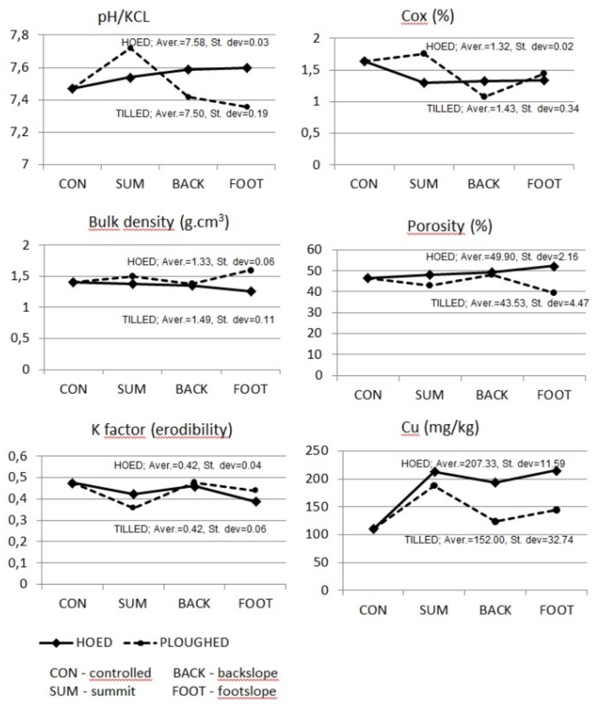

Figure 4. Change of the soil parameters along the slope catena.

Table 1. The comparison of standard deviations of measured soil properties

		CON	SUM	BACK	FOOT	AV	SD
pH/KCl	H	7.47	7.54	7.59	7.60	7.58	0.03
	P	7.47	7.72	7.42	7.36	7.50	0.19
Cox (%)	H	1.64	1.30	1.33	1.34	1.32	0.02
	P	1.64	1.76	1.08	1.44	1.43	0.34
Cu (mg.kg-1)	H	110.0	213.0	194.0	215.0	207.33	11.59
	P	110.0	188.0	124.0	144.0	152.00	32.74
Bulk density (g.cm3)	H	1.41	1.38	1.36	1.26	1.33	0.06
	P	1.41	1.50	1.38	1.60	1.49	0.11
Porosity (%)	H	46.70	48.10	49.30	52.30	49.90	2.16
	P	46.70	43.10	48.20	39.30	43.53	4.47
K factor	H	0.48	0.42	0.46	0.39	0.42	0.04
	P	0.48	0.36	0.48	0.44	0.42	0.06

H – hoed, P – ploughed, AV – average, SD – standart deviation

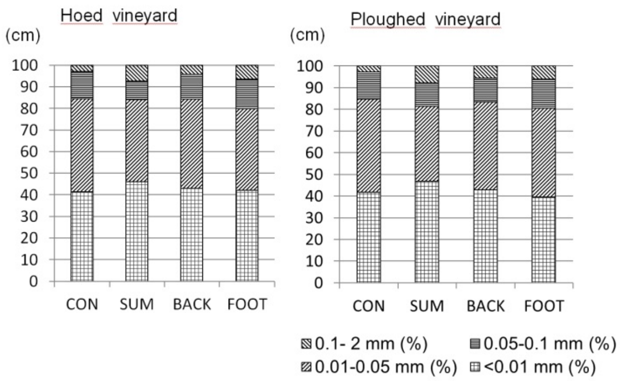

Figure 5. Textural classes of the surface soil horizons (%).

Bulk density increases in the footslope positions causing decreasing of porosity in same time. K factor was positively correlated with erosion, the highest values occurred on backslope positions. The highest Cu concentrations were measured on hoed vineyard. They were also negatively correlated with erosion in both cases (Fig. 4).

The analysis of textural classes of soil samples taken from surface horizons did not show a significant variation along the slope profile (Fig. 5).

The measurement of the thickness of diagnostic soil horizons exhibited a notable variation along the soil profile. The typical sequence of diagnostic horizons for luvisols represents Ao-Bt-C. We can also observe the presence of light colored El albic eluviation horizon above the argic subsurface horizon and the presence of calcic conglomerates. However due to long-term cultivation we can observe truncation and inversion of soil profile through loss of soil mass on convex summit positions and in the upper areas, while the opposite effect takes place in concavities and the lower areas of the field where the original soil profile becomes buried (Fig. 6)

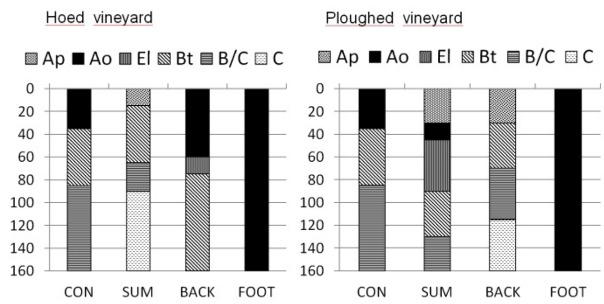

Figure 6. Stratification of the soil profiles.

4. DISCUSSIONS

4.1. Erosion measurement

Sources of possible errors causing the high variability of the measured erosion/deposition rates have been identified during the data collection. The levelling method for erosion/deposition estimation could include errors caused by factors other than erosion, such as humidity variations, freezing and thawing, cultivation, etc. (Zachar, 1982). The errors could be also triggered by the variablility of initial poles heights or by vertical shift of the poles (Lieskovský & Kenderessy, 2012). Despite some data variability we found the leveling method adequate for obtaining of long-term erosion data in a short time period, and for the evaluation of average erosion/deposition rates for our study. Such method was also applied in vineyards by Brenot et al., (2008), Casalí et al., (2008), Paroissien et al., (2010), Novara et al., (2011) and could be useful, for example, in validation of the erosion models proposed for Landscape ecological planning (Hrnčiarová et al., 2000; Hreško et al., 2003).

At the summit of the slopes and at the control plot, the mean erosion/deposition rates were minimal (depositon of 0.42 $t.ha^{-1}.year^{-1}$ for hoed vineyard and 3.70 $t.ha^{-1}.year^{-1}$ for ploughed vineyard; and erosion of 3.48 $t.ha^{-1}.year^{-1}$ measured at the control plot). Prevailing deposition on the summits could be caused by incoming soil material from the road located above the transects. Prevailing erosion, measured on the control plot could be caused by the errors mentioned above. The poles heights at the control plot were measured only once in 2011, therefore the effect of natural soil surface variation was not minimized by repeated measurements. Considerable higher differences in erosion/deposition rates were recorded in backslopes and footslopes. As we assumed, the erosion rates were significantly higher in ploughed vineyard (-44.67 $t.ha^{-1}.year^{-1}$) than in hoed vineyard (-22.97 $t.ha^{-1}.year^{-1}$). A deeper soil profile (9 - 18 cm) is disturbed with the plough, thus more soil is transported downslope. Contradictory, the deposition rates on the footslopes were highest in hoed vineyard. The deposition process is very sensitive to local changes in topography and the increased deposition could be caused by the barrier effect of the vineyard houses that are located under the slope.

4.2. Analysis of soil properties

The comparison of standard deviations of measured soil properties (Table 1) showed, that variability of soil properties in hoed vineyard was lower than in ploughed vineyard. We assume that the higher variability of the soil properties is related to higher erosion/deposition rates in ploughed vineyards. The variability of pH content along the slope on hoed vineyard was negligible. In case of ploughed vineyard decrease of pH value along the slope catena was noticed. This indicates that calcic carbonates could be leached from the surface layer by excess water from upper positions as a result of accelerated erosion.

The total volume of organic carbon (Cox) was lower in hoed vineyard, which could be caused by lower amount of used fertilizers. Cox value remained almost constant along the slope. In contrast, in case of ploughed vineyard the value of Cox content varied downslope significantly with lowest value at heavy eroded backslope position. This confirms the findings of other authors that the effect of soil erosion on soil organic carbon content reduction (Ruiz-Colmenero et al., 2013). The changes in soil bulk density values have increased from summit to footslope in ploughed vineard. The highest bulk density values at footslope positions may be a result of soil compaction because of possible higher soil moisture contents at the footslope positions as compared to the others. Higher soil moisture content at footslope were expected because of runoff and seepage effect from the upper slopes. In the case of hoed vineyard the trend was opposite. The lowest value was recorded at the footslope. However, the difference between summit and footslope was not very significant.

Since the copper substances are widely used in vineyards to protect grapevines against fungus diseases (Komárek et al., 2010, Huzum et al., 2012), the vineyard topsoils exhibit high Cu concentrations with values commonly ranging from 100 up to 1500 mg/kg (Chaignon et al., 2003; Chopin et al., 2008; Fernández-Calviño et al., 2008; Mirlean et al., 2007). The Cu concentration in our samples has exceeded the indication limit of 100 $mg.kg^{-1}$. The soil with Cu concentrations above this should have potentially negative impact on human health (MARDSR-Ministry of Agriculture and Rural Development of Slovak Republic, 1994). The Cu concentration was highest at summit due to slightly erosion and at the footslope due to soil deposition, while on backslope positions lowest values were observed. Comparison of Cu contractions in between the vineyards is not reliable, because the initial Cu input is different and depend on amount of fungicides used by vineyard growers. However, variation of Cu was considerably higher in ploughed vineyard. In runoff water, Cu appears to be predominantly transported by suspended sediments (Velleux et al., 2006; Leblanc & Schroeder, 2008). This results from Cu high affinity for clay minerals, organic matter, Fe- and Mn-oxides (Hoang et al., 2008; Sipos et al., 2008). Several authors (Zapusek

& Lestan, 2009; Lafuente et al., 2008; Hale et al., 2012; Barančíková, 1998) pointed to a fact that mobilisation of Cu highly depends on pH value, while highest mobility has been observed in range of pH < 4.5 and pH > 7.0. Since pH of the soil of our sample site is higher than 7, the high mobility of Cu can be predicted in the study area.

Water erosion selectively transports soil materials, which could result in higher soil organic matter, clay, and nutrients in the tillage layer at footslope (Quine et al., 1999; Quine & Zang, 2002; Papiernik et al., 2005; Govers et al., 1999; Zhang et al., 2004). There are no considerable soil textural differences between the hoed and ploughed vineyard in our case study. Tillage erosion unselectively transported soil materials downslope and thus induced insignificant spatial variations within the short slope, whereas water erosion selectively transported soil fine particles and consequently caused notable spatial variations in soil elements (Su, 2010).

Therefore, within different landscapes, i.e., short, medium, and long linear slopes, different dominant processes of the soil redistribution triggered different spatial variations of the soil surface properties. Zhang et al., (2006), Ni & Zhang (2007), and Ge et al., (2007) reported similar results, but Quine & Zhang (2002) advocated that soil redistribution by tillage was the most important process contributing to within-field soil variability and that higher soil variability could be expected to develop in complex landscapes due to continuous tillage operation. These differences could be explained by different landscapes (linear slope and complex landscapes), and different types of tillage operation (downslope vs. upslope and downslope) and tillage tools (hoe vs. tractor).

4.3. Soil profiles transformation

The measurement of soil profile stratification showed significant differences in soil profiles along the slope catena, as it was noticed by De Alba et al., (2004), Lindstrom et al., (1990), Van Oost et al., (2000). In our case study we have observed the effect of net soil loss on convexities and the upper part of the hillslopes. The medium- and long-term effects of such process resulted in truncation of the soil profile by removing the surface soil horizon or horizons (A, Bt). At that point, material from an original subsurface genetic horizon becomes directly exposed at the surface and constitutes the plow layer (Ap horizon). This was most obvious on the backslope positions in the case of ploughed vineyard and the summit of the hoed vineyard. Furthermore, due to long-term cultivation in case of ploughed vineyard, the inversion of soil horizons was noticed. At backslope positions where the surface Ap(Bt) horizon is not as thick as the plow layer, the surface horizon is replaced with soil coming from upslope, resulting in the formation of truncated soil profiles of the types Ap(Bt)-Bt-B/C-C. At summit position, where the original surface horizons were deeper than the plow layer, this horizon becomes only partially substituted causing the soil profiles to have an inversed sequences of horizons. This is the case of profiles Ap(Bt)-A-Bt- B/C. The inverted profiles are also characterized by high presence of calcic conglomerates.

In contrast to processes described above, a tillage causes a net soil gain on concavities and at the bottom of hillslopes, giving place to the infilling of depressions and the formation of slope banks at the lower boundary of the fields. In the long-term, the original soil profile becomes buried under deposited material coming from upslope creating homogeneous soil profile.

5. CONCLUSIONS

Increased erosion/deposition processes in vineyards have a significant impact on the soil properties along the slope catena. The higher variability of the soil properties in more eroded ploughed vineyard has been noticed. Due to the increased erosion processes on the backslope, the pH values, soil organic carbon and Cu content were considerable lowered. The main problem is the impact of soil erosion on the soil organic carbon. Furthermore, results of the soil texture analyses support the fact that downslope tillage operation contributed to erosion/deposition processes as well.

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